Saving Energy in U.S. Transportation

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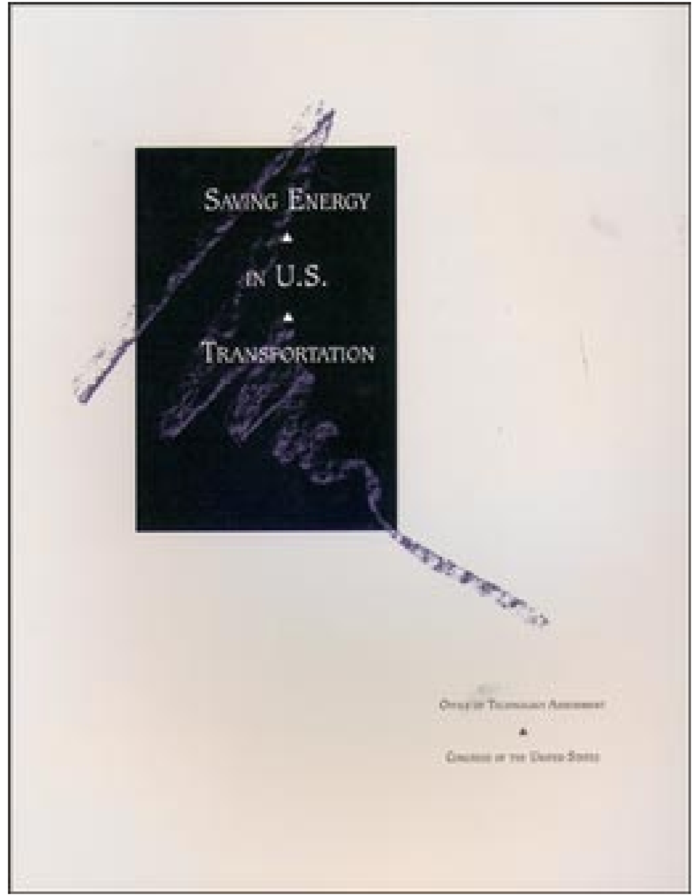

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Foreword

This report was prepared as the final part of an OTA assessment on *U.S. Energy Efficiency: Past Trends and Future Opportunities,* requested by the Senate Committees on Governmental Affairs and Energy and Natural Resources: the House Committee on Energy and Commerce; with an endorsement from the Subcommittee on Environment, Energy, and Natural Resources of the House Committee on Government Operations. Other reports in this assessment examine energy use in the Federal Government, industry, buildings, and the role of utilities in energy efficiency.

This report focuses on energy use in U.S. transportation, which accounts for over 60 percent of U.S. oil consumption. Opinions about the health of the U.S. transportation system and the efficacy of proposed measures to reduce its energy consumption are extremely polarized: some view the system as basically healthy, though in need of some "fine-tuning" to deal with future growth pains: others view the system as extremely wasteful in its energy use, environmentally destructive, and verging on breakdown, with the need for systemic changes. The report attempts to put these opinions into context by examining the current status of the system and evaluating critical problems such as congestion, presenting forecasts of future energy use, making some pointed comparisons with European transportation, and describing and evaluating a range of options for saving energy.

ROGER C. HERDMAN
Director

Advisory Panel

James F. Gibbons, Chairman
Dean
School of Engineering
Stanford University

Dale Compton
School of Industrial Engineering
Purdue University

Mark Cooper
Director of Research
Consumer Federation of America

Robert deHaan[1]
Amana Refrigeration, Inc.

Daniel A. Dreyfus
Director of Civilian Radiation Waste Management
U.S. Department of Energy

Clark W. Gellings
Vice President
Customer Systems Division
Electric Power Research Institute

David B. Goldstein
Senior Scientist
Natural Resources Defense Council

Cheryl Barrington
Director
Regulatory Assistance Project

Kenneth Hickman
Vice President
Applied Systems Division
The York International Corp.

Edward McInerney
Chief Engineer
GE Appliances Division
General Electric Co.

Alan Miller
Executive Director
Center for Global Change
University of Maryland, College Park

Gary Nakarado
Technical Director
National Renewable Energy Laboratory

John W. Rowe
President and CEO
New England Electric System

Maxine L. Savitz
Director
Garrett Ceramic Components
Garrett Processing Co.

Sherwood Smith, Jr.
Chairman and President
Carolina Power & Light Co.

Richard Tracey
Manager
Engineering Services
Ryland Homes

B.C. Waycaster
Vice President and General Manager
Hydrocarbons and Energy
Dow Chemical

Irvin L. White
Senior Director
Laboratory Energy Programs
Battelle Pacific Northwest Laboratories

Mason Willrich
Pacific Gas and Electric Enterprises

James L. Wolf
Vice President
Energy and Environmental Markets
Honeywell, Inc.

Eric R. Zausner
President
Strategic Performance Management

[1] Retired.

Note: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the advisory panel members. The panel does not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents,

Project Staff

Peter D. Blair
Assistant Director
Industry, Commerce, and
International Security Division

Emilia L. Govan
Program Director
Energy, Transportation, and
Infrastructure Program

PRINCIPAL STAFF

Steven E. Plotkin
Project Director

Paul Komor
Senior Analyst, Freight Analysis

Andrew Moyad
TDM Measures

Jeffrey Boberg
Alternate Demand Forecasts,
Telecommunications

ADMINISTRATIVE STAFF

Lillian Chapman
Division Administrator

Marsha Fenn
Office Administrator

Linda Long
Administrative Secretary

Tina Aikens
Administrative Secretary

Gay Jackson
PC Specialist

Lynette Cooper
Contractor

CONTRACTORS

Mark A. Delucchi
University of California at Davis
Social Costs of Motor *Vehicle Use*

James L. Sweeney
Stanford University
Gasoline Taxes

Florence Poillon
Editor

Reviewers

Michael Arendex
American Trucking Associations

Steven A. Barsony
Federal Transit Administration

Norman L. Bryan
Pacific Gas & Electric

Chris Calwell
Natural Resources Defense Council

Donald Chen
Rocky Mountain Institute

Cheri Davis
California Energy Commission

Elizabeth Deakin
University of California at Berkeley

Jack Faucett
Jack Faucett Associates

Lew Fulton
U.S. Department of Energy

Bernard Gelb
Congressional Research Service

Clark Gellings
Electric Power Research Institute

John German
U.S. Environmental Protection Agency

David Goldstein
Natural Resources Defense Council

Deborah Gordon
Union of Concerned Scientists

David Gushee
Congressional Research Service

R.J. Kinsey
Ford Motor CO.

Marilyn Klein
Federal Railroad Administration

Robert Larson
U.S. Environmental Protection Agency

Charles Lave
University of California, Irvine

Michael F. Lawrence
Jack Faucett Associates

James Lerner
California Air Resources Board

Tom MacDonald
California Energy Commission

James MacKenzie
World Resources Institute

Barry McNutt
U.S. Department of Energy

Marianne Mintz
Argonne National Laboratory

Sergio Ostria
Jack Faucett Associates

Philip Patterson
U.S. Department of Energy

Marc Ross
University of Michigan

Harvey M. Sachs
University of Maryland

Danilo Santini
Argonne National Laboratory

Maxine Savitz
Allied Signal, Inc.

Lee Schipper
Lawrence Berkeley Laboratories

Will Schroeer
U.S. Environmental Protection Agency

Vic Suski
American Trucking Associations

Edward Thomas
Federal Transit Administration

Steve Thompson
Congressional Research Service

Irvin L. White
Battelle Pacific Northwest Laboratories

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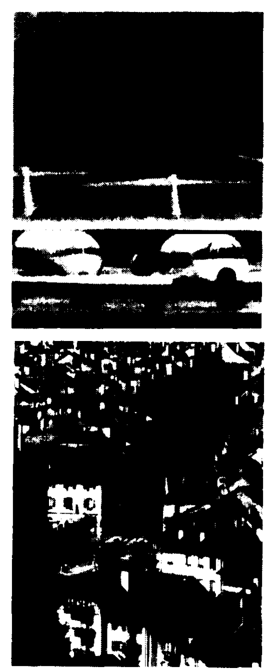

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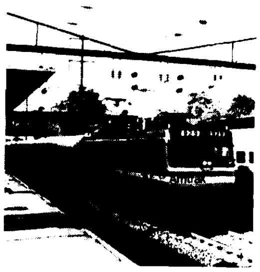

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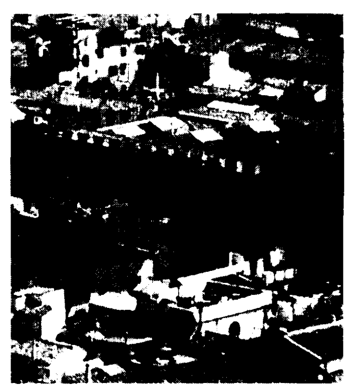
Summary

This report assesses an array of transportation policies designed to reduce energy use and describes the intersection of these policies with general transportation problems such as congestion and air pollution. The report:

- describes the U.S. transportation system and its energy use;
- presents and evaluates forecasts of energy use to 2010;
- compares and contrasts U.S. and European travel and energy use patterns;
- discusses reasons governments may choose to intervene in transportation markets; and
- describes and evaluates a range of policy options to reduce U.S. transport energy use, from gasoline taxes to urban planning.

Its objective is to provide a balanced, qualitative perspective of issues and problems rather than a highly quantified analysis.



INTRODUCTION

A primary characteristic of transportation in the United States is its high per capita energy consumption. *The average U. S. citizen consumes nearly five times as much energy for transportation as the average Japanese and nearly three times as much as the average citizen of France, Britain, or West Germany.*[1] The energy efficiency of U.S. transportation has improved substantially over the past two decades (both absolutely and in comparison to Europe) and U.S. travel volume has grown more slowly than in most of the developed world. However, the United States still consumes

[1] L. Schipper et al., "Energy Use in Passenger Transport in OECD Countries: Changes Between 1970 and 1987," *Transportation, The International Journal*, April 1992.

ENVIRONMENTAL PROTECTION AGENCY

Washington, DC, on a smoggy day **About 100** *U.S. cities still violate national ambient air quality standards for ozone.*

more than one-third of the world's transport energy.[2] Also, 96 percent of U.S. transport energy is in the form of oil products.[3] This is more oil than the United States produces,[4] despite its position as one of the world's largest oil producers.

In 1990, the U.S. transportation sector accounted for nearly 65 percent of all U.S. oil consumption.[5] The oil consumed by U.S. transportation creates problems in terms of: 1) air pollution— about 100 urban areas violate the ozone air quality standard, and emissions from transportation sources, primarily highway vehicles, contribute 30 percent of the volatile organic compound and 39 percent of the nitrogen oxide precursors of ozone; 2) national security and balance of trade, because so much of our oil is imported; and 3) greenhouse warming, because large quantities of carbon dioxide (the primary greenhouse gas) are emitted with oil combustion.

The intensity and magnitude of U.S. travel create other problems as well. Growing congestion, especially in urban areas, leads to expensive delays in passenger and freight transport, and increases fuel use and pollution. U.S. reliance on automobiles has resulted in a high percentage of land being devoted to highways, parking facilities, and other auto uses; the loss of wetlands and other ecologically sensitive lands to highways and the diffuse land use that highways support; and a range of other environmental impacts.

Energy use in U.S. transportation is expected to increase despite continued improvements in efficiency. The Energy Information Administration's (EIA) *Annual Energy Outlook 1993* projects steady but moderate growth in transportation energy use across all scenarios. EIA projects a 19- to 38-percent increase over the 20-year period of the forecast. Thus, by 2010, transport energy use would be 26.8 to 31.0 quadrillion British thermal units (10^{15} Btus = 1 quad[6]), about 12.9 to 14.9 million barrels of oil per day (mmbd), compared with its 1990 level of 22.5 quads, or 10.5 mmbd. And, as discussed later, the Office of Technology Assessment (OTA) believes these forecasted levels are likely to underestimate future transportation energy use, because they rely on optimistic assumptions about improvement in vehicle efficiency and growth in personal travel.

With current problems and expectations of continued growth in travel and energy use, Congress has increasingly turned to transportation energy

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[2] U.S. Congress, Office of Technology Assessment, *Changing by Degrees: Steps To Reduce Greenhouse Gases,* OTA-O-482 (Washington, DC: U.S. Government Printing Office, February 1991), table 5-1.

[3] S.C. Davis and S.G. Strang, *Transportation Energy Data Book,* ed. 13, ORNL-6743 (Oak Ridge, TN: Oak Ridge National Laboratory, March 1993), table 2.8.

[4] Total 1990 transportation oil products consumption was 21.81 quadrillion British thermal units (Btus), versus domestic liquid production (crude oil, lease condensate, and natural gas plant liquids) of 17.91 quadrillion Btus. Energy Information Administration, *Annual Energy Outlook 1993,* DOE/EIA-*1383(93)* (Washington, DC: January 1993), tables G1 and G2.

[5] Ibid., table A-8.

[6] A "quad" of energy, aside from being one quadrillion (10^{15}) Btus, is equivalent to about one trillion cubic feet of natural gas, or about one-twentieth of current annual U.S. natural gas consumption; about 170 million barrels of oil, or a bit more than one-thirtieth of current U.S. yearly oil consumption; about 40 million short tons of coal (coal energy content is variable, so this is a rough approximation), or about one-twentieth of U.S. yearly coal consumption. In 1990, U.S. energy consumption was about 85 quads.

conservation—in the form of improvements in the technical efficiency of travel, increases in load factors, reductions in travel demand, shifting to alternative fuels, and shifts to more efficient travel modes—as an important policy goal. For example, the Clean Air Amendments of 1990 incorporate transportation demand management as a critical tool in reducing urban air pollution. ISTEA—the Intermodal Surface Transportation Efficiency Act of 1991—allows States to shift highway funds to transit, promotes new high-speed ground transportation systems, and generally establishes energy efficiency as a major goal of new transportation investment. EPACT—the Energy Policy Act of 1992-establishes fleet requirements and a series of economic incentives to promote the use of nonpetroleum alternative fuels. Legislation proposed (but not passed) in the 102d Congress sought rigorous new automobile and light truck fuel economy standards. With continued increases in U.S. oil imports, urban traffic congestion, and greenhouse gas emissions, and the failure of many urban areas to meet air quality standards, strong congressional interest in new energy conservation initiatives is likely to continue.

Varying Perspectives on the Nature of the Problem and on Potential Solutions

Although policy makers and the transportation community may agree that transportation energy conservation is a worthwhile goal *in the abstract,* severe disagreements exist about the urgency of the problems that conservation measures can serve to address and the efficacy of conservation alternatives.

Disagreement begins with two very different perspectives about transportation itself:

1. *Transportation, and especially automobile-dominated transport, is a primary source of social and environmental ills such as air pollution, loss of ecosystems, greenhouse emissions, loss of life and limb, and noise pollution.*
2. *Transportation is a key to economic progress and to social, cultural, and recreational opportunity.*

Since both perspectives are valid, both should be considered in seeking a balanced approach to policymaking. Many transportation stakeholders, however, lean heavily toward one perspective or the other. Those leaning toward the first tend to focus on the need to reduce and restrict travel, shift travelers to less harmful modes, and enact strong environmental safeguards; those leaning toward the second focus on the need to increase access to travel and to make traveling easier and more efficient. Thus, in terms of these two perspectives, some of the key features of U.S. transportation—the highest level of personal travel in the world (13,500 miles per person per year) and the most vehicles per person in the world (nearly six autos or light trucks for every 10 persons, and two vehicles per household)—appear as signs either of the profligacy of the U.S. system or of its superiority. Such varying perspectives about the success of the American system in turn lead to very different perspectives about the need for changing that system, with one tending toward substantive change and the other toward fine-tuning.

That transportation is not an end in itself, but a means to attain access to economic and personal opportunity, may aggravate the differences in perspective. The concept of access to a variety of opportunities is easy to grasp but difficult to measure, so transportation services are generally measured simply in miles traveled or trips made. Thus, there is a danger that a traveler who must commute several hours to work will be judged in some analyses to have obtained more value from transportation services than another who walks 20 minutes to work. Also, those judging proposed changes in transportation policy must distinguish

[7] Transportation demand management (TDM) measures seek to reduce traffic volumes (or shift some traffic to less congested times or routes), especially during peak travel hours, by increasing vehicle occupancy, encouraging modal shifts, and other means.

carefully between changes that reduce travel *and* access to opportunity, and those that reduce travel but bring opportunity closer.

Three major problems are driving most transportation energy conservation initiatives—air pollution (especially urban), energy security, and greenhouse warming. Different views about the urgency of these problems in turn lead to different perspectives about the types of tradeoffs worth making to achieve lower energy use. There appears to be a consensus that urban air pollution is a critical national problem, and clear support exists for strong corrective measures. There is a modest level of agreement about the importance of rising oil imports as a national security and balance-of-trade problem, with levels of concern ranging from moderate to substantial and limited support for corrective measures. Agreement is lacking about the urgency of reducing greenhouse emissions to slow down potential warming: environmental groups urge strong action, whereas much of the business community urges that no action be taken until more is known.

Another potential disagreement about the nature of problems facing the transportation system could further polarize policymaking. The Federal Highway Administration (FHWA) projects large increases in urban and suburban traffic congestion, which implies that strong policy measures—including severe demand management and large shifts to alternate modes—will be needed to maintain acceptable levels of urban mobility. A small group of critics, however, claims that the FHWA projections are grossly in error, and that growth in congestion will be kept in check by changes in travel behavior and land use. These views, of course, yield a very different set of transportation policy priorities.

Another disagreement about the need for changes in transportation policy focuses on the extent to which prices for U.S. travel accurately reflect the true marginal costs to society of such travel. Many analysts believe that a combination of "externalities" (consequences such as air pollution that travelers do not pay for or take into account in their decisions) and inefficiently priced inputs (services such as parking, with hidden, subsidized, or inaccurate prices) yields an overall cost of travel that is too low and thus results in excessive travel. Other analysts conclude that the value of externalities and unpriced inputs is small compared with the prices paid openly by travelers, so that "correcting" prices would not result in large changes in travel behavior. These analysts hold that there is not much excess travel in the United States.

Finally, not surprisingly, there are major disagreements about the efficacy of virtually all conservation measures. For example:

- Proponents of *increased mass transit* foresee it as playing a major role in energy conservation and the revitalization of U.S. cities. Skeptics view it as basically irrelevant to most travel, having only a small role to play (mobility for disadvantaged populations, a major general role in a few of America's older, high-density urban cores) given the auto-oriented U.S. land use patterns and offering little if any benefits in energy efficiency.
- Proponents of *stronger fuel economy standards* believe that there are inexpensive ways to achieve large improvements in auto fuel economy, and view standard setting as a proven success in forcing these improvements. Opponents see little opportunity for more than slow, incremental growth in fuel economy, and view standards as an antimarket, inefficient method of achieving the small improvements that are available.
- Proponents of *higher gasoline taxes* view them as proven revenue raisers, which offer improved economic efficiency by capturing "externalities" and inefficiently priced transportation inputs, and allow significant energy savings. Opponents view them as harmful to the U.S. economy, and as offering no economic efficiency benefits and limited energy savings benefits, given the unresponsiveness of travel demand and technical efficiency to gasoline price.

A unifying feature of these policy arguments is a difference of views about the importance of policy-dependent factors versus policy-independent factors in shaping travel patterns. If history (including the history of technology), geography, income, and demographics are the primary determinants of travel patterns, policy may play only a minor role in changing energy use; but if fuel taxes, urban planning, parking policies, and other instruments of public policy are primary travel determinants, there is a large potential for policy to reduce U.S. energy use.

Although much of the disagreement about transportation policy stems from differences in values and philosophy, including different views about the role of government in markets, a significant portion stems from the lack of adequate research and data in several crucial areas.[8] These include:

- the relationship among travel behavior and demographics, urban design, and transportation system characteristics (e.g., the extent to which new transportation facilities can be used as part of an integrated effort to shift land use patterns and travel behavior);
- the magnitude of transportation "externalities," or costs that are not accounted for or borne by transport users;
- identification and quantification of transport benefits; and
- the measurement of "accessibility," which is the primary goal that personal transportation attempts to satisfy.

A SNAPSHOT OF THE U.S. TRANSPORTATION SYSTEM AND ITS ENERGY USE

Passenger Travel

The transportation system in the United States provides U.S. residents with the highest level of personal mobility—in terms of trips made and miles traveled—in the world. The United States has the greatest number of automobiles per capita--0.575 in 1989—in the world,[9] 1.07 vehicles *per licensed driver and 1.92 vehicles per household.* The average adult with a driver's license travels 30 miles per day of local, personal travel, and even adults without licenses manage to travel 10 miles per day.[11] In 1990, the average U.S. resident traveled well over 13,000 miles.[12]

U.S. passenger travel is dominated by the automobile and the highway system. In 1990, about 86 percent of passenger-miles were auto (and personal light truck) miles, and over 10 of the remaining 14 percent were air miles; buses and trains provided only 4 percent of passenger-miles.[13]

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[8] A recent report by the Transportation Research Board (TRB) identifies critical research needs in transportation, land use, and air quality; TRB, *Transportation Research Circular 389: Environmental Research Needs in Transportation* (Washington, DC: National Research Council, March 1992).

9 S.C. Davis and M.D. Morris, *Transportation Energy Data Book*, ed. 12, ORNL-6710 (Oak Ridge, TN: Oak Ridge National Laboratory, March 1992), table 1-3.

10 Ibid., table 4-1. Note that "vehicles" includes trucks and buses.

11 A.T. Reno, "Personal Mobility in the United States, " *A Look Ahead-Year 2020,* Transportation Research Board Special Report 220 (Washington, DC. Transportation Research Board, 1988).

12 Data obtained from L Schipper and N. Kiang, International Energy Studies, Lawrence Berkeley Laboratory, in advance of Publication in the *Transportation Energy Data Book,* ed. 14 (Oak Ridge, TN: Oak Ridge National Laboratory, forthcoming).

13 Ibid.

The U.S. highway system consists of about 3.8 million miles of roadway, including 44,000 miles in the Interstate System.[14,15] The system also includes nearly 577,000 bridges.[16] Much of this infrastructure—more than 10 percent of the Nation's roads and nearly 42 percent of its bridges—is considered deficient.[17]

The U.S. mass transit system consists of a wide array of regional and municipal systems, including buses, light rail, commuter rail, trolleys, and subways, as well as an array of vehicles providing "paratransit" services--dial-a-ride, van pools, subsidized taxis, and shared rides in minibuses or vans. Most cities of 20,000 or higher population have bus systems, and buses on established routes with set schedules account for more than half of all public transit passenger trips. However, about 70 percent of all such trips were in the 10 cities with rapid rail systems, with 35 percent of transit passengers and 41 percent of transit passenger-miles in New York City and its suburbs.[18]

Low-density suburban development creates travel patterns that are not easily served by transit.

The highway and public transportation systems in U.S. cities are shaped largely by the need to offer capacity to satisfy peak traffic periods. These peaks now are no longer dominated by worktrips, although these trips still account for 37 percent of peak person-trips.[19] And although the pattern of workers living in surrounding areas and commuting to the central business district (CBD) may once have been dominant, in 1980 the CBDs employed only 9 percent of the workers in their total urban areas and only 3 percent of workers living outside the central city.[20] In other words, peak trips in general, and work trips in particular, are now quite diffuse in origin and destination and thus not easily served by transit. One reason for this travel pattern is that urban development in the United States is characterized by an "undifferentiated mixture of land uses and a broad plateau of population density. . other central places scattered over the urban landscape challenge the primacy of the historic CBD."[21]

Although the automobile continues to dominate U.S. travel, autos face strong competition from commercial aircraft for trips of a few hundred miles or longer. As noted above, air transportation has now captured about 10 percent of the

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14 U.S. Congress, Office Of Technology" Assessment, *Delivering the Goods: Public Works Technologies, Management, and Finance,* OTA-SET-477 (Washington, DC: U.S. Government Printing Office, April 1991), based on Department of Transportation data.

15 Routes that connect principal metropoli(an areas, serve (he national defense, or connect with routes of continental importance in Mexico or Canada.

16 Office of Technology Assessment, op. cit., footnote 14.

17 Ibid.

18 Ibid

19 H.W. Richardson and P. Gordon, University of Southern California, "New Data and Old Models in Urban Economics," preliminary draft, December 1992, table 3. Peak periods are from 6 to 9 a.m. and 4 to 7 p.m. The precise character of changes in trip purposes is made uncertain by the manner in which trip purpose data are collected, A worktrip interrupted by a stop to run an errand would be counted as a shorter worktrip and another trip. Because trip "chaining" of this sort has increased, some of the shift away from worktrips may be an artifact of the data rather than an actual shift.

20 I.S. Lowry, "Planning for Urban Sprawl, " in *A Look Ahead-Year 2020,* op. cit., footnote 11.

21 Ibid.

total passenger-miles traveled and is the most rapidly growing segment of the U.S. transportation system, with passenger-miles growing more than 7 percent a year in the 1980s.[22]

The U.S. air travel system is quite centralized: There are more than 17,000 airports in the United States, but the top 100 handle 95 percent of all passenger trips, and the 10 largest serve 40 percent of all passenger trips. This is due primarily to widespread use by the major air carriers of "hub-and-spoke" routes.[23] The major airports experience substantial capacity problems and resulting delays--conditions that waste significant amounts of fuel by idling aircraft on runways and keeping arriving planes in holding patterns. Of the 25 airports with the most delays, Chicago's O'Hare ranks first, with total delays exceeding 100,000 airplane-hours per year; two airports have annual delays between 75,000 and 100,000 hours; two more have annual delays between 50,000 and 75,000 hours; and the remainder are between 20,000 and 50,000 hours.[24]

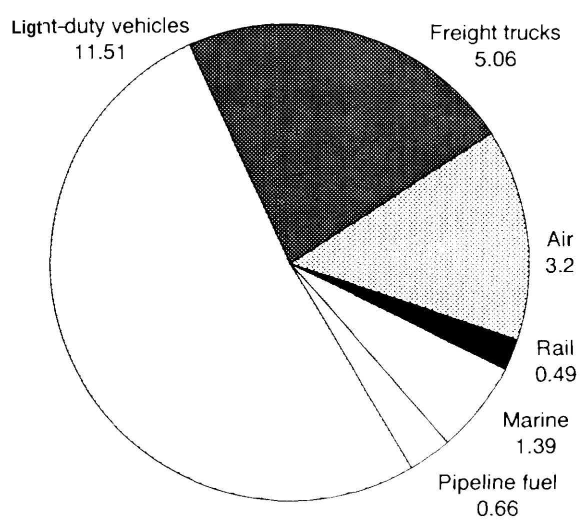
■ Freight Movement

The U.S. freight system moves about 3.2 trillion ton-miles of freight per year.[25] Trains and trucks each carry about 30 percent of this, barges about 25 percent, oil pipelines 16 percent, and air less than 1 percent. Trucks are the dominant transport mode for nonbulk cargo, such as mail, processed foods, and consumer goods. Truck types and cargo are extremely varied, with light trucks used primarily for short-distance urban and suburban delivery and for carrying craftsman's equipment, and heavy trucks hauling mixed cargo, processed foods, and building materials. Trains, on the other hand, carry primarily bulk products, which the United States ships in large quantities over very long distances. Key products moved by train in-elude coal, farm products, and chemicals. An increasing fraction of train movement-now more than one-quarter—is in the form of trailers or containers (i.e., intermodal shipments involving both train and another freight mode, e.g., truck or barge), typically carrying manufactured or intermediate goods.

TRANSPORTATION ENERGY USE AND POTENTIAL FOR CONSERVATION

Figure 1 provides a broad overview of where energy is being used in the U.S. transport system. The figure illustrates that light-duty vehicles—automobiles, pickup trucks, utility vehicles. and vans—account for more than half of all U.S. transportation energy consumption. These vehicles are used predominantly for passenger travel. Airplanes, also used predominantly for passenger

FIGURE 1: Transportation Energy Use in 1990



SOURCE Energy Information Administration data

[22] Ibid.

[23] J.F. Hornbeck, *Transportation Infrastructure: Economic and Policy Issues*, 92-158E (Washington, DC. Congressional Research Service, Feb. 11, 1992).

[24] Office of Technology Assessment, op. cit., footnote 14.

[25] Davis and Strang, op. cit., footnote 3, p. 2-25.

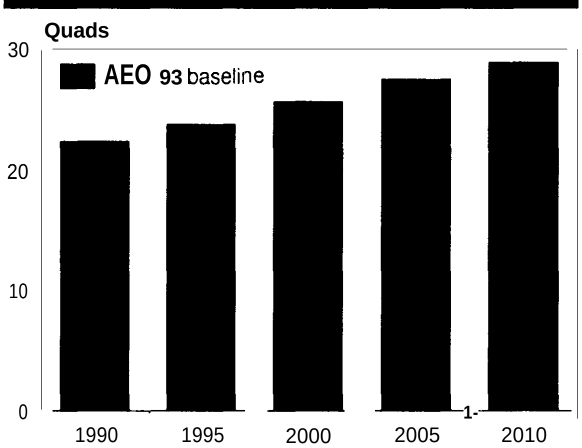
travel, account for 14 percent of U.S. transportation energy use. These two components of passenger travel thus represent a tempting target for energy conservation measures.

Freight trucks are the second largest consumer of transportation energy, accounting for nearly 23 percent of the total U.S. use. Freight truck energy use is expected to grow substantially during the next two decades and thus should also be an important focus for energy conservation. Other freight modes-pipelines, shipping, and rail (most rail energy is freight energy)—are all important, and rail may represent an opportunity to attract freight from trucking, with subsequent energy savings, but they are clearly of lesser significance than trucks for national energy savings.

U.S. TRANSPORTATION ENERGY CONSUMPTION: WHERE IS IT HEADING?

EIA's *Annual Energy Outlook 1993 (AEO93)* provides a detailed picture of future U.S. energy supply and demand, and transportation energy consumption in particular. The forecasts of transportation energy consumption depend on a number of critical factors and assumptions, including:

FIGURE 2: Expected Growth in U.S. Transport Energy



SOURCE U S Department of Energy *Annual Energy Outlook* 1993

- assumptions about future oil prices;
- assumptions about important demographic and socioeconomic trends, for example, the nature of women's evolving role in the workplace and how this will affect their driving patterns, and future rates of immigration;
- future progress in automobile and light-truck fuel economy;
- the market success of alternative fuels; and
- overall and sectoral growth rate of the economy.

EIA's baseline forecast accepts mainstream ideas about oil prices and economic growth: that a combination of plentiful oil supply, gradually increasing world demand, and Saudi restraint will maintain prices in the $20 per barrel (bbl) range for a few years and then gradually push prices upward, to $29/bbl (1991 dollars) by 201 O; and that slower growth in the U.S. labor force for the next few decades (a projected rate of about 1 percent per year versus 2.1 percent annually in 1970-90) will restrain the growth in real output of goods and services, but that the U.S. economy will remain sufficiently competitive in world markets to keep growing at the moderate rate of 2.0 percent per year.[26]

The forecast projects steady but moderate growth in transportation energy use: 1.26 percent per year, yielding a 28.5-percent increase from 1990 to 2010—the 1990 level of 22.50 quads (10.8 mmbd) increases to 28.93 quads (13.9 mmbd) by 2010 (figure 2).

EIA has formulated alternative forecasts based primarily on different economic assumptions: Alternative price scenarios reflect, on the low side, a combination of more conservation than expected, significant competition among Organization of Petroleum Exporting Countries (OPEC) members to expand production capacity, and high non-OPEC production and on the high side, more global economic growth and less conservation than expected, which boosts world oil demand, as well as a decreasing supply. Alternative economic growth scenarios reflect differing assumptions

[26] Energy Information Administration, 1991, op. cit., footnote 4.

about the rate of labor force growth and product i v-ity. As noted earlier, these scenarios introduce a range of transportation energy projections for year 2010 of 26.86to31.00 quads (12.9 to 14.9 mmbd) versus the 28.93 quads/ 13.9 mmbd base] inc.

The uneven history of energy forecasting demands that EIA forecasts, and all others, be viewed with some skepticism. Over the past few decades, sharp changes in both energy demand and supply characteristics-especially the former—have caused actual national energy trends to diverge sharply from widely accepted forecasts. For example, during the 1970s, forecasts of future electricity demand were revised downward so often that a simultaneous plotting of forecasts made in consecutive years described a wide fan, with the top of the fan representing the earliest forecast and the bottom, the latest.

Absent important new Federal policy measures—many of which are the province of Congress—several factors may increase the likelihood that actual transportation energy use in2010 will diverge substantially from EIA forecasts. *Potential* sources of divergence include: sharp changes in urban travel behavior (e. g.. more carpooling and telecommuting), initiated by Transportation Control Measures under the Clean Air Act; major success of alternative fuels spurred by fleet purchases mandated by the Energy Policy Act, California's low-emission and zero-emission vehicle requirements, and technological breakthroughs; large increases in mass transit usage courtesy of State initiatives supported by ISTEA: breakthroughs in automotive technology, together with large shifts in market conditions: and continuation of recent trends in vehicle-miles traveled (i.e., high rates of grow(h) and energy efficiency (i.e., stagnation), in contrast to EIA's more optimistic assumptions.

Some potential sources of divergence (e.g., unforeseen success of Transportation Control Measures) imply that the EIA forecasts of transportation energy growth could be too high. The most likely sources, however, imply the opposite. *The most likely sources of forecasting error are assumptions about growth rates of travel and efficiency.* EIA has consistently chosen growth rates of travel that are lower, and efficiency increases that are higher, than recent historic rates. For example:

- Light-duty vehicle-miles traveled (vmt) grew at rates well over 3 percent per year during the 1980s, compared with EIA's assumed 1990-2010 rate of 1.7 percent annually. The history of light-duty vmt growth during the past four or five decades has been one of seemingly inexorable growth, despite expectations to the contrary.
- New car fuel economy has fallen since 1987. compared with EIA's assumed 1990-2010 increase of 1.1 percent per year. Low oil prices and consumer preferences for luxury, performance, and size are pushing the market away from fuel economy gains.
- Air travel grew at a better than 7 percent per year pace in the 1980s, compared with EIA's assumed 1990-2010 pace of 3.9 percent per year.
- All categories of freight trucks had mileage increases well above 3 percent per year (combination trucks' mileage grew at 4.7 percent per year from 1982 to 1990), compared with EIA's assumed 1990-2010 annual rate of 1.9 percent per year.

In OTA's view, without substantial policy intervention (excluded in the projections), *future rates of travel are quite likely to be higher and efficiency lower than EIA projects, with a resulting greater increase in transportation energy use than the projected levels.* There is room for technological breakthroughs in engines and other aspects of vehicle design to make some difference (e.g., in energy savings) in the 2010 time frame, but this is less probable than the potential for significant diversions from the forecasts in travel and efficiency growth rates, toward higher energy use. There ap-

[27] OTA agrees, however, that growth rates for light-duty vmt will fall somewhat below recent rates, primarily because of the likely slower growth in the number of adults of driving age.

pears little likelihood (again, without substantial policy intervention) that shifts to mass transit, other important changes in travel behavior, or market breakthroughs in alternative fuels will cause major changes (beyond those already included in the forecasts) in transportation energy use by **2010.**

IS THE U.S. TRANSPORTATION SYSTEM ENERGY-EFFICIENT? A COMPARISON WITH EUROPE

Decisions to initiate pro-conservation policies would be served by a determinant ion about whether the current U.S. transportation system is particularly inefficient in terms of energy use, as suggested by some, or whether it is relatively efficient. Some analysts and policy makers have compared U.S. energy use in general, and that used for transportation, with energy use in other developed nations, particular y Japan and Western Europe. Typically, these comparisons are described as demonstrations of U.S. energy inefficiency, because Japan and Western Europe use considerably less energy per capita in most sectors. As noted above, the average U.S. citizen uses about five times as much transportation energy as the average Japanese, and about three times as much as citizens of Great Britain, West Germany, and France. An examination of comparative energy use in the United States and Western Europe demonstrates that the disparity in per capita consumption is caused by a variety of factors, some of which clearly are related to differences in efficiency, but some of which have little to do with efficiency or are only vaguely connected to it. The discussion here does not address the critical question of comparative access to recreational, social, cultural, and employment opportunities, nor can the relative roles of government policies and other influences in shaping transportation energy use be separated definitively.

The major reason for the difference between U.S. and European transportation energy use is a difference in travel volume: on average, Europeans travel only about half as much (in miles per capita per year) as Americans.** This one factor accounts for half of the total difference in energy use. The causes of the difference are multiple and difficult to unscramble: higher cost of travel; *much* denser land use in Europe—in urban areas, in suburbs, and overall (which may be due in part to higher travel costs, but also is the result of different cultural histories, lower availability of land, stricter land use controls); differences in socioeconomic factors affecting travel (e.g., women participation in the workforce, household size, willingness of workers to relocate far from their families); differences in lifestyle; and so forth. Another reason may be timing: Europe began its shift to "automobility" later than the United States and, despite now having per capita incomes equal to or greater than U.S. levels, is still catching up in auto ownership. Part of the difference in travel volume may translate into greater accessibility to economic, cultural, and recreational opportunities for U.S. citizens, but OTA is not aware of any evidence to support this; the existence of such a difference in accessibility, especially in urban areas, is debatable because European population densities and prevalence of mixed-use development make access to work, recreation, and other destinations closer at hand; because much European urban travel is by walking and bicycling (which tend to be overlooked in statistical analyses); and because accessibility is a subjective, culture-laden term. European land use patterns will be described as "more efficient" than U.S. patterns by some, but this too is highly subjective.

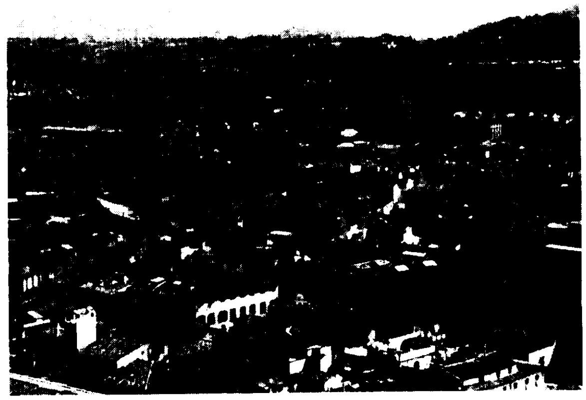
The other half of the energy difference is accounted for by differences in the proportions of various travel modes used (modal shares), load factors, and vehicle efficiency. As a fraction of their total travel, Americans travel somewhat more in private autos, and far more in energy-intensive airplanes, than do Europeans, who make far greater use of buses and trains. Mass transit has

[28] Schipper and Kiang, op. cit., footnote 12.

about a 15 percent modal share—measured as a percentage of passenger-miles—in Europe versus about 3 percent in the United States.[29] And European automobile fleets are more efficient than the U.S. fleet, partly because Americans purchase large numbers of light trucks for personal travel use, and partly because American automobiles are larger than their European counterparts. These differences are lessening, however, as are the differences in per capita travel: the rates of growth of travel and auto ownership are much higher in Europe than in the United States; U.S. auto fleet efficiency is catching up to most European fleets; and mass transit modal shares—although not absolute levels of ridership--are shrinking in most of Europe.

Unlike personal travel, European freight transportation is not more energy-efficient than its U.S. counterpart, though its volume in ton-miles in proportion to total economic activity is much lower than in the United States. The types of goods transported and the physical conditions differ sufficiently from those in the United States that there seem to be few lessons easily extracted from a comparison of the two systems.

The available statistical comparisons between Europe and the United States allow only tentative conclusions. They do demonstrate clear] y that *the substantial differ ence.s between European and U.S. transportation energy use patterns are associated largely with different levels of travel; about half of the difference in per capita energy use is due to differences in energy efficiency, at least in terms of common perceptions of what efficiency is.* On the other hand, Europe's faster rates of growth in travel demand should not be interpreted as meaning that European transportation is simply at an earlier stage of automobile dominance than the United States and destined to "catch up" to U.S. energy consumption levels. Although there will be some continued convergence between the two, *European levels of per capita travel and energy consumption should continue significantly below those of the United States because of a combination of different geography and urban histories; European gasoline prices that are three to four times higher than prices in the United States; different policies regarding land use controls, parking availability, automobile restrictions, and other factors that affect travel; Europe's reasonably robust mass transit systems; and cultural and socioeconomic differences.*


MICHAEL GLUCK

High European population densities and prevalence of mixed-use development reduce the need for long trips to access work, recreation, and cultural opportunities

Could the United States, if it chose, match European levels of transportation energy use? Fuel price and other policy differences between the United States and Europe can be made to disappear by legislative will, and future U.S. moves to raise fuel prices, enact land use controls that increase urban densities, restrict parking, and so forth *would* move U.S. transportation energy use in the direction of European levels. However, some or all of these policy changes may not be politically acceptable: they would not affect all of the factors that make European energy use lower than U.S. levels; and some resulting changes in energy use, especially those associated with land use, would come quite slowly, over many de-

[29] L. Schipper et al., *Energy Efficiency and Human Activity: Past Trends, Future Prospects* (Cambridge, England: Cambridge University Press, 1992).

cades. The remainder of this discussion examines the incentives for and potential of U.S. government intervention in transportation.

WHY INTERVENE IN THE TRANSPORTATION SYSTEM?

As noted above, a variety of problems and issues are driving U.S. transportation policymaking, and perceptions of the importance of these problems and issues will be a key determinant of future policy decisions.

Economic Efficiency, Externalities, and Unpriced Inputs

To the extent that travelers do not pay for, or do not account for, the full costs of their travel, they will overuse it. Travelers do not pay the full price of the air pollution and congestion they cause, the impacts on national security of the oil they consume, (a portion of) the costs of the injuries and fatalities they cause in auto accidents, and so forth. They indirectly pay for, but do not account for in their travel decisions, the costs of parking in the shopping malls they patronize (these costs are embedded in the price of the goods being sold). Similarly, they may indirectly pay (in the form of lower salaries) but not account for most parking costs at workplaces. They pay and/or take into account only a portion of the costs of building and maintaining roads, because some of this cost is met from general funds, not user fees. And they pay and account for some services inefficiently: gasoline taxes that pay for roadbuilding are only indirectly related to actual road requirements.

In this study, OTA asked Mark DeLuchi of the University of California at Davis to prepare estimates of the social costs of motor vehicle travel, separating private, efficient] y paid costs from external costs, hidden private costs, and inefficient y priced costs.[30] **These estimates indicate that approximately two-thirds to four-fifths of the total monetary costs of motor vehicle use[31] are efficiently priced, that is, paid for entirely by motor vehicle users, considered in their travel decisions, and priced at marginal costs to society. Based on some preliminary estimates of the dollar value of external costs, motor vehicle users efficiently paid for about one-half to two-thirds of the social (public plus private) costs of motor vehicle use, both monetary and nonmonetary, excluding the value of time.**

These estimates represent a long-term view of costs and their effects on behavior; that is, they make no distinction between costs that must be paid only occasionally (e.g., vehicle purchase price, insurance premiums) and those that are incurred frequently (e.g., fuel costs, air pollution damages). Some analysts prefer to focus on frequently incurred costs because they believe that these have a more powerful impact on travel behavior. Because many of the private, efficiently paid costs are paid infrequently, and most externalities and hidden or inefficiently priced costs are incurred daily or at least frequently, an analysis of frequently incurred costs would yield a lower ratio of efficiently priced costs to total societal costs. Which perspective—a focus on total costs or only on those costs incurred frequently—is more "correct," however, is not a settled issue.

These conclusions imply that there is some significant opportunity for improving the economic efficiency of motor vehicle travel by incorporating external costs, hidden private costs, and inefficiently priced private costs into the price paid by travelers. However, there are four important caveats:

[30] M.A. DeLuchi, University of California at Davis, "The Annualized Social Costs of Motor Vehicle Use Based on 1990-1991 Data," OTA contractor report, April 1994. Other studies of motor vehicle use are discussed in M.E. Hanson, *Results of Literature Survey and Summary of Findings: The Nature and Magnitude of Social Costs of Urban Roadway Use*, for Federal Highway Administration, U.S. Department of Transportation, 1992. OTA will soon publish a study reviewing different estimates of the environmental externalities of electricity generation.

[31] Including the cost of free parking and the monopsony cost of importing oil (the portion of oil consumption costs attributable to the effect that U.S. oil imports have on world oil prices), but excluding the costs of air pollution, travel time, and other nonmonetary costs.

1. Considerable uncertainty remains about both the magnitude and the appropriate monetary value of several external costs.
2. Measures to incorporate these costs must carefully match the pricing mechanism (gas tax, road pricing, etc.) to the patterns with which the costs are incurred and should avoid high implementation costs. If this cannot be done, it may sometimes be better to leave the costs unpaid by users.
3. Attempting to charge full social costs *only* in the motor vehicle sector ignores the reality that all economic activities have hidden, inefficiently priced, and external costs. Although there are reasons to believe that these represent a higher percentage of motor vehicle costs than of the costs for other activities, failure to apply full social cost accounting to other activities may reduce the economic efficiency benefits that would otherwise result from correcting transport pricing.
4. There may be external benefits as well as costs associated with motor vehicle travel that, ideally, would be incorporated in a "full social cost" accounting. Little research has been done on external benefits, but this does not mean that they are negligible.

Congestion

As noted, FHWA and others have projected large increases in traffic congestion for the coming decades, with delay costs soaring to tens of billions of dollars and average vehicle speeds dropping calamitously in many urban areas. For example, FHWA has projected a 450 percent increase in annual delay times from 1984 to 2005, from slightly more than 1 billion hours to nearly 7 billion hours. And local studies project that Los Angeles freeway speeds will drop to 11 miles per hour (mph) by 2010, from their present 31 mph. Skeptics of these estimates have attacked them at least in part on the basis of survey results showing that average U.S. commuting times remained essentially unchanged during the 1980s, a seemingly odd result if congestion has grown as much as estimated. Increases in reported average freeway speeds also appear at odds with estimated increases in congestion.

FEDERAL HIGHWAY ADMINISTRATION

Rush-hour traffic in the Virginia suburbs of Washington, DC, represents a familiar pattern that is spreading geographically to more cities and suburbs, and, temporally to a greater number of hours per day

OTA's evaluation of the available data indicates that it is possible that both the estimates of growing congestion and some of the apparently contradictory travel and highway speed data may both be right.[32] However, there is another reason to be concerned about the accuracy of the congestion estimates—they are based on traffic counts rather than on measurements of actual speed declines and travel delays, an indirect method that invites inaccuracy. And the dire projections of future congestion costs also invite skepticism because they take no account of shifts in job and residential locations or of changes in travel behavior (although these have been important factors in the past), and they assume that rising travel time costs will have no negative effect on the growth in traffic volume. In other words, these projections ap-

[32] This is primarily because congestion delays still represent a relatively small portion of total highway travel. Consequently, adverse effects of congestion on highway speeds and travel times could be offset by factors such as increased highway speeds during uncongested periods and shifts in commuting patterns.

pear to be worst-case extrapolations rather than "most likely case" estimates.

OPTIONS FOR REDUCING TRANSPORTATION ENERGY USE

The options available to policy makers to pursue transportation energy conservation activities include:

1. *economic incentives--direct taxes,* granting or eliminating tax breaks, subsidies, granting of regulatory exemptions, making pricing more efficient;
2. *public investment--in* new infrastructure (including new types of systems and services, e.g., mass transit), maintenance and rehabilitation of old transportation infrastructure, expansion of service, urban development, research and development; and
3. regulatoryincentives-efficiency standards, zoning, fuel use requirements, speed limits, inspection and maintenance requirements, and travel restrictions.

Some of the main thrusts of transportation energy conservation policy are discussed here, from raising gasoline taxes to increasing the use of mass transit.

Gasoline Taxes

Raising taxes on gasoline is often viewed as both a means to raise revenue and an energy conservation measure. Higher gasoline prices serve as an incentive to purchase more efficient cars and light trucks and to change travel behavior-toward carpooling, transit, and reduced tripmaking.

For every 1 percent increase in the price of gasoline, the number of vehicle-miles traveled is expected to decline by 0.1 to 0.25 percent;[33] new car fuel economy may also respond by increasing a small amount,[34] unless fuel economy standards are already forcing fleet miles per gallon (mpg) higher than the market would drive it. Current corporate average fuel economy (CAFE) standards do seem to be propping up fuel economy against a market-induced drop. Consequently, small increases in gasoline taxes maybe more likely to allow some automakers to stop subsidizing sales of small cars (which they do to comply with the standards) than to actually raise their CAFE levels.

Although there is a substantial range of views about the effect of gasoline taxes on gasoline demand and vehicle efficiency, the primary source of controversy about such taxes is disagreement about their impact on the deficit and on the economy. This disagreement stems from three major sources: failure to account for differences in the actual scenarios being analyzed; analytical uncertainty introduced by the use of different models, parameter choices, and baseline assumptions; and differences in beliefs about the extent to which gasoline is "underpriced" because of externalities and unpriced economic inputs associated with driving.

Any discussion of the impacts of a gasoline tax must recognize that such a tax, *like any tax,* acting alone, will in the short term depress the overall economy, increase unemployment, and reduce gross national product (GNP); after several years, these effects die out. Although there are multiple pathways for these effects, the primary paths include the reduction in gasoline demand and demand for new cars, which cuts jobs and income, and the reduction in aftertax income for people who must buy gasoline, which reduces their demand for most goods and services. These impacts then reverberate throughout the economy.

Gasoline taxes provide revenue, however, and the use to which this revenue is put makes a criti-

33 See C.A. Dahl, "Gasoline Demand Survey," *The Energy Journal,* vol. 7, No. 1, 1986, pp. 67-82.

34 The elasticity of fuel economy with respect to gasoline Price is highly uncertain, h'cause the large changes in fuel economy during the 1)705 and early 1980s, which provide the best opportunity to obtain data for computing elasticities, occurred during a period when factors other than current gasoline price probably played an important role in boosting fuel economy. In particular, CAFE standards had been passed and available forecasts predicted astronomical oil prices. Al so, U.S. new car fuel economy had declined to wry low levels, so that the in itial improvements were easy to achieve.

cal difference in the overall economic impacts of the taxes. This is why evaluation of gasoline tax impacts must be linked to scenarios of how tax revenues are used (e.g., reductions in other taxes, additional expenditures, or deficit reduction; in addition, the Federal Reserve System may accommodate tax changes with changes in monetary policy, and these changes will strongly influence overall economic impacts). For example, if revenues from an increase in gasoline taxes were used to reduce the tax rate on capital investments, the net macroeconomic effect would likely be positive because taxes on investment are particularly distorting to the economy. On the other hand, coupling the tax to a reduction in personal income taxes would likely yield a net negative impact because income taxes do not have large distortionary effects on the economy.

Analytical uncertainty is introduced to estimates of gasoline tax impacts by the use of alternative models. The Energy Modeling Forum at Stanford University has conducted carefully controlled evaluations of alternative model runs that examine the same tax scenario. These evaluations have uncovered large differences in predicted outcomes among the alternative models.

The above factors influence evaluations of the effects of a gasoline tax on quantifiable measures of the health of the U.S. economy. Another indicator of the health of the economy, one that cannot be directly measured, is economic efficiency, which is a theoretical concept of the "goodness" of resource allocation in the economy. As discussed earlier, the presence of externalities and unpriced economic inputs associated with driving leads to an underpricing of driving costs, and thus to more driving and more gasoline use than would be economical 1 y efficient. To the extent that a new gasoline tax reduces this underpricing, it will add to the efficiency of the economy; any further increase beyond the point at which gasoline price matches the marginal cost to society would reduce economic efficiency.

A gasoline tax is limited in its ability to compensate efficiently for externalities and unpriced inputs. It tracks well only with greenhouse warming and energy security costs. but quantification of monetary equivalents for these two externalities is extremely uncertain. Other externalities and unpriced inputs, such as congestion delays and unpriced road services, can be addressed more efficiently by means other than fuel taxes, for example, variable congestion charges on roads. According to the social cost estimates prepared for this study, inclusion of greenhouse warming[35] and energy security costs into the cost of gasoline would add approximately $0.15 to $0.80 per gallon to current prices. Thus, if these estimates are correct, additional gasoline taxes of up to $.15/gallon and perhaps higher would improve overall economic efficiency.

Full Cost Accounting

Although gasoline taxes should be considered a primary option for transportation energy conservation, they are also one component of a broader option, full cost accounting of all transportation modes. As discussed above, full cost accounting attempts to maximize economic efficiency by repricing transportation services so that travelers

PRICE CLUB

Free parking at suburban malls and "super stores" represents **a** *partially hidden cost of motor vehicle travel Parking* **costs** *must be "paid" in higher prices for goods but shoppers may not account for these costs in their travel decisions*

[35] Global warming cost estimates should be considered particularly speculative.

pay and account for the full marginal costs to society of the transport services they select. Such a system would force travelers to take account of the air pollution (and other environmental effects, and negative impacts on society) that a trip would cause; would force payment for all transport services received (e.g., law enforcement); and would move hidden payments, such as parking costs, into the open so that travelers would account for them.

There is little argument about the clear value of full cost accounting in the abstract, but extensive controversy about the practical aspects of such accounting—the magnitude of externalities and unpriced inputs; the monetary values that should be placed on various externalities; the appropriate methods for implementing required price changes; and the likely impacts of price changes on travel behavior.

As noted, gasoline taxes could serve well to "internalize" the external costs associated with energy security and greenhouse warming because these effects vary with gasoline consumed, and thus with gasoline taxes collected. A variety of options exist to incorporate other externalities, unpriced inputs, and other ignored costs into the transportation price structure. For example, congestion pricing with electronic scanning of vehicles can be used to internalize the externalities associated with highway congestion. Parking costs can be "charged" to commuters by requiring firms to offer a cash option as an alternative to free parking. The costs of currently subsidized services—police and fire protection, for example, and a portion of local roadbuilding--can be translated into travel charges, although matching the nature of the services to an appropriate collection mechanism will be difficult. And the external costs of accidents can be added to driving charges by stricter requirements for insurance coverage or by incorporating a portion of insurance costs into fuel prices, vehicle registration fees, or other charges, thereby decreasing the incidence of uncompensated accident victims.

Automobile and Light-Truck Fuel Economy Standards[36]

Because light-duty vehicles—automobiles and light trucks---consume more than 50 percent of all transportation energy and 70 percent of energy from all motor vehicles, raising fuel economy standards for new light-duty vehicles is an obvious candidate for part of a national conservation strategy. The earlier legislative debate on new standards focused on a number of critical issues: the effectiveness of a regulatory approach to increasing fuel economy; achievable fuel economy levels; the most effective format for a new standard; timing of implementation; potential adverse effects on auto safety; effects on employment; and the likely fuel use reductions that would occur if standards are implemented. Each of these issues has generated substantial controversy.

Arguments about the effectiveness of new standards tend to revolve around perceptions about the actual impact of the 27.5-mpg standard (for automobiles only) set in 1975. Claims and counterclaims have been made about whether the large gains in U.S. fleet fuel economy in the 1970s and early 1980s37 were a response to the standard or to changed market conditions. '*Proof" of either side of the argument is elusive, but the sharply different fuel economy trends of companies that were either constrained or not constrained by the standards are persuasive that the past standard was a critical factor in the fleet's improvement.

The range of estimates for an "achievable" level of fuel economy over the next decade or so has been very wide, with domestic automakers arguing that future gains will at best be small and incremental, and conservation groups arguing that gains of 40 to 50 percent over current levels are readily achievable soon after the turn of the centu-

36 For more details, see U.S. Congress, Office of Technology Assessment, *Improving Automobile Fuel Economy: New Standards, New Approaches*, OTA-E-504 (Washington, DC: U.S. Government Printing Office, October 1991).

37 U.S. new car fleet fuel economy rose from 17.2 mpg in 1976 to 27.9 mpg in 1986.

ry. OTA concluded in 1991 that U.S. new car fleet fuel economy levels of about 33 mpg could likely be achieved soon after the turn of the century, with additional vehicle costs balanced by oil savings[38] and few measurable safety consequences (no downsizing would be necessary), but (probably) some limits on performance. Fleet levels of about 35 or 36 mpg were projected to be achievable in the same time frame with little technical risk and no forced early retirement of model lines but with costs that would not be recouped by fuel savings alone. During the nearly 3 years since these estimates were made, U.S. new car fleet fuel economy has not improved, and average vehicle weight has risen. Taking this into account, an updated estimate would likely project potential attainment of 33 mpg (at full cost recovery) or 35 to 36 mpg (cost recovery at $2 per gallon gasoline) by 2004 or 2005.[39]

The potential for- light trucks is somewhat less than for automobiles. Recent analysis of light-truck fuel economy projects that the domestic light-truck fleet could achieve about 23 mpg by 2005 with additional vehicle costs balanced by oil savings, and about 26 mpg by the same date with application of all available fuel economy technologies but no forced early retirements.[40]

Justification for the higher targets for both automobiles and light trucks would presumably be based on a belief that further fuel savings will yield added societal benefits in the form of lower greenhouse emissions. national security benefits from reduced oil imports (for the United States), and environmental benefits from lower oil production that are not incorporated in the price of oil.

The above increases in fleet fuel economy are based on application of well-known technologies and designs. New technologies, not yet introduced commercially into the fleet, could begin to play a significant role within the same time frame, The potential for these technologies is discussed below'.

If more stringent standards are to be imposed on new automobiles and light trucks, lawmakers will have to give serious consideration to the appropriate format for new standards. The current uniform 27.5-mpg standard for automobiles. applied separately to domestic and imported fleets for each company, has created large marketplace distortions by ignoring differences in the mix of vehicles manufactured by each automaker and by allowing gaming between domestic and imported fleets.[41] In particular, the uniform standard offers substantial market advantages to makers who have focused on smaller cars (e.g.. the Japanese automakers), by leaving these makers relatively unconstrained. Lawmakers might consider standards that vary with the average attributes of each automaker's fleet, so that each company's fuel economy target bears some relationship to the true technical potential of the vehicles it manufactures. Attributes such as interior volume, “footprint” (wheelbase x track width). or even combinations of weight, engine torque, and interior volume might be appropriate candidates for such a standard. New standards for light trucks might deal with different categories of trucks individually—for example, basing standards for passenger vans on interior volume and standards for pickup trucks on load carrying capacity. Design of appropriate

[38] If gasoline prices in year 2001 were $1.50 per gallon (1991 dollars). Office of Technology Assessment, op. cit., footnote 6.

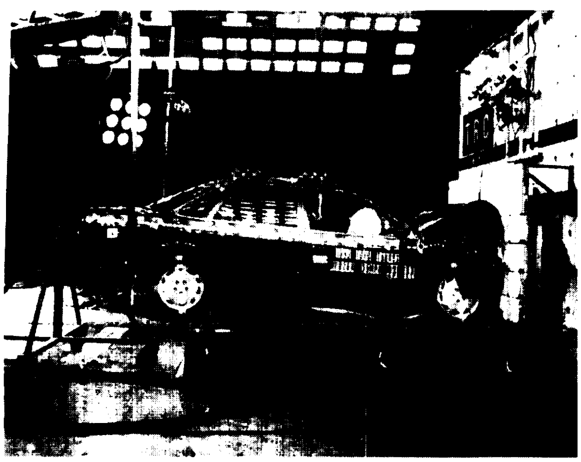
[39] Full cost recovery would occur if gasoline prices rose to $2 per gallon by 2001. In comparison, the National Research Council (NRC) projected a "practically achievable level" of 31 to 33 mpg for 2001 using similar assumptions; the most appropriate value for comparison to OTA's projection appears to be the lower value, NRC's "high confidence" level.

[40] Energy and Environmental Analysis, Inc., "Domestic Manufacturers Light Duty Truck Fuel Economy Potential to 2005," paper prepared for Oak Ridge National Laboratory, July 1993.

[41] For example, by shifting the manufacturing location of a few parts, automakers have changed vehicle designations from "import" to "domestic" or vice versa when this would ease their compliance requirements.

standards for the light-truck fleet will be a special challenge for regulators.

A centerpiece of recent congressional debates about new fuel economy standards has been concern about effects on vehicle safety, with the chief concern being the potential for forced downsizing of vehicles and an accompanying increase in injuries and fatalities from higher incidence of vehicle rollover or other causes. The potential for adverse safety consequences from either downsizing or downweighting is a legitimate concern. Although 10-year fleet fuel economy gains of 30 percent or so are feasible *without* downsizing, and market forces would appear likely to weigh against downsizing, there are no guarantees that automakers would not choose this course; further, moderate reductions in weight (a few hundred pounds would be likely) might have some adverse safety consequences. Also, requiring gains greater than 30 percent in this time frame, or a shorter schedule for required gains, could create severe pressure to downsize the fleet, with likely adverse safety consequences. On the other hand, measures are available to mitigate safety problems, including small increases in track width to reduce rollover risks, universal application of anti lock brakes, and enhancement of interior padding to prevent head injuries.



U.S. DEPARTMENT OF TRANSPORTATION

Barrier tests are an important safeguard in assuring the safety of new car designs, including designs stressing materials changes and other weight reduction measures

Another strong concern of lawmakers has been the potential employment consequences of new standards. Clearly, standards that can be achieved only by severely compromising consumer amenities could adversely affect sales and have an unfavorable impact on industry employment. However, there is no indication that standards at the levels discussed would hurt domestic automakers' competitive position or strongly affect their sales.

Analyses by both the industry and the conservation community have concluded that new standards would have strong employment impacts. However, competing analyses drew sharply different conclusions: the industry's analysis projected large job losses, and the conservation community's analysis projected large job gains. OTA found that both projections were driven more by their starting *assumptions* than by objective analysis.[42] The only defensible conclusion is that oil savings from new standards, like oil savings from any source, will tend to have positive impacts on national employment because the oil backed out of the economy will likely be imported oil, which generates fewer jobs per dollar spent than most other expenditures.[43] However, this is only one of several sources of employment impacts from new standards. Depending on the cost of required changes in auto design and the gasoline savings achieved, consumers may have more or less to spend on other goods and services, which would affect nonindustry employment; and net auto sales as well as auto manufacturing productivity rates might change, which would affect industry employment. These impacts could be negative or positive.

Finally, there has been considerable debate about the likely fuel savings associated with new

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[42] Although the conservation community's analysis, conducted by the American Council for an Energy-Efficient Economy, made much more use of economic analysis in its projection.

[43] In other words a dollar not spent on imported oil costs fewer jobs than are added by spending that dollar elsewhere in the economy.

standards. Most of the debate has been centered around Senate bill S. 279, which required each company fleet to improve by 20 percent for 1996 and 40 percent by 2001. Most differences in estimates occurred because of differences in assumptions about the likely values of fuel economy that would occur *without* new standards; the likely use of alternative fuel credits by automakers; the magnitude of any increase in driving because of reduced "per-mile" fuel costs associated with higher-efficiency autos; and the likely magnitude of future growth of vehicle-miles traveled. Two estimates that can serve as "outliers" are the Department of Energy's estimate of 1 mmbd saved by 2010, and the American Council for an Energy-Efficient Economy's estimate of 2.5 mmbd saved by 2005. OTA estimates that the most likely savings from compliance with S. 279 would be about 1.5 to 2.2 mmbd by 2010, *if compliance does not significantly hurt new car sales.*

"Feebates": An Alternative or Complement to Fuel Economy Standards

"Feebate" plans offer a market substitute for, or supplement to, new fuel economy standards. Feebate plans involve charging fees to purchasers of new cars that have low fuel economy[44] and awarding rebates to purchasers of new cars with high fuel economy. The plans can be designed to be revenue neutral or revenue generating, but their general purpose is to provide an incentive for consumers to purchase efficient vehicles and for manufacturers to produce them. Feebates avoid the danger inherent in CAFE standards: that the estimated costs and fuel economy benefits of available technologies are too optimistic. so that complying with the standards will end up costing much more than expected. Also, unlike CAFE standards, feebates provide continuing incentives to improve fuel economy beyond the level initially desired by rewarding the deployment of new, unforeseen technologies. On the other hand, leaving fuel economy results entirely to the market runs the risk that the actual improvements obtained may be considerably less than hoped for. In OTA's view, the potential for error in projecting the costs and benefits of feebates is quite high. Attempting to predict the actions of auto manufacturers in a free market adds considerable uncertainty to an analysis of fuel economy potential —beyond the important uncertainties in technology costs and benefits inherent in OTA's analysis of CAFE standards.[45]

Recent analyses by Lawrence Berkeley Laboratory (LBL) conclude that feebates large enough to award a $500 differential between a 20-mpg and a 25-mpg car can achieve a significant new car fleet fuel economy increase—15 percent over expected levels by 2010.[46] Virtually all of this improvement is expected to come from manufacturer responses to feebates, with changes in consumer behavior contributing little. If this analysis is correct, feebates will have an impact similar to CAFE standards aimed at the same 15 percent improvement, although with more flexibility y for manufacturers but less certainty of attaining the desired improvements in fuel economy. The dominance of the manufacturer response implies, however, that small-scale programs (e.g., programs conducted by one or a few small States) are unlikely to have much effect because they would be unlikely to affect manufacturer decisions.

An important concern of feebates is the possibility that they would provide an advantage to foreign automakers, because foreign companies, especially the Japanese, tend to have higher CAFE levels than U.S. automakers. The LBL analysis concludes that foreign automakers will gain more rebates than U.S. automakers, although this effect would diminish over time. Basing the feebate system on car size would diminish the adverse impact

[44] Measured against the average for all cars, or for cars in that class, or some other value.

[45] Office of Technology Assessment, op. cit., footnote 2.

[46] Using the same estimates of technology costs and fuel economy improvements that OTA used to evaluate CAFE standards.

on U.S. companies, because much of the difference between the U.S. fleets and the Japanese fleets is due to the larger average size of U.S. cars. However, LBL concludes that this type of feebate yields considerably less improvement in fuel economy than a feebate that allocates fees and rebates based only on fuel economy.

Transportation Demand Management Measures

Both the Clean Air Act Amendments of 1990 and ISTEA include requirements for programs that improve transportation efficiency by reducing traffic volume, especially during peak travel times. These transportation demand management measures (TDMs),[47] including parking charges, high-occupancy vehicle (HOV) lanes, and intelligent vehicle-highway systems (IVHS), could play an important role in a national conservation strategy. (In essence, many TDM measures are similar or identical to measures that would form the basis for full cost accounting.) Although few analysts expect any particular TDM to make great inroads in fuel use, especially because of likely political limitations on the severity of incentives considered, fuel savings of several percent may be possible from an intensive program combining a variety of such measures. Unfortunately, the limited number of trials of TDM measures and the diversity and complexity of travelers' reactions to them imply that policymakers must accept considerable uncertainty in gauging their likely impacts. Some promising or prominent measures include:

1. *Pricing parking:* Parking charges would be one of the largest and most visible costs of commuting and other local travel if most travelers paid them, but 90 percent of commuters receive free parking. Asking employers to offer workers a cash alternative to free parking (i.e., either parking or cash, at their choice) or otherwise providing a market incentive not to park appears to have substantial potential to reduce vehicle worktrips.
2. *Congestion pricing:* Placing electronic tolls on heavily traveled roads during peak periods should both reduce total trips and displace trips out of peak periods, when congestion makes them inefficient. Although congestion pricing is economically efficient because it asks travelers to pay for costs they impose on others, the substantial magnitude of the per-mile charges needed to make significant inroads on traffic volumes (estimated to be as high as $0.65 per mile in California's urban areas) represents a powerful roadblock to implementation.
3. *Telecommuting:* The growth of information-oriented service industries and simultaneous radical improvements in telecommunications capabilities may allow growing numbers of workers to "telecommute" from home or satellite offices, thereby avoiding long commutes. Currently, between 2 million and 8 million workers telecommute,[48] and the Department of Transportation projects that as many as 15 million workers could telecommute by 2002. Although all such estimates are highly uncertain, the potential clearly is large, with accompanying energy savings of more than 1 billion gallons of gasoline per year at the upper end.
4. *High-occupancy vehicle lanes:* HOV lanes are freeway lanes restricted during peak hours to vehicles containing two or more passengers. They provide an encouragement to carpooling, as well as providing some potential congestion relief—and increased efficiency-to the remainder of the roadway (unless they are conversions from previously unrestricted lanes, in which case their effects on congestion depend on circumstances). There is controversy about the ability of new HOV lanes to reduce overall vehicle-miles of travel and energy use, because the added roadway capacity and reduced congestion will stimulate additional travel, cancel-

[47] Or transportation control measures (TCMs).

[48] The range reflects the severe lack of data.

ing some of the benefits from increased ride sharing.

5. *Intelligent vehicle-highway systems:* IVHS encompasses a range of systems that can provide services from timely information to drivers about congestion and alternative routes to fully automated control of vehicles on limited access roads. ISTEA authorizes several hundred million dollars for IVHS development. These systems should have substantial potential to relieve congestion in crucial corridors. The ability of IVHS to reduce overall energy use is more problematic, however, because the energy saved by reducing congested (and inefficient) traffic flow must be balanced against any increased energy use from additional travel stimulated by increased road capacity.

Public Transportation

Whether public transportation is a key to revitalizing U.S. central cities and substantially reducing automobile use or has only minor relevance to future transportation policy is an ongoing argument in the transportation community. This is largely an argument between the hoped-for potential of public transportation and the disappointing record of its actual performance in the United States; it is also an argument about unpaid-for costs and unaccounted-for benefits.

There may be many local success stories of U.S. public transportation, and the central business districts of many American cities could not survive in their present forms without mass transit; yet for the past several decades, transit has shown a disturbing trend toward increasing costs and declining market shine despite heavy subsidies. Labor productivity y, for example, fell sharply during 1960-85, although it has rebounded a bit during the past few years. Similarly, per-mile labor costs rose by 80 percent *after inflation* from 1965 to 1983, with relative stability since then. With higher operating costs and reluctance to raise fares because of declining patronage. transit subsidies have risen. Local, State, and Federal governments now pay about 57 percent of transit operating costs and almost 100 percent of capital costs. This means that on capital-intensive systems (e.g., heavy rail systems such as Atlanta, Washington, DC, Buffalo), ticket prices may be paying for only 1() or 20 percent of total costs, with governments picking up the rest.

Heavy rail systems are a transportation mainstay of many U S cities, including New York, Philadelphia, Chicago, Boston, Washington DC (Washington's METRO shown here) and others

Aside from high costs, it also is not clear that most U.S. transit systems *in their present form* are saving much energy. From 1970 to 1989, both bus and rail transit energy intensity (fuel use per passenger-mile) increased substantially: buses by 70 percent, primarily because of lower load factors, growing urban congestion, and greater orientation to suburban services that require more nonrevenue backhauls; and rail systems by 38 percent, at least in part because a number of new systems were added that are faster and tend to operate at lower load factors than earlier ones. Right now, *on average* there is little difference between auto efficiency and public transportation efficiency in Btus per passenger mile.[49] Unfortunately, obtaining a fair comparison between auto and transit energy in ten-

[49] Davis and Strang, op. cit., footnote 3, table 2-13.

sity is quite difficult, requiring an accounting of trip circuity;[50] energy built into capital structures; trips used to access mass transit: appropriate auto load factors, given not only the type of trip but the characteristics of those auto users who are potential transit users; travel conditions (e.g., congestion); and transit system characteristics. Automobiles may in some instances be more energy-efficient than mass transit.[51] This does not imply, of course, that transit systems cannot save considerable amounts of energy under the right circumstances: high load factors for the transit system; private vehicles operating in congested conditions, often with single occupancy; transit operating on its own right of way or lane, or sharing an HOV lane.

Urban Planning

The potential of public transportation cannot be discussed properly without simultaneously discussing the role of urban form in shaping transportation patterns and energy use. It is clear from evaluation of urban areas worldwide and within the United States that residential density, as well as other urban characteristics such as centralization and mix of land uses, plays a crucial role in both the amount of per capita travel and the mode chosen. Cities with high residential densities (greater than 12 persons per acre), a strong central focus, and an intertwining of residential and commercial land uses tend to have both low overall per capita travel and relatively high use of public modes of transportation, as well as walking and bicycling, compared with cities with lower densities, lack of centralization, and separated land uses. Other urban characteristics that are strong indicators of both travel and mode choice are the relative volume of roadway and the volume of parking spaces per 1,000 vehicles. Given these relationships, many in the environmental community wish to consciously reshape American cities to make them more compatible with transit, bicycling, and walking, and to greatly reduce the travel necessary for access to employment, recreational, and cultural opportunities.

The urban characteristics discussed above are the result of both immutable factors—the cities' wealth and its distribution, their history (especially when they experienced their major growth), and their geography-as well as factors that are controlled by governments, such as roadbuilding policies, housing policies (including tax breaks afforded private dwellings), parking requirements, and land use planning controls. The precise role of the various forces is still the subject of considerable debate, with environmental groups stressing the role of policy and pro-development groups stressing the role of factors not controllable by policy. In reality, however, even those factors theoretically controllable by policy have become embedded in the American political system and are difficult to change. A few U.S. cities have made serious attempts to change some of these factors, however—Portland, Oregon being one of the most widely known[52]—but the results are not yet evident, And even these cities can change only some factors; other important matters, such as mortgage interest exemption and a tax policy that treats free employee parking as exempt from taxation, are controlled by the Federal Government. What this implies is that a serious effort to shift land use patterns into forms more compatible with reduced travel and greater use of transit, bicycling, and walking will require strong efforts at all levels of government, that changing the necessary policies will be politically difficult, and that the re-

[50] Trip circuity is the degree to which a trip between origin and destination diverges from the shortest path between the two.

[51] For example, in carpools, or more generally, when transit load factors are low.

[52] Portland has established an Urban Growth Boundary to direct development into the city rather than its suburbs, prohibited automobiles in a key downtown corridor served by bus transit; restricted parking spaces incorporated into new office development; and developed a light rail system. The city has thus far obtained good results regarding traffic volume and transit share for a small downtown area but, as a whole, has seen both a loss in transit share and a large increase in single-occupancy vehicles from 1980 to 1990.

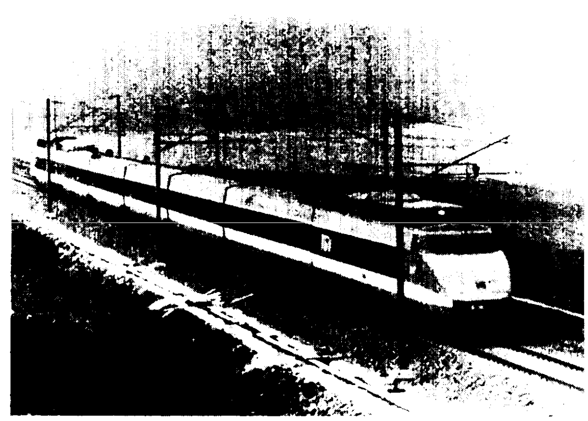
suits, in terms of actual changes in land use, are uncertain. Without a coordinated effort of this sort and a successful shift to denser land use patterns, however, it is difficult to imagine any kind of revitalization of public transportation in this country, regardless of the investment capital poured into new systems.

A corollary to the idea of changing land use to revitalize transit and reduce travel demand is that of installing transit systems to shape land use. Unfortunately, although it is clear that introduction of rapid transit systems can have large effects in the immediate locality around stations, there is little indication that such systems have had much effect on urban structure, at least over the past few decades. This lack of a strong, measurable impact implies that access to a transit system, although certainly a factor in determining locational decisions for new development, is only one of many such factors. Building a transit system can be part of a multifaceted strategy to affect land use, but it is unlikely to do much in relative isolation.

This conclusion is disputed by some environmental organizations, which maintain that comparisons of travel behavior and land use density across areas with different levels of transit service show clearly that such service creates higher densities of land use and reduces per capita levels of travel. Were such an effect to occur, transit evaluations should properly count the induced reductions in travel—and resulting decrease in air pollution, congestion, and other social costs of auto travel—as a direct benefit of transit. OTA's evaluation of the available studies indicates, however, that they are not adequate to demonstrate such an effect: they generally do not show changes over time, do not account sufficiently for demographic differences between areas with differing land use, fail to distinguish among different trip purposes, and cannot prove cause and effect. However, the positive relationship between good transit service and dense land use, on the one hand, and lower levels of travel, on the other, does lend weight to the argument that policies aimed at both increasing transit service and increasing land use density, if successful, would likely reduce travel and should be credited with this reduction in a cost-benefit analysis. Further study is needed to define the likely magnitude of such an effect, however.

High-Speed Intercity Public Transportation

Only 1.2 percent of all person-trips are at least 75 miles in length, but these trips represent more than one-quarter of all person-miles of travel. For trips from 100 miles (below which autos can be expected to continue their dominance) to about 500 miles in length (beyond which air travel should continue dominance), investments in high-speed ground transportation (HSGT) systems capable of speeds around 200 mph or faster—rail or maglev[53]—represent an option to relieve congestion in both auto and air modes and possibly (depending on system characteristics) to save energy (and reduce oil use). In fact, proposals have been made to install such systems in a number of U.S. inter-



The Train a Grand Vitesse (TGV) currently operates at high speeds (185 mph) along more than 1,000 miles of track in France

[53] Maglev systems are trains that operate suspended in air on fixed, dedicated guideways, held up by magnetic forces and propelled by linear electric motors.

city corridors, including Miami-Orlando-Tampa, Cleveland-Columbus, San Diego-Los Angeles-San Francisco-Sacramento-Reno-Las Vegas, Atlanta-Columbus/Macon-Savannah, and the Northeast Corridor (Boston-New York City-Washington, DC). The Transportation Research Board has found that further testing and development are necessary for maglev systems to prove they can operate safely and reliably in revenue service; European high-speed rail systems operating at speeds approaching 200 mph are firmly established.[54]

Although high-speed rail systems have been successful in Europe and Japan, this does not automatically demonstrate their applicability to U.S. conditions. The United States has some key disadvantages—less densely populated intercity corridors, with major cities farther apart; lack of preexisting heavily traveled rail links; lack of well-established intracity trains in most destinations; and availability of competitively priced air shuttle services. Further, much of the current and projected airport congestion is due to airline management decisions favoring hub-and-spoke operations, and is not entirely a function of physical capacity. Thus, the extent of future airport congestion, which is a key argument in favor of intercity high-speed rail, is somewhat in question.

Available analyses indicate that new HSGT systems would likely require strong government capital subsidies to maintain financial viability. With full capital subsidies (which new urban rail transit systems have received), operating and maintenance costs for new systems should be low enough to allow them to compete well with air and low-occupancy auto travel. Without such subsidies, annual ridership levels would have to be at least 2 million, and most likely about 6 million, passengers (high estimate: 17 million passengers per year), for the systems to break even. By 2010, only four city pairs are expected to have total air ridership exceeding this mark—Los Angeles-San Francisco, Boston-New York, Washington, DC-New York, and Los Angeles-Phoenix. Although maglev costs are quite uncertain because full-scale systems have not been built, early analyses imply that they would have a more difficult time breaking even without subsidies; OTA has found that the infrastructure costs of a maglev system for the Northeast Corridor would be approximately double those of a high-speed rail system.[55]

The keys to the future success of HSGT systems, if they are built, will be the extent of congestion growth in both road and air modes (available forecasts for both modes have large uncertainties), the level of subsidies Federal and State governments are willing to extend (which depend, in turn, on the value society places on the oil displacement, congestion relief, and other societal costs reduced by use of the systems), and the response of competing modes.

Improving Auto Fuel Economy: Moving Beyond Current Technology

Recent congressional deliberations about fuel economy standards have focused on relatively evolutionary improvements in automobile design, on moving available fuel efficiency technologies widely into the fleet, and on a short-term (10 to 15 years) time horizon. Another potential direction for fuel economy improvements is a radical shift in technology and design, possibly including a change in basic powerplant. Such a direction is embodied in calls for the introduction of "supercars," extraordinarily light-weight, electric-hy-

[54] Transportation Research Board, *In Pursuit of Speed: New options for Intercity Passenger Transport*, Transportation Research Board Special Report 233 (Washington, DC: National Research Council, 1991).

[55] U.S. Congress, Office of Technology Assessment, *New Ways: Tiltrotor Aircraft and Magnetically Levitated Vehicles*, OTA-SET-507 (Washington, DC: U.S. Government Printing office, October 1991).

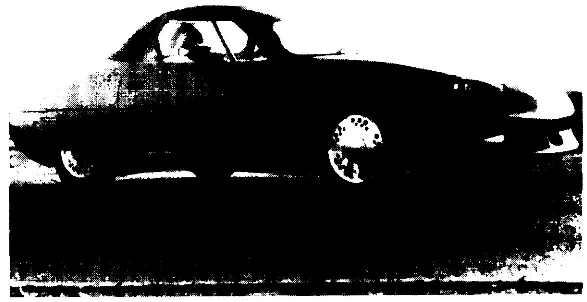
brid-powered vehicles, by the conservation community[56] and in a recent announcement by the Administration and the three domestic automakers of a partnership to develop a new passenger car with up to three times the fuel efficiency of current autos.

The basic features of an advanced automobile, one that went well beyond current technology, might include:

- a shift in body materials, probably to carbon-fiber or other composite materials, with higher materials costs counteracted by greatly reduced assembly costs;
- a total dedication to streamlining, bringing the vehicle drag coefficient down to the range of 0.2 or lower, compared with the current commercial state of the art of about 0.3;
- high-pressure, low-rolling resistance tires, perhaps similar to those in General Motors' Impact electric vehicle;
- an advanced engine, probably either a super-efficient four-stroke design with four or more valves per cylinder, adjustable valve lift and timing, and other low-friction measures or a two-stroke design; and
- extensive use of aluminum and other lightweight materials in suspension and other components (e.g., brake rotors and calipers, sway bars, wheels).

Rather than an advanced internal combustion engine, a radically redesigned automobile might use electric motors powered by batteries or fuel cells. or a hybrid combination including batteries and a motor/generator (or one of a variety of other combinations of power sources, including flywheels).

Recent strong technical advances have placed such an automobile closer to reality, although still a considerable way from commercialization. Some important advances are small, lightweight direct-current inverters that allow use of highly efficient, lightweight alternating current motors:


GENERAL MOTORS

GM's Impact electric vehicle represents a "ground up," innovative design focused on the unique requirements of an electricity based power source

and a 40-fold reduction in the amount of platinum required in proton-exchange membrane fuel cells, moving platinum availability and costs into the "realistic" range. Not surprisingly, there remain a number of crucial technical hurdles: improving the manufacturability and reducing the cost of advanced materials; designing adequate safety systems for a vehicle in the 1,000-pound range; achieving major improvements in fuel cell and battery technology; and so forth.

Thus far, the major "driver" for the development of advanced light-duty vehicles has been California's zero emission vehicle (ZEV) requirements. which require automakers to achieve at least 2 percent of their in-State sales with vehicles emitting no criteria pollutants by 1998, and 10 percent by 2003 (some northeastern States have adopted identical requirements). These vehicles will almost certainly be electric. The ZEV requirements have succeeded in stimulating a major research effort to develop electric cars: the eventual success of the requirements in bringing commercially acceptable electric cars to the marketplace remains an open question. however.

On September 29, 1993, the President announced a "Clean Car Initiative" with the three

[56] See A.B. Lovins et al., Rocky Mountain Institute, "Supercars: The Coming Light-Vehicle Revolution," unpublished report, Mar. 31, 1993.

domestic auto manufacturers. The initiative has as a primary goal the development of a manufacturable prototype automobile within 10 years that achieves a threefold increase in fuel efficiency while maintaining the affordability, safety standards, performance, and comfort of today's cars. This joint government-industry research program may add to the impetus for a large improvement in light-duty vehicle efficiency.

Shifting to Alternative Fuels[57]

The use of alternative, nonpetroleum-based fuels in vehicles, though generally viewed as a fuel substitution measure, also offers opportunities to reduce overall energy use and greenhouse emissions; in other words, alternative fuels can play a role in energy conservation. Energy savings may be gained from changes across the entire fuel cycle, ranging from changes in fuel efficiency at the vehicle[58] to changes in the energy required to find, collect, and transport fuel feedstock materials. Greenhouse gas emission reductions may be obtained directly from the energy savings and also from differences (from gasoline) in the alternative fuels' carbon content and general chemical makeup, which yield different fuel cycle emissions of carbon dioxide and the other greenhouse gases (carbon monoxide, nitrogen oxides, nitrous oxide, methane, etc.) .59

The primary alternative fuels under consideration for use in light-duty vehicles are the alcohols methanol and ethanol, natural gas, liquefied petroleum gas (LPG), hydrogen, and electricity. Except for electricity, all the fuels can be used in internal combustion engines. Hydrogen also can be used in fuel cells;[60] and methanol and natural gas, which are hydrogen-rich, can act as hydrogen carriers for fuel cells.[61]

Several factors inhibit the introduction of these fuels into the marketplace: the entrenchment of gasoline in the light-duty vehicle market; the lack of supply infrastructures and mature vehicle technologies for most of the alternative fuels; and various cost and range problems.[62] The Energy Information Administration expects, however, that a range of government incentives will help alternatively fueled light-duty vehicles capture from 1.9 to 2.4 percent of the light-duty vehicle fuel market by 2010.[63] These incentives include the 1990 Clean Air Act Amendments (CAAA), which establish a set of clean fuels requirements; the State of California's Low Emission Vehicle Program under the CAAA, which requires minimum sales of vehicles in different emissions cate-

57 For more details, see U.S. Congress, Office of Technology Assessment, *Rep/acing Gasoline: Alternative Fuels for Light-Duty Vehicles*, OTA-E-364 (Washington, DC U.S. Government Printing Office, September 1990).

S8 Because the alternative fuels have different combustion characteristics (e.g., methanol's octane rating is 101.5 and natural gas's is 120 to 130 versus 87 to 93 for typical gasolines; this allows methanol and natural gas engines to use higher compression ratios, raising thermal efficiency) and may require basic shifts in the drive train and fuel storage systems (e.g., electricity demands the use of electric drive motors and battery or ultracapacitor storage).

59 See M.A. DeLuchi, *Emissions of Greenhouse Gases From the Use of Transportation Fuels and Electricity*, ANL/EDS-TM/22 (Argonne, IL: Argonne National Laboratory, 1991). This report presents detailed estimates of the greenhouse emissions for each portion of the fuel cycle for a variety of alternative fuel/vehicle/supply source combinations.

60 Fuel cells are electro-chemical devices that convert hydrogen into electricity without combustion and with water as their only byproduct, acting like batteries that have continual recharge of their chemical electrolyte.

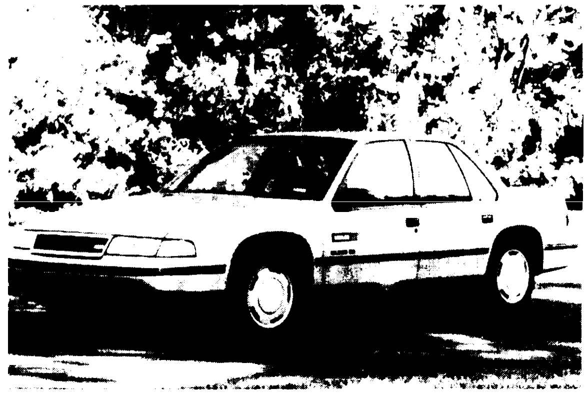
61 However, use in fuel cells of hydrogen carriers rather than pure hydrogen requires the addition of an onboard reformer to first release the hydrogen from these fuels. Although the fuel cell has no air emissions, the reformer does, so a fuel cell vehicle with a hydrogen-carrier fuel will not strictly be a zero emission vehicle.

62 All of the alternative fuels are less energy-dense than gasoline, and thus need a higher volume of fuel to achieve an equivalent range.

63 U.S. Department Of Energy, Energy Information Administration, *Assumptions for the Annual Energy Outlook 199.?*, DOE/EIA-0527(93) (Washington, DC: January 1993).

gories, including the 19982 percent ZEV sales mandate discussed earlier; and alternative fuel fleet requirements and tax incentives under the Energy Policy Act of 1992. Vehicle manufacturers can also get fuel economy credits toward meeting their CAFE requirements by manufacturing alternative fuel vehicles. Because most automakers can comply with current CAFE standards without a great deal of difficulty, the availability of the credits may have little effect unless CAFE requirements are raised.

Government incentives for alternative fuel use hinge on three potential benefits: energy security and economic benefits from reducing oil use and imports; air quality benefits, especially from reduced emissions of ozone precursors; and greenhouse benefits from reduced fuel cycle emissions of CO_2 and other greenhouse gases. The likelihood that these benefits will actually be obtained is mixed and uncertain, however. Take energy security, for example. Although all of the alternative fuels will substitute for oil, some raise their own security concerns because they may be imported (e.g., methanol if U.S. natural gas prices were to rise,[64] LPG in large quantities). These concerns may not be as severe as those associated with oil imports, however; feedstock resources, e.g., natural gas, tend to be less concentrated geographically. Security benefits also will depend on market penetration (which will affect fuel supply sources and costs) and other factors that are uncertain. And the existence of fuel economy credits adds uncertainty to security benefits. Were CAFE standards to be raised, automobile manufacturers might choose to use credits from sales of alternative fuel vehicles to avoid some of the fuel economy improvements otherwise required by the standards; the oil use reduction benefits of the alternative fuels might then be at least partially offset by he loss in efficiency gains.



GENERAL MOTORS CORP

Chevrolet Lumina Flexfuel auto can use straight gasoline, M85 (85 percent methanol, 15 percent gasoline mixture), or any combination in between

Air quality benefits depend on the nature of emission standards promulgated for alternative fuel vehicles and on the tradeoffs vehicle designers make among factors such as emissions, vehicle performance, and fuel economy. Where regulators try to adjust standards so as to weight emissions according to their potential to impact air quality, as California is doing, the emissions from vehicles using gasoline, methanol, natural gas, and other alternative fuels in internal combustion engine vehicles may be similar; only electricity and hydrogen. and methanol and natural gas in fuel cell vehicles, would then enjoy a clear emissions advantage.[65] Finally, greenhouse benefits depend on a variety of system design details, including choice of feed stocks, tradeoffs in conversion facility energy efficiency between capital and operating cost, and vehicle design decisions, as well as the uncertain progress of immature technologies. In the near term, any greenhouse benefits are likely to be small and easily lost (though early growth

[64] Methanol would likely be produced primarily in the United States and Canada at current gas prices; at higher prices, overseas production would be more likely, though some analysts believe there would still be potential for domestic methanol production as a byproduct of steel production, assuming shifts in steel production technology to allow co-production of pig iron and methanol.

[65] See D.E. Gushee, Congressional Research Service, "Alternative Fuels for Automobiles Are They Cleaner Than Gasoline?" Report for Congress, 92-235 S, Feb. 27, 1992.

of alternative fuels use may lay the groundwork for later benefits); large greenhouse benefits will come when renewable provide the majority of t he feedstocks or when design decisions are controlled by strong incentives to reduce greenhouse emissions from the entire fuel cycle.

Two important issues facing Federal policymakers involve fuel taxation policy and the current Federal policy of fuel neutrality. Currently, Federal taxation of alternative fuels seems at odds with interest in promoting fuels such as methanol and in maintaining a "level playing field" among competing fuels. Electricity, for example, pays no Federal highway tax, and natural gas pays very little, whereas LPG and methanol pay higher taxes than gasoline (on a $/Btu basis). Although it may make sense to tax different fuels at different rates based on their perceived benefits, current rates seem to bear no relation to Federal goals. Congress might consider adjusting tax rates to establish either a uniform tax (per unit energy) among competing fuels or a differential tax weighted according to emissions benefits or other perceived benefits.

Current legislation (especially EPACT) provides large economic incentives (thousands of dollars per vehicle) to alternative fuels with little regard to any differences among the various fuels in their likelihood of satisfying environmental or other Federal goals. Some types of alternatively fueled vehicles likely to enjoy success in the marketplace may, however, provide benefits that are significantly inferior to those provided by other vehicles.[66] At some point, perhaps when the environmental and energy security attributes of various vehicle/fuel combinations become clearer, Congress may want to reconsider the current policy of fuel neutrality (among the competing alternative fuels) in awarding incentives.

FREIGHT POLICY

The future potential for energy conservation in the freight sector lies largely in reducing truck energy use, because trucks consume the major part of U.S. freight energy (more than 80 percent) and because truck mileage is expected to grow rapidly—about 2 percent per year in the EIA forecast, and, in OTA's opinion, probably somewhat faster. The technical measures available include improvement in truck fuel economy-both for new trucks and, with retrofit technology, for the fleet as a whole (including improvement in driver skills); shifting to alternative modes and intermodalism (linking with other modes); and changes in operations to reduce waste.

Tests of the most energy-efficient new trucks under optimal driving conditions for high efficiency have achieved fuel economies 50 to 70 percent above the current fleet average efficiency. Similar tests of prototype trucks have achieved fuel economies over twice the current fleet average. Although real-world operating conditions, including average rather than optimal driving skills, would yield reductions in these efficiency advantages, the test results do suggest that there is a considerable energy savings potential from using commercially available and new technologies. Thus, a key to improving the efficiency of the fleet is both to encourage purchase of the most efficient vehicles and to speed up turnover, which is slow. Policy options to raise new truck fuel economy include fuel taxes, fuel economy standards, feebate programs, and government purchase programs; measures to encourage turnover include fuel taxes, retirement programs, and tax code changes.

Both fuel economy standards and feebate programs will encounter difficult technical problems because the great variety of truck types and cargo confounds efforts to establish fair efficiency goals

[66] For example, a flexibly fueled vehicle, fueled by gasoline, M85 (a mixture of 85 percent methanol and 15 percent gasoline), or any mix of the two will likely yield significantly smaller air quality benefits than a dedicated methanol vehicle.

for trucks and to appropriately group trucks into classes. Combination trucks pose a special problem for regulation because they are sold as separate trailer and engine units, with the design of each being crucial to fuel economy.

It is sometimes argued that mode shifts from trucks to rail or to barges would save significant amounts of energy since rail and barge shipping appears to be much more energy-efficient than trucks. In fact, shippers have found intermodal operations to be very attractive, and this form of shipment has been growing rapid] y, with the common form being containers moving from truck to train to truck. Care must be taken not to exaggerate the energy benefits, however: national data suggest that rail movement is 11.5 times as efficient as truck, but not for the same types of cargo. Limited analysis of alternative modes of moving the same cargo over the same routes suggests that trucks use 1.3 to 5.1 times as much energy as do trains. And incorporating the energy embodied in equipment and in getting freight to and from the rail terminal may reduce rail advantage further, although it still comes out ahead. With the limited portion of freight movement likely to be eligible for shifting to rail, however, total likely savings are in the range of one- or two-tenths of a quad, a few percent of total U.S. freight energy consumption.

POLICY OVERVIEW

Depending on their perception of the urgency of transportation problems and problems associated with urban air pollution, energy security, and greenhouse warming, Federal policy makers have a number of choices to make regarding transportation that can be simplified into three basic options:

1. retention of the status quo, with fine-tuning;
2. an activist approach that focuses primarily on improving technology; and
3. an approach that attempts to move U.S. transportation gradually away from its dependence on the private vehicle.

A status quo approach might use some moderate regulatory and economic policies to ease transportation problems: new CAFE standards set at levels achievable with available technology; modest gasoline taxes, perhaps $0.25 to $0.50 per gallon but likely lower; encouragement of local transportation initiatives taken in response to Clean Air Act requirements; some increased investment in transit with funds shifted from highway allocations (allowed by IS TEA); and so forth. Under such a scenario, congestion would likely increase, but the marketplace would moderate the increase by forcing changes in business and housing locations and in travel behavior. Cars will become more comfortable and will offer more opportunity for entertainment and work. In particularly congested areas, businesses will establish more use of telecommuting, perhaps by establishing satellite work centers. There would likely be a diversity of solutions to local transportation problems, most of them modest, but some drastic as in Portland, Oregon, a city that seeks to remake itself. Given political realities, most jurisdictions will likely try to satisfy both majority auto-oriented drivers and the conservation-environmental community by improving highways and transit services, but the latter is likely to have limited success without more basic changes in the existing incentives for private travel and in urban form.

The “livability” of the results of such an approach is difficult to predict, because analyses that forecast disastrous results invariably ignore society's adjustments to emerging problems. In the absence of technological breakthroughs (e.g., an inexpensive, energy- and power-intensive battery that allows electric vehicles to compete successfully with gasoline cars), urban pollution levels may worsen or not improve, congestion will probably grow worse (but not by as much as current government analyses predict), most urban centers will likely continue to weaken, and transportation energy use is likely to grow and continue to depend primarily on oil. However, there may be some surprises. If local solutions work well and seem transferable to other areas, they will spread. Simple steps that fit well into this overall strategy might make some inroads into auto use. Two measures that could work are requiring employers to “cash out” parking costs to employees and congestion pricing using electronic sensors (although this measure might more comfortably fit into the next approach).

A "technological fix" approach could make some serious inroads into some important transportation problems, while not affecting others. Such an approach might focus on leapfrogging current automotive technology to achieve very high levels of fuel economy, perhaps twice as high as today 's. Government-industry cooperative research programs could also move toward replacing internal combustion engines with electric drives powered by batteries or fuel cells, but strong economic incentives would probably be necessary to make the transition. Investment in IVHS could make moderate inroads in congestion, although probably not in urban centers. It is not clear that the congestion relief offered by such systems would yield better conditions than simply allowing marketplace adjustments, however, because the increased highway capacity such systems create could easily spur travel demand.

In predicting the eventual outcome of this approach, a key unknown is whether travel demand will keep on growing and overwhelm the effects of efficiency or will, instead, reach a plateau or period of very slow growth so that raising efficiency will reduce total energy use.

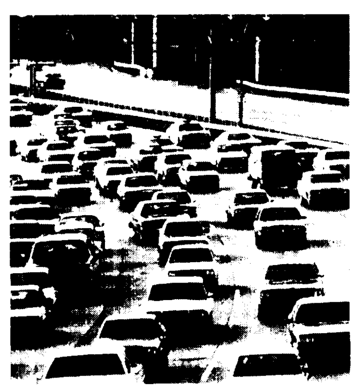
The third approach is to try to shift the U.S. transportation system substantially away from the private automobile, especially in urban areas and for intercity travel. Such an approach could have a chance of success *only* if it followed a multi-pronged strategy of drastically reducing highway building and accepting slower highway speeds; practicing '*full societal cost accounting" on automobiles, probably with significant increases in driving costs; redirecting urban structure toward higher density, centralization, and corridor development, with strong limits on parking and limits on suburban/exurban development; and investing massively in existing and new public transportation systems, with high-density mixed-use development focused on station areas.

The goal of such an approach is not only to drastically reduce gasoline use and urban air pollution, but to revitalize America's urban centers, making them places where walking and bicycling to multiple activities are feasible and where urban life is far more vibrant than is possible in most of today's U.S. cities. Whether the measures necessary to follow this approach are politically and socially feasible, and whether the goal is achievable even if such measures are taken, are two critical uncertainties. Many of the measures that would be necessary for this strategy to have a chance for success+ specially the strong controls on development and the increased costs of driving—are likely to draw severe opposition. Also the strategy seeks to reverse a process that appears to be going on worldwide, in a country that has a mature infrastructure designed around inexpensive automobile access. Ultimately, whether the goal is achievable even with successful implementation of the necessary policy measures depends on the answer to the question raised earlier: Has the past and continuing evolution of our city structures and travel behaviors depended primarily on policy or on technological change, rising income, and other immutable factors, and what will be the future relationships among these variables? Only prolonged experimentation with sharp changes in policy can answer this question.

Introduction 1

The focus of this report is transportation energy use in the United States and the potential for reducing that use. The quality of an area's transportation system is central to its over-till quality of life. A system's characteristics impact numerous vital areas: the accessibility of employment. recreational, and cultural opportunities; the availability of leisure time to its users, as well as their levels of frustration and tension; environmental parameters such as air pollution, noise, visual intrusion of roads, and their disruption of communities; the economic and social viability of inner cities and the shape of new development: the ability to move goods easily and inexpensively, which is crucial to economic competitiveness: and the safety of users and the general public. Moreover, these impacts are intertwined with wider impacts at a national level—the U.S. use of oil and its implications for global warming, energy security. and balance of payments.

By some important measures, the United States has a transportation system of very high quality, U.S. citizens enjoy the highest level of personal mobility in the world[1]--at least on the average. They travel more miles--13,500 miles per person per year[2]—than the citizens of any other country, nearly twice as far as the citizens of the richest European nations.[3] They own the



[1] In terms of relatively simple quantitative measures. Measuring mobility directly—in terms of actual access to activities and services—is more problematic.

[2] Data for 1990 obtained from L. Schipper and N. Kiang, International Energy Studies, Lawrence Berkeley Laboratory, in advance of publication in Oak Ridge National Laboratory, *Transportation Energy Data Book*, Ed. 14 (Oak Ridge, TN: forthcoming).

[3] Some 1990 examples from Schipper and Kiang: France, 7,800 miles; West Germany, 7,100 miles; United Kingdom, 7,000 miles.

most vehicles—nearly six autos or light trucks for every 10 persons, or almost two vehicles per household, compared with fewer than five per 10 persons for West Germany (the European leaders in vehicle ownership,) and fewer than three vehicles per 10 persons for Japan.[4] They also benefit from an efficient freight system that allows rapid delivery of everything from mail to oil to manufactured goods, virtually anywhere in the country.

However, the United States also faces daunting transportation problems. First, the U.S. transport system uses enormous quantities of oil—almost 65 percent of the total U.S. oil consumption,[5] and more oil than produced by all U.S. oil fields,[6] despite the United States' position as one of the world's largest oil producers (second in 1990[7]). The average U.S. citizen consumes nearly five times the transportation energy used by the average Japanese citizen and three times that used by the average citizen of France, Britain, or West Germany.[8] Although this higher level of consumption is not solely', and perhaps not even primarily, a function of relative "inefficiency" (at least not in the usual sense of the word) compared with Japan or Western Europe, it still represents a combined problem involving national economic security, balance of trade, and greenhouse gas emissions.

Second, the automobile's dominance of the transportation system contributes greatly to the Nation's problems with urban air quality. Today, almost two decades after passage of the Clean Air Act, about 100 urban areas (depending on weather conditions) still violate the ozone air quality standard.[9] Transportation sources, primarily automobiles and trucks, account for about 30 percent of the emissions of volatile organic compounds and 39 percent of the nitrogen oxides, which are precursors of ozone.

Further, other environmental impacts from U.S. auto dominance include high percentages of urban land devoted to highways, parking facilities, and other auto uses; the loss of wetlands and other ecologically sensitive lands from both the highways themselves and the diffuse land use that the highways support; and high emissions of greenhouse gases.

Third, although the *average* U.S. citizen enjoys great mobility, the dependence of the transportation system on privately owned vehicles leaves many lower-income people with the consequences of poor mobility—inability to get to decent jobs, limited access to convenient (or lower-cost) shopping, and inaccessibility to many recreational and other amenities that most citizens take for granted.[10]

4 L. Schipper and N. Kiang, op. cit., footnote 2, 1990 data, except for Japan (1988 data).

5 Energy Information Administration, *Annual Energy Outlook 1993*, DOE/EIA-1383(93) (Washington, DC: U.S. Department of Energy, January 1993), table A.8.

6 In 1990 transportation oil products consumption was 21.81 quads versus domestic liquids production (crude oil, lease condensate, and natural gas plant liquids) of 17.91 quads. Ibid., tables G1 and G2.

7 In 1990, only the Soviet Union outproduced the United States. Energy Information Administration, "International Energy Outlook 1992," DOE/EIA-0484(92), April 1992.

8 Schipper and Kiang, op. cit., footnote 2.

9 As of 1991, according to U.S. Environmental Protection Agency, *National Air Quality and Emissions Trends Report, 1991*, 450-R-92-001 (Washington, DC: October 1992).

10 It is important to note that, in the United States, autos are so inexpensive and fuel prices are so low that many poor people do own and operate automobiles." For example, according to Pisarski, 60 percent of workers in the poverty population (defined in 1989 as a family of four with annual income less than $ 12,674) commute to work in single-occupancy vehicles (A. E. Pisarski, *Travel Behavior Issues in the 90's*, Federal Highway Administration, July 1992). Of course, a less positive view of this high level of auto ownership and use among the poor is that the U.S. transportation system gives poor people few other options than to somehow obtain an auto, and that doing so forces them to forgo other uses of their limited income. Also, any move to increase fuel prices and auto ownership costs could reduce the access of the poor to automobiles. In fact, a forthcoming increase in the "waiver limit" in emission inspections required by the Clean Air Act Amendments, to $450 per vehicle, may have a similar effect by forcing retirement of many older autos.

Fourth. growing congestion is beginning to rob many travelers, especially in urban areas, of a precious commodity-time. Congestion also adversely affects freight movement and degrades U.S. economic competitiveness. Further, congestion reduces the efficiency of vehicle use, adding to fuel use and to pollution levels. Although widely cited projections of impending highway gridlock deserve careful (and perhaps skeptical) scrutiny, congestion represents an important and increasing problem for U.S. highway and air travel.

The combination of high mobility and daunting problems contributes to sharply different perceptions about U.S. transportation energy use and travel demand. Some observers of the U.S. transport system see the measures of high U.S. personal travel (e. g., 13,500 miles of travel per year per capita) as distinctly positive indications of a high quality of life. In this view, high levels of travel are directly translated into access to a wide range of employment, educational, recreational, cultural, personal, and shopping opportunities. Others, however, question whether this level of travel is, at least in part, a reflection of how inefficiently U.S. cities are laid out, how widely separated its residences are from centers of employment, and how distant its sterile suburbs are from exciting recreational and cultural opportunities. Similarly. the high levels of energy use are viewed differently. To some, they are an indication of high mobility, albeit inflated by certain technical inefficiencies in the transport system (which should be corrected). To others, they are a measure of systemic inefficiencies involving hidden subsidies for energy-intensive travel modes and the abovementioned failure to build habitats that put a diversity of employment, recreational, and cultural opportunities within easy reach of where people live.

The existence of these conflicting views represents a problem to policymakers because some significant opportunities for transportation energy conservation involve reductions in the number of trips made and miles traveled. For example, not only will raising energy and other transportation prices encourage improvements in the technical efficiency of transportation and shifts to more efficient modes, it also will reduce travel. Is this a positive or a negative outcome? Economists would consider this outcome positive only to the extent that transportation may have previously been underpriced because of subsidies (e.g., road maintenance and services paid out of general revenues rather than through user taxes), externalities (e. g., uncontrolled vehicle emissions causing damages to the general public), or inefficient pricing (e.g.. parking costs for shopping malls embedded in the price of goods rather than priced separately). To the extent that fuel prices. parking costs, and other transportation costs might be raised to a level that exceeded the full societal costs of transportation (market price plus subsidy costs plus externalities), any travel reductions caused by the portion of the price that exceeds total costs are a negative outcome. To place this issue in better perspective, chapter 4 explores the externalities, subsidies, and inefficient pricing associated with automobile travel. Chapter 5 discusses options for "internalizing some of the hidden costs of transportation, as well as pricing some transportation services more efficiently.

Valuing transportation services and energy conservation measures that involve reduced tripmaking is further complicated by the reality that transportation is not an end in itself, but a means to attain access to economic and personal opportunity. The concept of access to a variety of opportunities is easy to grasp but difficult to measure, so transportation services are generally measured simply in miles traveled and trips made. Thus, there is a constant danger that a traveler who must commute several hours to work will be judged (at least in the "benefits" value of some transportation analysis) to have obtained more value from transportation services than another who walks 20 minutes to work. Also, those judging proposed changes in transportation policy must distinguish carefully between changes that reduce travel and access to opportunity, and those that reduce travel by bringing opportunity closer. This complication conceivably could be resolved by introducing a factor that measured accessibility. Although this is a worthy goal, it is not attempted here. In discussing alternative policy measures to reduce transport energy use, however, the attempt is made to distinguish qualitatively between reduced travel and reduced access to opportunity.

Transportation and energy policy makers are faced with other dilemmas, as well, in addressing potential reductions in transport energy use. For example, they must deal with the essential incompatibility of attempts to simultaneously improve both private and public transportation modes: because public transport is generally at a severe disadvantage in competing with the private auto, in terms of comfort, flexibility, and travel time, in most cases transit can thrive only when auto travel is allowed to become congested or otherwise restricted. Further, policy makers face a highly polarized public and analytical view of mass transit potential, ranging from a basic rejection of any large additional role to continued hopes for a massive increase in transit usage. And efforts to improve highways, to reduce congestion and the environmental damages it causes, are controversial because of continuing arguments about the likelihood that adding new highway capacity will ultimately prove self-defeating by attracting more travel and creating the same levels of congestion and even greater oil use, air pollution, and other damages.

Policy makers also are faced with critical disagreements about the nature of the forces that have shaped the patterns of urban development in the United States. Because land use patterns are important determinants of travel demand and modal choice, changing these patterns could be a critical component of a transportation energy conservation strategy. But substantial controversy exists about whether the U.S. pattern of low-density development is due primarily to policy choices that can be changed (zoning rules, tax treatment of mortgage interest and parking costs, etc.) or to basic economic and technological forces that cannot be altered.

Energy costs are only a moderate fraction of the total costs of transportation, and energy use is rarely the critical driver of transportation decisions. In recognizing this, the report explores transportation's energy conservation potential in the wider context of the range of problems associated with the U.S. transportation system and the various market forces driving transportation decisions.

Given the diversity and complexity of the transportation sector, this report is not intended to be a comprehensive and quantitative evaluation of transportation problems and policy options. Instead, the report seeks to survey the transportation "landscape," to integrate the previous transportation energy work of the Office of Technology Assessment into a common framework, and to add selected analysis and evaluation of a few critical issues. OTA views this report as an introduction to the issue of transportation energy conservation, placing earlier OTA work in context and framing key issues that deserve further analysis.

Where We Are, Where We're Going 2

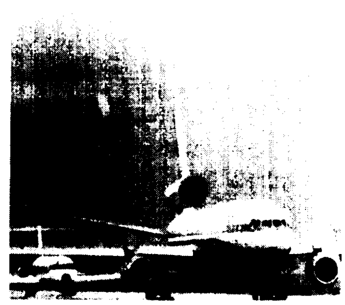
This section describes the current status of the U.S. transportation system and, in so doing, illuminates the "targets" for energy conservation. Although statistics are used extensively, the reader should note that transportation data are often of relatively poor quality (see box 2-A)_.

A SNAPSHOT OF THE U.S. TRANSPORTATION SYSTEM

Figure 2-1 provides a broad overview of where energy is being used in U.S. transportation. As shown, light-duty vehicles—automobiles, pickup trucks, utility vehicles, and vans—account for more than half of all U.S. transportation energy use. They are used predominantly for passenger travel. Airplanes, also used predominantly for passenger travel, account for 14 percent of U.S. transport energy use. These two components of passenger travel thus represent a tempting target for energy conservation measures.

Freight trucks are the second largest user of transportation energy, accounting for nearly 23 percent of total U.S. use. Freight truck energy use, expected to grow substantially during the next two decades, should thus also be an important focus of attention for energy conservation. Although other freight modes—pipelines, shipping, and rail (most of rail energy is freight energy)—are important (and rail could attract freight from trucking, with subsequent energy savings), they are clearly of lesser significance than trucks for national energy savings.

The transportation system in the United States provides U.S. residents with the highest level of personal mobility—in terms of vehicle trips made and miles traveled—in the world. The United States has the world's highest number of automobiles per capita



BOX 2-A: Transportation Data and Precision

Data on transportation passenger- and vehicle-miles traveled and energy consumed often are imprecise and apparently contradictory Part of the problem involves differences in assumed boundaries and definitions Do vmt data for light trucks include all trucks less than 10,000 pounds gross vehicle weight, all trucks judged to be driven for personal use, or all 2-axle 4-tire trucks? Do estimates of energy consumption for air travel Include fuel purchased by international earners in this country and then consumed outside of our boundaries? How are the various urban boundaries--central business district, central city, urban area, suburbs—defined? Where do government and military vehicles fit in? Alternative data sources use different definitions and boundaries and many do not specify precisely what these are Problems created by different definitions and boundaries virtually explode when International comparisons are made, because practices in other countries may be radically different from U S norms

A second problem concerns data collection Critical transportation data often are obtained by extrapolating from limited samples (e g household and mileage data) National data are aggregated from State data that may not be collected in a uniform manner (e g vmt data sources range from limited survey instruments to odometer readings from annual vehicle Inspections) Fuel use often is estimated by adjusting gasoline sales data, but there are startling differences among areas in the percentage of purchased fuel actually consumed within each area's boundaries

The result of these problems is that estimates for Important transportation variables may differ substantially among different sources For example measures of energy use in air transport vary significantly between values used by the Energy Information Administration (EIA) in its "Annual Energy Outlook" and those found in Oak Ridge National Laboratory's "Transportation Energy Data Book " The EIA value is *3.21* quads for 19901, the Oak Ridge value is about **2.55** quads for 1989.[2] Since air travel's energy use has recently (1982-89) been Increasing at an annual rate of 44 percent,[3] the Oak Ridge value adjusted for a year's growth is 266 quads—more than half a quad less than the EIA value Both estimates include military air travel and both Include purchases of domestic fuel by International earners, and there is no apparent discrepancy in definitions or boundaries

Discrepancies such as these can cause major analytical problems, particularly when values sought are the differences between two data points that do not come from the same source When seeking the difference between two variables of similar magnitude, relatively small discrepancies in the variables can yield huge errors in the resulting difference For example, if the result sought is (A-B) where the estimate for A is 200 and the estimate for B is 1.80 a 5 percent uncertainty in A yields a range for (A-B) of O 10-030, that is (A-B) could be off by as much as 200 percent

SOURCE Office of **Technology** Assessment 1994

[1] Energy Information Administration *1992 Annual Energy Outlook* DOE EIA-0383(92) (Washington, DC January 1992) table Al 4

[2] S C Davis and M D Morris *Transportation Energy Data Book* ed 12 OR NL-671 O (Oak Ridge TN Oak Ridge National Laboratory March 1992) table 27

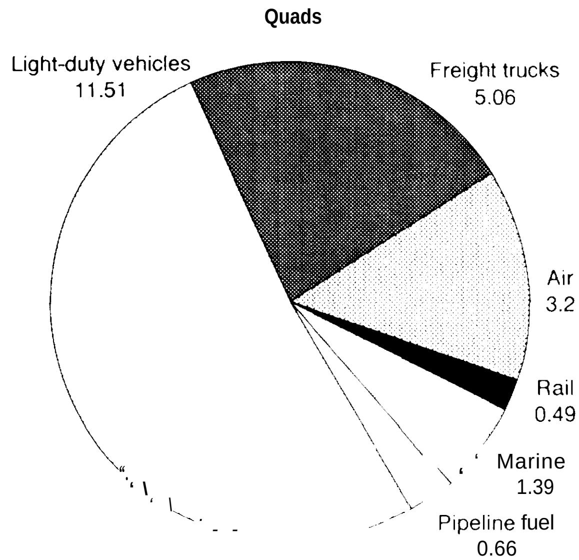
[3] Ibid table 210

—0.575 in 1989.[1] In 1990, the United States had a total population of 250 million, 167 million licensed drivers, and 179 million vehicles operating—1.07 vehicles per licensed driver, or 1.92 vehicles per household.[2] The average adult with a driver's license travels 30 miles per day of local, personal travel, and even adults without licenses manage to travel 10 miles a day.[3] In 1990, the average U.S. resident traveled about 13,500 miles—compared with about 7,800 miles for the average Frenchman or 6,400 miles for the average Japanese.[4]

The overall U.S. transportation system is the largest user of oil in the U.S. economy and is itself almost totally dependent on oil. In 1990, 63.6 percent of all U.S. oil use went directly to transportation,[5] and much of the remaining oil use (e.g., residual oil) was in byproducts of transportation fuel production. In the same year, the system was 97.1 percent dependent on oil as a fuel and lubricant.[6] Consequently, the U.S. oil import problem is primarily a *transportation* problem.

The large quantity of oil, and of energy per se, consumed by U.S. transport may pose a problem for its global warming potential as well. The United States is responsible for about 24 percent of current world emissions of carbon dioxide from fossil fuel combustion,[7] and the transportation sector emits 22 percent of U.S. fossil fuel carbon dioxide (almost 30 percent if the entire fuel cycle is considered).[8] As transportation energy use grows, so will its contribution to worldwide emissions of greenhouse gases.

FIGURE 2-1: U.S. Transportation Energy Use in 1990



SOURCE Energy Information Administration

Passenger Travel

U.S. passenger travel is dominated by the automobile and the highway system. In 1990, about 86 percent of passenger-miles were auto (and personal light truck) miles, and about 10 of the remaining

[1] S.C. Davis and M.D. Morris, *Transportation Energy Data Book*, ed. 12, ORNL-6710 (Oak Ridge, TN: Oak Ridge National Laboratory, March 1992), table 1.3.

[2] Ibid., table 4.1. Note that "vehicles" includes trucks and buses.

[3] A T Reno, "Personal Mobility in the United States," Transportation Research Board, Special Report 220, 1988.

[4] Data for 1990 obtained from L. Schipper and N. Kiang, International Energy Studies, Lawrence Berkeley Laboratory, in advance of publication in the *Transportation Energy Data Book*, ed. 14 (Oak Ridge, TN: Oak Ridge National Laboratory, forthcoming). The Japanese data are for 1989.

[5] Davis and Morris, op. cit., footnote 1. Statistical Summary.

[6] Ibid.

[7] U.S. Congress, Office of Technology Assessment, *Changing by Degrees: Steps To Reduce Greenhouse Gases*, OTA-O-482 (Washington, DC: U.S. Government Printing Office, February 1991), figure 3-3.

[8] S.C. Davis and S.G. Strang, *Transportation Energy Data Book*, ed. 13, ORNL-6743 (Oak Ridge, TN: Oak Ridge National Laboratory, March 1993), table 3.49.

14 percent were air miles. Buses and trains accounted for only 4 percent of passenger-miles, versus 15 **to 20** percent in Europe and 38 percent in Japan.[9] Autos and light trucks used for passenger travel accounted for more than 50 percent of all transportation energy use in 1990,[10] and 70 percent of all highway energy use.[11] This dominance is not surprising given a series of U.S. policies strongly favoring the automobile and automobile-oriented development:

- low gasoline taxes that allow U.S. gas prices to stay at about one-third those of most Organization for Economic Cooperation and Development (OECD) nations;
- low taxes on autos (average 5 percent in 1992);
- treatment of free employee parking as a normal business cost and a tax-free benefit to employees (and the widespread availability of free parking as a result);
- tax subsidy of homeowner mortgages, promoting single-family home development and sprawl;
- payment of many highway transportation services from general funds rather than gasoline taxes; and
- remarkably easy availability of driver's licenses.[12]

The U.S. highway system consists of about 3,800,000 miles of roadway, including 44,000 miles in the Interstate System,[13] 260,000 miles in the Federal-Aid Primary System,[14] 400,000 miles in the Federal-Aid Secondary System,[15] 125,000 miles in the Federal-Aid Urban System,[16] 2,751,000 miles of local roads,[17] and 226,000 miles of Federal roads in national forests and parks and on military and Indian reservations.[18] The system also includes nearly 577,000 bridges. Virtually every local jurisdiction has a large backlog of road and bridge maintenance and repair needs: more than 10 percent of the Nation's roads have enough potholes, cracks, ragged shoulders, ruts, and washboard ridges to be classified as deficient; and nearly 42 percent of the Nation's bridges are rated as unable to handle traffic demand or structurally deficient.[19] In the Nation's largest cities, the result of the poor state of repair of the road system coupled with inadequate peak capacity results in several billion dollars in congestion costs each year.[20]

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[9] Schipper and Kiang, op. cit., footnote 4.

[10] U.S. Department Of Energy, Energy Information Administration, *Annual Energy Outlook 1993*, DOE/EIA-0383 Washington, DC: January 1993), table A. 14. Note that definitions of total transportation energy use can differ and thus change the percentages of different sectors. For example, the Oak Ridge *Transportation Energy Data Book* defines "transportation energy use " in two different ways—with or without off-road heavy-duty use for construction and farming, and military travel—and thus reports 1990 transportation energy as 23.2 and 21.8 quadrillion Btu (quads), respectively.

[11] Ibid.

[12] J. Pucher, "Urban Travel Behavior as the Outcome of Public Policy: The Example of Modal-Split in Western Europe and North America," *Journal of the American Planning Association,* autumn 1988, pp. 509-520.

[13] Routes that connect Principal metropolitan areas, serve the national defense, or connect with routes of continental importance in Mexico or Canada.

[14] Interconnecting roads important to interstate, statewide, and regional travel.

[15] Major rural collectors that assemble traffic and feed to the arterials.

[16] Urban arterial and collector routes, excluding urban extensions of the major primary arterials.

[17] Residential and local streets.

[18] U.S. Congress, Office of Technology Assessment, *Delivering the Goods: Public Works Technologies, Management, and Finance*, OTA-SET-477 (Washington, DC: U.S. Government Printing Office, April 1991), based on U.S. Department of Transportation data.

[19] Ibid.

[20] Ibid. Congestion cost is the estimated cost of travel delay, excess fuel consumed, and higher insurance premiums paid by residents of large, congested urban areas. The magnitude of these costs is controversial.

TABLE 2-1: Mass Transit Active Vehicle Fleet and Infrastructure

Vehicles	
Buses	52,945
Vans for service to senior citizens and people with disabilities (not public)	20970
Subway cars	10325
Rural service vehicles (primarily vans—public)	10101
Commuter rail cars	4646
Vans	2412
Streetcars and cablecars	940
Commuter rail locomotives	472
Others (including ferryboats)	372
Total	103,183
Infrastructure	
Miles of commuter rail track	4830
Miles of rapid rail transit track	1 744
Commuter rail stations	958
Rapid rail transit stations	911
Miles of light rail track	687
Bus light maintenance facilities	523
Demand response service maintenance facilities	86
Rapid rail transit maintenance facilities	43
Commuter rail light rail maintenance facilities	35
Light rail light maintenance facilities	18
Ferryboat light maintenance facilities	4

SOURCE U S Department of Transportation Federal Transit Administration *Public Transportation in the United States Performance and Condition* Report to Congress (Washington, DC June 1992) table 12 p 18

The U.S. transit system consists of an array of regional and municipal systems, including buses. light rail, commuter rail, trolleys, and subways, as well as an array of vehicles providing "paratransit" services--dial-a-ride, van pools, subsidized taxis, and shared rides in minibuses or vans. The basic characteristics of U.S. mass transit are presented in table **2-1.** Most cities of 20,000 or more population have bus systems, usually operated by a municipal transit authority. In fact, buses on established routes with set schedules account for more than one-half of all public transit passenger trips, U.S. transit operations are heavily subsidized, with subsidies paying for about 57 percent of operating costs in 1990[21]**—probably** the highest cost-per-ride subsidy level among OECD nations.[22]

Although most cities have some kind of transit system, most mass transit in the United States is concentrated in a relatively few cities. In 1991.71 percent of all transit trips were in the 10 cities with rapid rail systems: New York City, Boston, Philadelphia, San Francisco, Chicago, Washington, DC, Cleveland, Atlanta, Baltimore, and Miami.[23] In fact. in 1990, 35 percent of transit passengers and 41 percent of transit passenger-miles were in New York City and its suburbs.[24]

[21] Federal Transit Administration, *Public Transportation in the United States: Performance and Condition* (Washington, DC: U.S. Department of Transportation, June 1992).

[22] Pucher, op. cit., footnote 12. In 1982, the Netherlands, Belgium, and Italy paid a higher *share* of total costs than the United States, but their cost per ride was much lower.

[23] Federal Transit Administration, op. cit., footnote 21.

[24] Ibid.

The road system in U.S. cities is shaped largely by the need to offer capacity to satisfy peak traffic periods. Traditionally, the peaks largely consisted of worktrips, and these still dominate, although not as much as before (in metropolitan areas, worktrips constitute 37 percent of all person trips in the two peak periods from 6 to 9 a.m. and 4 to 7 p.m.[25]). The commute represents 26 percent of the total household vehicle trips and 20 percent of the household person trips.[26] A key characteristic of U.S. commuting patterns is that worktrips generally are relatively short and diffuse in both origin and destination. The mean worktrip is slightly less than 10 miles long and takes 20 minutes; more than half are under 6 miles; and less than 4 percent are more than 30 miles.[27] And although the pattern of workers living in surrounding areas and commuting to the central business district (CBD) may once have been true, in 1980 the CBDs employed only 9 percent of the workers in their total urban areas and 3 percent of workers living outside the central city. Data for the average urban area in 1980 illustrate the diffusion of worktrips: 37 percent of the workforce lived and worked in the central city, 36 percent lived and worked in fringe areas outside the central city, and the remaining 27 percent commuted between central city and fringe (in both directions).[28] This is not a commuting pattern that can be well served by transit, or by walking or biking. In fact autos accounted for more than 90 percent of commuting trips in 1990-a dominance that has been stable for 20 years.[29]

As noted above, the diverse commuting patterns of most U.S. cities are not easily served by mass transit, which depends on large numbers of travelers having common origin and destination. Aside from *patterns*, transit also requires *density* of origins and destinations. With a few conspicuous exceptions (e.g., New York City), U.S. cities have extremely low residential densities, fewer than eight persons per acre compared with European urban densities 2 to 3 times as high and Asian densities 10 times higher.[30] Further, U.S. cities are far less centralized than European cities, and they do not tend to mix residential and commercial development (which might promote walking and bicycling). Instead, a combination of forces and circumstances—taxation and other policies discussed above, massive roadbuilding, strong consumer preferences for single-family homes, high incomes, and the relatively young age of American cities (most either were developed after the beginning of the automobile era or experienced much of their growth during this era)—have yielded a U.S. urban development pattern characterized by:

> [an] undifferentiated mixture of land uses and a broad plateau of population density . . . other central places scattered over the urban landscape challenge the primacy of the historic CBD.[31]

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25 H.W. Richardson and P. Gordon, "New Data and Old Models in Urban Economics," University of Southern California, preliminary draft, December 1992, table 3. The precise character of changes in trip purposes is made uncertain by the manner in which trip purpose data are collected. A worktrip interrupted by a stop to run an errand would be counted as a shorter worktrip plus another trip. Because trip "chaining" of this sort has increased, some of the shift away from worktrips may be an artifact of the data rather than an actual shift.

26 Davis and Morris, op. cit., footnote 1, tables 4.9 and 4.10. The vehicle load factor for commutes is Only 1.2, versus 1.6 for all trips.

27 I.S. Lowry, "planning for Urban Sprawl, " *A Lwk Ahead--Year* 2020, Transportation Research Board, Special Report 220, 1988. This pattern of commuting breaks down only in the extremes of urban development-in very small towns where workers may 1ive quite far away, and in large cities of more than 1.25 million people where the sheer size of the area, and the difficulty of optimizing location because so many households have twu or more workers, cause average worktrips to be longer.

28 Ibid.

29 Davis and Morris, op. cit., footnote 1, table 4.11.

30 P.G. Newman and J.R. Kenworthy, *Cities and Automobile Dependence: A Sourcebook* (Aldershot, England: Gower Publishing Co., 1989).

31 Lowry, op. cit., footnote 27.

In other words, central business districts in most American cities have neither the preponderance of jobs nor the proximity of residential areas. Residences are now primarily in the suburbs, and to a large extent, a significant portion of the business community has followed, to gain access to suburban labor and (for shipping operations and manufacturing) to interurban transportation.[32] Many of these businesses have coalesced into subcenters. This produces a complex and multidirectional travel pattern.

The result is that in 1990 transit carried a mere 5.5 percent of urban commutes, with an additional 3.1 percent walking or bicycling.[33] For overall national travel in 1989, buses (excluding school buses) accounted for only about 45 billion passenger-miles, and trains for only about 26 billion passenger-miles—1.4 and 0.8 percent, respectively,[34] of a total of more than 3 trillion passenger-miles for all vehicular modes.

Estimating or comparing the energy intensities of different passenger travel modes is confusing and often controversial because much of the collected data are not specific about trip purposes for each mode, and the different modes often compete with each other only (or primarily) for specific types of trips. Also, the energy intensity of the vehicles tells a limited story, since a great deal of energy is embedded in each mode's capital infrastructure and expended in ancillary activities such as powering stations, repairing roadways and guideways, and so forth. Further, national averages hide large variations from city to city, because average auto travel speeds vary greatly among cities, and the service and physical characteristics of public transport systems (especially rail) vary greatly as well. In the following discussion, only vehicular energy use is considered, and the focus is on national averages.

In city travel, the energy efficiency of different passenger travel modes has tended to converge somewhat over the past few decades, as auto travel has grown more efficient and public transportation has declined in efficiency. When the same types of trips are compared, however, transit probably still retains an edge.[35] In highway or intercity travel, bus transit, at least, remains substantially superior to auto. In 1989, the fuel intensity of private autos was 6,095 Btus per vehicle-mile[36] (about 20.3 mpg[37]), or 4,063 Btus per passenger-mile (p-m) when the load factor of about 1.5 passengers per auto is accounted for. The intensity of personal light trucks was about 6,605 Btu/p-m in 1989. For city travel, the intensity of autos was about 4,510 Btu/p-m, and of light trucks, about 7,340 Btu./p-m.[38] For worktrips, however, the intensity is higher—about 6,150 and 9,340 Btu/p-m, respectively (given a load factor of 1.1). For highway travel, auto intensity was about 3,470 Btu/p-m, and light truck intensity about 5,650

[32] Richardson and Gordon, op. cit., footnote 25.

[33] Davis and Morris, op. cit., footnote 1, table 3.16.

[34] Ibid., table 2.12.

[35] However appropriate comparison of the energy intensities of competing modes requires sophisticated evaluation of specific trips. As discussed in the section on public transportation in ch. 4, these comparisons should account for a variety of factors, including trip circuity, travel conditions, and traveler characteristics.

[36] Davis and Morris, op. cit., footnote 1. table 2.12.

[37] U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1991*, DOE/EIA-0384(91) (Washington, DC: June 1992), table 23.

[38] If city fuel economy is about 90 percent of the combined highway-city value. This fraction holds fairly well for new car and light truck EPA fuel economy values. after adjusting for the different factors applied to city and combined fuel economy (0.90 and 0.85, respectively) to estimate on-road fuel economy. Based on Heavenrich et al., "Light-Duty Automotive Technology and Fuel Economy Trends Through 1991," EPA AA CTAB 91-02 (Ann Arbor, MI U.S. Environmental Protection Agency, May 1991), table 1. A possible flaw in this estimate is that it does not account for differences in load factor for city and highway travel; presumably, highway load factor will be higher.

Btu/p-m.[39] For long trips with higher load factors, however, the intensity is lower-perhaps 2,480 for autos (by assuming 2.1 persons per auto).[40]

For comparison's sake, the fuel intensity of transit buses was about 3,711 Btu/p-m, 82 percent of city auto intensity and 66 percent of city auto worktrip intensity; the intensity of intercity buses was 963 Btu/p-m, only 28 percent of highway auto intensity and perhaps 38 percent of intercity auto intensity. Rail systems exhibit similar energy relationships for city travel, but show much less gain when shifting to intercity travel. Transit and commuter rail had energy intensities of 3,397 and 3,102 Btu/p-m, 75 and 69 percent of city auto intensity, and 60 and 55 percent of city auto worktrip intensity, respectively. Intercity rail intensity was 2,731 Btu/p-m, 79 percent of highway auto intensity and 110 percent of intercity auto intensity. Air passenger travel, comparable with high-load-factor auto highway travel and intercity bus and rail, had an energy intensity of *4,796* Btu/p-m.[41]

Although automobiles continue to dominate U.S. travel, they face severe competition from commercial aircraft for trips of a few hundred miles and longer. As noted earlier, air transportation captures about 10 percent of the total passenger-miles traveled—447 billion passenger-miles for commercial aviation plus 12 billion in general aviation, in 1989[42]-—and is the most rapidly growing segment of the U.S. transportation system. In the 1980s air passenger-miles grew at a rate of more than 7 percent per year.[43] Air transportation accounts for about 12.5 percent of total passenger travel energy use, or 1.74 quadrillion Btu (quads) .44

The U.S. air travel system is extremely centralized, with most trips starting and finishing at relatively few major airports. In fact, the 10 largest airports serve 40 percent of all passenger trips, primarily because of widespread use by major air carriers of "hub-and-spoke" routes;[45] the top 100 handle 95 percent of all passenger trips. There are, however, more than 17,000 airports in the United States, most being public-use general aviation airports owned by municipalities, counties, or private groups, and used primarily by personal and business aircraft.[46]

The major airports experience substantial capacity problems and resulting delays, which waste significant amounts of fuel by idling aircraft on the runways and keeping arriving planes in holding patterns. Of the 25 airports with the most delays, Chicago's O'Hare ranks first, with total delays exceeding 100,000 hours per year; two airports have annual delays between 75,000 and 100,000 hours; two more have delays between 50,000 and 75,000 hours; and the remainder are between 20,000 and 50,000 hours.[47] If no capacity improvements are made or peak shaving measures taken, the Federal Aviation Administration

[39] If highway fuel economy is about 117 percent of the combined highway-city value. This fraction holds fairly well for new car and light truck EPA fuel economy values, after adjusting for the differential factors applied to highway and combined fuel economy (0.78 and 0.85, respectively) to estimate on-road fuel economy (based on Heavenrich et al., op. cit., footnote 38, table 1). As before, no account was taken of possible differences in load factor between city and highway travel.

[40] Davis and Morris, op. cit., footnote 1, table 4.10.

[41] For auto trips comparable with competing air trips, however, load factor was likely higher than the 1.5 assumed for the auto intensity estimates.

[42] Davis and Morris, op. cit., footnote 1, table 6.2.

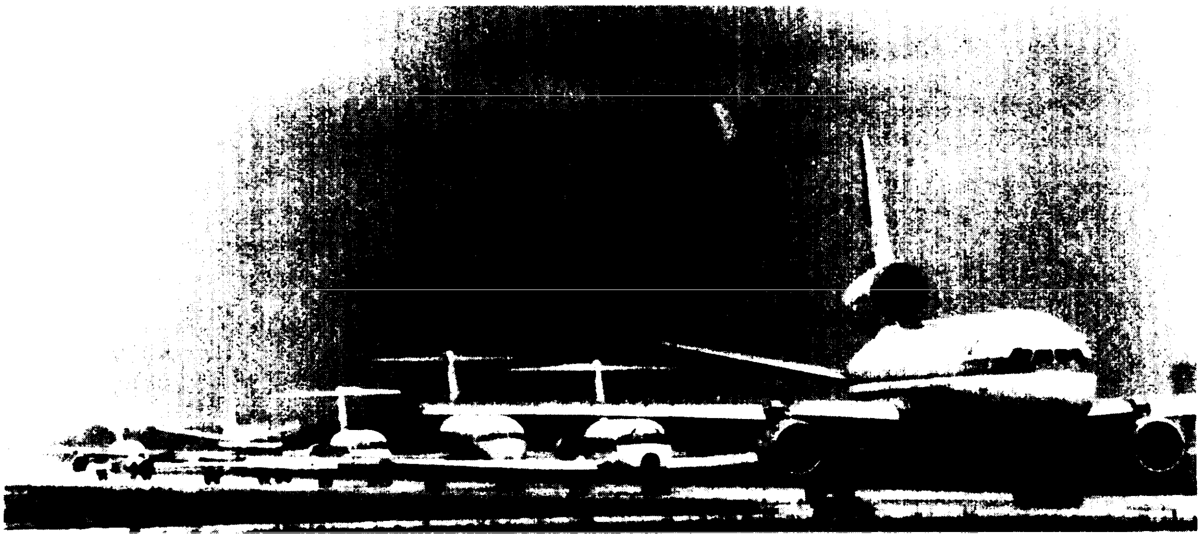
[43] Ibid.

[44] Ibid., table 2.12.

[45] J.F. Hornbeck, *Transportation Infrastructure: Economic and Policy Issues*, 92-158E (Washington, DC: Congressional Research Service, Feb. 11, 1992).

[46] Office of Technology Assessment, op. cit., footnote 7.

[47] Ibid.



FEDERAL AVIATION ADMINISTRATION

Major airports experience substantial capacity problems and resulting delays, which waste significant amounts of fuel by idling aircraft on the runway and keeping arriving planes in holding patterns

expects 17 airports to move into the 75,000 -hour-and-up delay category by 1997.[48]

Freight Transport

The movement of freight—including everything from basic materials such as coal and grain to final consumer products such as clothing and computers-consumes about 6 quads of energy per year, accounting for about 17 percent of total U.S. oil consumption.[49] The freight system moves about 3.2 trillion ton-miles of freight per year. Trains and trucks each carry about 30 percent of this, barges about 24 percent, oil pipelines 16 percent, and air less than 1 percent. Energy use for freight shows a very different pattern than ton-miles. **Trucks dominate freight transport energy use, accounting for more than 80 percent of the total.** Trains and barges are far behind, accounting for 7 and 6 percent, respectively, of freight transport energy use (table 2-2).

Truck Freight

For nonbulk cargo-mail, perishable food, packaged goods, and so forth-trucks are the dominant transport mode. In 1989, trucks transported about 30 percent of cargo (table 2-2). In contrast, European freight shippers used trucks for about 64 percent of their shipping requirements, primarily because European countries do not produce or ship volumes of bulk goods comparable with the United States.

Trucks carry a wide range of goods.[50] The cargoes carried by light (less than 5-ton) trucks differ significantly from those carried by heavy (greater than 13-ton) trucks. Almost one-third of light truck miles (excluding passenger only) are for the movement of craftsman's equipment; no other single cargo accounts for more than 10 percent of light truck miles. **Light trucks** (excluding passenger only) **account for 40 percent of total**

[48] Ibid.

[49] Davis and Strang, op. cit., footnote 8, p. 2-7; also table 2-2.

[50] A more detailed discussion of the trucking industry can be found in U.S. Congress, Office of Technology Assessment, *Gearing Up for Safety*, OTA-SET-382 (Washington, DC: U.S. Government Printing Office, September 1988), p. 34.

TABLE 2-2: The U.S. Freight Transport System, 1989

	Energy use (percent)	Ton-miles (percent)	Expenditures (percent)	Energy Btu/ton-mile	Intensity index[a]
Train	7	30	10	427	**1 0**
Freight truck	83	29	83	4,924	115
Water (domestic)	6	24	2	403	0 9
Air cargo	1	<1	3	9,548	224
Oil pipelines	3	16	3	274	0 6
Total	**5.9 quads**		**$311 billion**		

[a]Intensities are simply energy use divided by ton-males Because cargo carried by the various modes may be very different, intensities are not, by themselves accurate indicators of energy efficiency

NOTE Data are uncertain Excludes light passenger-only trucks, natural gas and water pipelines, and International movements

SOURCE Office of Technology Assessment, 1994

freight truck energy use (table 2-3). These trucks are typically used for short-distance urban or suburban delivery. The technologies and policies affecting the energy efficiency of these trucks are quite similar to those for automobiles. For example, most new light trucks are required to meet Federal fuel efficiency standards.

Significant loads for heavy trucks, in contrast, include mixed cargo. processed food, and building material. The heaviest class of trucks, with a (gross vehicle) weight of more than 13 tons, accounts for over half of truck energy use (table 2-3). Most of these trucks are the familiar 18-wheel tractor-trailers with a capacity of 40 tons, and typically are driven many miles per year (heavy trucks driven more than 75,000 miles per year account for more than half of all heavy truck-miles).[51] Most are powered by diesel engines, typically large (greater than 800-cubic-inch displacement and 300 horsepower), 6-cylinder units.

TABLE 2-3: Current Truck Fleet, 1987

	Light	Medium	Heavy
Number of units (1 ,000)	11,760	1,700	1 820
Energy use (percent of total)	40	9	51
Average miles per gallon	148	7 4	5 5
Significant cargo	Craftsmen's equipment	Mixed cargo, processed food	Mixed cargo, processed food, building materials

NOTE Excludes trucks used for personal transportation Light - < 10000 pounds, Medium - 10000 to 26000 pounds, Heavy -26,000- pound

SOURCES U S Department of Commerce Bureau of the Census, *Truck Inventory arm Use Survey,* TC87-T-52 (Washington DC August 1990), and Office of Technology Assessment estimates

[51] U.S. Department of Commerce, Bureau of the Census, *Truck Inventory and Use Survey*, TC87-T-52 (Washington, DC: August 1990), pp. 102-106.

The penetration of energy-efficient technologies into today's heavy truck fleet varies.[52] Some technologies, such as demand-actuated cooling fans and air deflectors, are found in almost all units. Other technologies, such as trip recorders and auxiliary cab heaters (to eliminate engine idling), have achieved relatively low penetration—less than 25 percent. Trucking firms have paid increased attention to improving driver behavior in recent years. Some firms have instituted programs to reward drivers for energy efficiency, for example, offering prizes to drivers achieving the highest miles per gallon.[53]

Rail Freight

The freight railroad industry is dominated by 13 large Class 1 companies, which collectively account for more than 90 percent of railroad freight revenue.[54] These companies are regulated by the Interstate Commerce Commission (ICC), and extensive data on their operations and performance are available. The total revenue of these Class 1 firms in 1991 was $28 billion, Energy accounted for 7 percent of total operating expenses.[55]

The railway network consists of 117,000 miles of track.[56] This figure has been dropping steadily, as little-used tracks are abandoned or sold to non-Class 1 railroads. In comparison, there are more than 1.7 million miles of heavy-duty (i.e. appropriate for use by trucks) roads in the United States.[57]

Today rolling stock consists of 18,300 operating locomotives, all of which are diesel-electric, and about 1.2 million freight cars. Locomotives are typically rebuilt many times and therefore have very long lives—about one-third of today's fleet was built before 1970.[58] The relatively slow turnover of both locomotives and freight cars has slowed the penetration of energy-efficient technologies into the railroad system. For example, although since 1985 most new locomotives have microprocessor controls, improved wheel slip detectors, and other energy-efficient technologies, they represent only about 4 percent of the operating fleet.[59] Retrofit technologies have achieved higher penetration-flange lubricators, for example. are used by most train companies. Operational improvements such as improved dispatching, pacing, and reduced idling are also becoming more common.[60]

Coal accounts for the bulk of train movements—at 41 percent of total train tonnage. Other significant train movements include farm products (10 percent), chemicals and chemical products (9 percent), and nonmetallic minerals (7 percent).[61] An increasing fraction of train movement

[52] This discussion draws from Abacus Technology Corp., "Rail vs. Truck Fuel Efficiency," report prepared for the Federal Railroad Administration, April 1991, pp. 2-6 to 2-9 and 3-6 to 3-8.

[53] For a discussion of these programs, see "Driving for Fuel Economy," *Commercial Carrier Journal*, April 1993, pp. 67-70.

[54] Data in this paragraph are from Association of American Railroads, *Railroad Facts 1992* (Washington, DC: September 1992), pp. 3, 11.

[55] Interstate Commerce Commission, Office of Economics, *Transport Statistics of the United States* (Washington, DC: 1991, pp. 9-10; includes depreciation expenses.

[56] This includes only track owned by Class 1 railroads and excludes yards, sidings, and parallel lines. Association of American Railroads, op. cit., footnote 54, p. 44.

[57] This excludes unpaved roads and roads with less than 1 inch of pavement. U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics 1991*, FHWA-PL-92-025 (Washington, DC: 1992), p. 123.

[58] Association of American Railroads, op. cit., footnote 54, p. 45.

[59] Abacus Technology Corp., op. cit., footnote 52, pp. 2-3, 3-1.

[60] Ibid.

[61] Association of American Railroads, op. cit., footnote 54, p. 29. Data are tons loaded, not ton-miles. Data on ton-miles are not available.

is in the form of trailers or containers (i.e., intermodal shipments, using both train and another mode), typically carrying manufactured or intermediate goods.[62]

Waterborne Freight[63]

The water transport system consists of the inland waterways, coastal routes, and international (oceangoing) routes; the system includes about 200 major ports, each handling at least 250,000 tons of cargo annually or having channels deeper than 20 feet.[64] Many of the ports have linkages with truck, rail, and pipeline operations to provide integrated freight transport service. Although deep-water service is critical to handling international cargo operations, barges and tows carrying bulk commodities on the Nation's shallow draft (water depth less than 14 feet) inland and intracoastal waterway system are an important component of the U.S. freight transport system. The bulk of inland barge movements occurs on the Mississippi River, the Gulf Coast Intracoastal Waterways, and connected waterways. Other significant inland waterways include the Atlantic Waterway and the Columbia-Snake Rivers system.

Today's inland water vessel fleet consists of about 30,000 barges and 5,000 tugs. Most of these barges are built for dry cargo and can carry about 1,400 tons apiece. There are also tank barges, with an average capacity of about 2,700 tons per barge. The tugs include smaller workboats (typically 500 to 1,000 horsepower) used to maneuver barges near terminals, and larger line-haul boats (typically 1,500 to 10,000 horsepower) used for long-distance towing of barges.

Products carried by barges are quite similar to those carried by trains: coal accounts for the bulk of tonnage (30 percent), followed by petroleum products (19 percent), farm products (13 percent), and nonmetallic minerals and products (12 percent).[65]

Air Freight

Air movement of freight includes both "belly freight," which is cargo carried on passenger planes, and all-cargo aircraft. In general, only cargo with a very high time value (such as perishables, business documents, and specialized machinery) travels by air. Although air cargo movements have been growing very rapidly—almost 10 percent per year since 1980—they still account for only about 1 percent of freight transport energy use. Air cargo is very energy-intensive, requiring about twice the energy of trucks to move 1 ton 1 mile (table 2-2).

Pipelines

Pipelines carry virtually all the natural gas and water consumed in the United States, as well as about half of oil and oil product ton-miles.[66] In the case of natural gas, the only technical alternative to movement by pipeline is movement of liquefied natural gas (LNG) by tanker truck or train, which is technically feasible but often not cost-effective. Therefore, pipelines will continue to be the primary carrier of natural gas. Similarly, water will continue to move almost exclusively by pipeline due to the cost advantage. Oil, however, is moved by all modes; although in areas where pipelines already exist, they are often the least expensive (and most energy-efficient) mode.

TRENDS IN U.S. TRANSPORTATION

The previous section presents a snapshot of the U.S. transportation system. To examine the system further and take the first step in projecting its

62 Intermodal Association of North America, 1992 *Intermodal Index* (Riverdale, MD: December 1992).

63 This discussion draws primarily from the U.S. Army Corps of Engineers, *The 1992 Inland Waterways Review* (Ft. Belvoir, VA: October 1992), pp. ES-5, ES-7, 34-42.

64 Office of Technology Assessment, op. cit., footnote 7.

65 U.S. Army Corps of Engineers, op. cit., footnote 63, p. 4. Data are for 1990.

66 Eno Transportation Foundation, Inc., *Transportation in America, 9th* ed. (Waldorf, MD: 1991), p. 59.

future, recent trends in key transportation indicators are discussed briefly here.

The year 1973 was a key turning point for the U.S. transportation sector. Before 1973, transportation energy use rose strongly and steadily at about 4.5 percent annually, spurred by strong growth in travel demand and only modest changes in efficiency. The great increase in oil prices that began in 1973, coupled with expectations of very high future prices, changed the trend line dramatically: after 1973, growth in transportation energy use dropped sharply, averaging about 1.0 percent annually between 1973 and 1990.[67] Even so, transport energy use grew far more swiftly than other sectors of the economy, which either declined (industry) or were relatively stagnant (residential and commercial) after 1973 because of strong conservation efforts.

Passenger Travel

Passenger travel was not a primary cause of the growth in total transportation energy consumption during the 1973-87 period; its energy use grew only 9 percent during this time.[68] This slow growth was accomplished despite trends in personal vehicle occupancy, volume of passenger travel, and air travel that are clearly in an energy-intensive direction. For example, during the 1973-87 period, load factors for autos and light trucks declined from about 2.0 to 1.7, yielding a 15 percent drop in efficiency, all other things being equal.[69] This trend toward lower load factor was particularly pronounced in commuting; from 1980 through 1990 there was an extraordinary 35 percent increase in drivers traveling alone to work, from about 62 million to more than 84 million.[70] Although this rapid increase was due in part to an overall increase in employment. much of it was due to a shift away from carpooling. One clear reason for this trend was rising vehicle availability, as shown by the growing number of multivehicle households. The percentage of households with more than one vehicle has risen sharply over time. from 31 percent in 1969 to 57.9 percent in 1990.[71] In fact, the proportion of households with three or more vehicles rose from 4.6 percent in 1969 to 19.5 percent in 1990.[72]

From 1970 through 1987, the total volume of travel (in passenger-miles) increased by 2.27 percent per year—a higher growth rate than population.[73] As discussed in the next section, this growth reflects a number of changing demographic factors:

- an increased percentage of working-age persons (between 1980 and 1990, population increased 9.7 percent, while the working-age population increased 19.1 percent[74]);
- the rise in female workers:

[67] Davis and Morris, op. cit., footnote 1 table 2.6.

[68] L. Schipper et al., "United States Energy Use From 1973 to 1987: The Impacts of Improved Efficiency," draft, Feb. 14, 1990.

[69] Ibid.

[70] A.E. Pisarski, *New Perspectives in Commuting* (Washington, DC: Federal Highway Administration, July 1992).

[71] P.S. Hu and J. Young, *Summary of Travel Trends, 1990 Nationwide Personal Transportation Survey*, FHWA-PL-92-027 (Washington, DC: Federal Highway Administration, March 1992), table 4. The 1969 data do not include pickups or other light trucks as household vehicles.

[72] Ibid.

[73] L. Schipper et al., Lawrence Berkeley Laboratory, "Energy Use in Passenger Transport in OECD Countries: Changes Between 1970 and 1987," LBL-29830, 1991.

[74] Pisarski, op. cit., footnote 70.

- high rates of household formation (between 1980 and 1988, the number of households rose by 13.9 percent, population by 8.5 percent; [75]) and
- a large increase in the number of automobiles (from 89 million, or 0.44 per capita, in 1970 to 143 million, or 0.58 per capita, in 1987[76]).

This last factor—rising automobile ownership-is connected, at least in part, to the shifting form of U.S. cities, which have become increasingly dispersed over the past several decades. For the last 40 years, 86 percent of U.S. population growth has been suburban;[77] growth in rural and center-city areas has been slow, and many such areas have lost population. Similarly, job creation has been skewed to the suburbs: the percentage of all jobs located in suburban areas increased from one-third in 1960 to about one-half in 198078 and continues to grow. A recent examination of 12 major metropolitan areas shows a striking and consistent loss during the period 1982-87 of central-city job shares in all employment categories —manufacturing, retail, wholesale, and services—as well as employment growth rates increasing with distance from the central city in all sectors but manufacturing.[79] Thus, during the last 40 years, the character of U.S. cities changed markedly: from an employment and residential pattern focused on the central city and central business district, to a shift of population out of the central city and into the suburbs, and to the subsequent movement of employment to the suburbs in order to gain access to suburban labor and escape congestion, high land costs, high taxes, and declining services. Richardson and Gordon postulate that the current pattern of suburban businesses coalescing into subcenters may be only a waystation to an almost totally dispersed land use pattern, as telecommunications reduce the advantages of businesses grouping together even at the subcenter level.[80]

This shifting location of residences and jobs has changed the character of commuting. While overall rush-hour traffic has been growing because of disproportionate increases in the number of working-age adults, the *pattern* of commuting has shifted from the traditional suburban-to-city to a suburban-to-suburban commute. This shifting pattern is an important reason why, in the face of growing numbers of vehicles vying for basically the same road space and indications of increasing average worktrip lengths, average travel time to work has remained virtually unchanged (in two surveys of changes in commuting times between 1980 and 1990, one shows an increase, the other a decrease of less than a minute[81]).[82]

Finally, air travel, the most energy-intensive passenger travel mode, moved from a 4.6 percent share of passenger-miles in 1977 to 9.9 percent in 1987.[83] Passenger-miles have grown at a rapid rate over the past two decades, and the rate has accelerated slightly over time. From 1970 to 1989, the annual growth rate was 6.6 percent, with a 7.3

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75 J.F. Hornbeck, *Demographic Trends and Transportation Infrastructure*, 90-551 E (Washington, DC: Congressional Research Service, Nov. 28, 1990).

76 Davis and Morris, op. cit., footnote 1, tables 1.1, 1.3.

77 Hornbeck, op. cit., footnote 75.

78 Ibid.

79 P. Gordon and H.W. Richardson, University of Southern California, "L.A. Lost and Found," unpublished report, May 1992.

80 Richardson and Gordon, op. cit., footnote 25.

81 Pisarski, op. cit., footnote 70.

82 Two other factors are the sheer size of the commuting population (large time delays due to congestion—hundreds of millions of hours per year--could occur without substantially increasing the *average* commuting time) and a substantial excess capacity of roadway that needed to be worked off before significant congestion began.

83 Davis and Morris, op. cit., footnote 1, table 1.1.

percent rate for the period 1982-89.[84] The increase in actual energy use has been slower, however, because of increased energy efficiencies stemming from higher load factors, use of larger aircraft, gradually lengthening trips (the cruise portion of an aircraft trip is the most energy-efficient part), and improved technology. During 1970-89, the annual growth rate of energy use has been only 2.3 percent, less than half the growth rate of passenger-miles.

Most of the effect of the energy-intensifying changes in passenger travel was nullified by large increases in vehicle efficiency during the period 1973-87: the automobile fleet improved from about 13.3 to 19.2 mpg,[85] a 43 percent improvement in efficiency, and the entire light-duty fleet (autos and personal light trucks) improved from about 13.0 to 17.5 mpg, a 26 percent increase.[86] The lower figure for the light-duty fleet reflects the smaller increase in fuel efficiency of light trucks during this period as well as the growth in fleet penetration of these lower-efficiency vehicles.

Increasing the modal share of mass transit is a key component of most strategies to reduce transportation energy use and pollution. Past trends in transit usage are not, however, encouraging. In the 1950s and 1960s, transit ridership declined to less than half of pre-World War II levels; virtually no subsidies were available during this period, however.[87] Although subsidy levels increased 14-fold in the 1970s, there was little change in ridership. The number of workers who commute by transit actually *declined* between 1980 and 1990 by about 100,000 riders, or from 6.4 to 5.3 percent of all workers.[88] However, data from the American Public Transit Association for all trip purposes indicate a gradual *increase* in *unlinked* transit trips (a complete trip may include a few unlinked trip segments) from about 1975 to the present—from 7.3 billion to 9.1 billion trips,[89] an increase of about 1.6 percent a year.[90] According to the Nationwide Personal Transportation Survey, however, total transit person trips have been relatively stagnant over the past two decades, starting at about 4.9 billion in 1969, reaching a high of about 5.5 billion in 1983, and dropping again to 4.9 billion in 1990.[91]

Part of this stagnation in mass transit use undoubtedly is due to the sharp rise in multivehicle households, which discourages transit trips. Also, the number of households with no vehicles—prime transit candidates—has declined sharply, from nearly 13 million, or 20.6 percent, in 1969 to less than 9 million, or 9.2 percent, in 1990.[92] Pucher also attributes this stagnation to the funneling of most subsidy resources to expensive rapid rail systems, which created few new transit trips[93] and drew most of their ridership from buses.

[84] Ibid.

[85] Energy Information Administration, op. cit., footnote 37.

[86] Schipper et al., op. cit., footnote 68.

[87] Pucher, op. cit., footnote 12.

[88] Pisarski, op. cit., footnote 70.

[89] American Public Transit Association, *1990 Transit Fact Book* (Washington, DC: September 1990), table 17.

[90] Unfortunately, interpreting this increase is difficult because nearly half of the added trips were on heavy rail systems. Many heavy rail trips generate home-to-station and work-to-station bus trips that are not independent transit trips but inflate the selected statistic: many of the new trips are probably statistical artifacts, i.e., transit users went from one long bus trip (one unlinked transit trip) to a short bus trip to the rail station and a long rail trip (two unlinked transit trips).

[91] Hu and Young, op. cit., footnote 71, table 16.

[92] Ibid., table 4.

[93] Pucher, op. cit., footnote 12.

Freight

Much transportation energy growth after 1973 was due to freight transport energy use, which increased 37 percent between 1973 and 1987; *passenger* energy use, as noted earlier, grew only 9 percent during this period. The growth in freight energy use was nearly **2.3** percent per year during this time, in contrast to a growth in freight *volume* of only 1.2 percent annually, much slower than the rate of economic growth.

Why did freight levels grow more slowly than the economy? First, the economy has gradually shifted away from basic materials and toward greater consumption of services and higher-value-added goods.[94] Although production of raw materials (such as coal and minerals) has increased, production of manufactured goods has grown much faster (table 2-4). And consumption of services—health, legal, amusement, education, and so on—has grown much more rapidly than consumption of goods. In 1970 goods accounted for 46 percent of the gross domestic product (GDP), while services accounted for 43 percent; in 1990 these numbers were 39 and51 percent, respectively.[95] This slowed freight tonnage growth, because services generate additions to gross national product (GNP) with fewer goods that require shipment; services also make use of higher-value-added goods that weigh far less per dollar of value than raw materials. Second, increased imports reduced freight because much of the U.S. market is close to the coasts and to ports of entry, thereby reducing *domestic* shipping distances.

TABLE 2-4: Changes in Production of Selected Materials and Goods (production index, 1970 = 1.00)

	1970	1990
Raw materials		
Coal production	100	1 55
Crude 011 production	100	076
Minlng	100	1 02
All crops	100	1 48
Primary metals	100	094
Manufactured goods		
Instruments	100	301
Electrical machinery	100	275
Rubber and plastic products	100	293

SOURCE U S Department of Commerce Bureau of the Census *Statistical Abstract of the United States* (Washington, D C 1992), pp 563, 657, 745

Changes in the nature of goods being shipped were reflected in changes in shipping modes. Over the last 20 years, movements by train and barge, which typically carry basic commodities (such as coal, farm products, and chemicals), grew slowly. Over the same period, truck and air freight movements, which carry greater value-added goods, grew more rapidly—in excess of GNP growth. Truck and air generally require more energy than trains and barges; therefore, these economic shifts have resulted in relatively rapid growth in freight transport energy use despite slow growth in total tonnage.

Other major trends have influenced the form and energy use of the freight transport system. Major Federal legislation was passed that partially deregulated portions of the system and generally encouraged competition. The Regional Rail Reorganization (1973) and Railroad Revitalization and Regulatory Reform (1976) Acts provided financial support for bankrupt train companies and relaxed some rate regulation by the Interstate Commerce Commission. The Staggers Act (1980) removed regulatory control of markets in which train companies faced substantial competition, and streamlined regulations relating to company mergers and track abandonment. The Motor Carrier Act of 1980 reduced restrictions on entry and expansion in the trucking industry and relaxed various regulations related to trucking. The Surface Transportation Assistance Act (1982) super-

[94] The shift to less material-intensive consumer goods is discussed in R. Williams et al., "Materials, Affluence, and Industrial Energy Use," *Annual Review of Energy*, vol. 12, 1987.

[95] The remainder was for structures. U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States* (Washington, DC: 1992), p. 430.

sealed certain State requirements on size and weight limits for trucks. These regulatory changes have resulted in greater competition, both within and among modes.

Another major influence on freight transport has been the growth of intermodal movements. Intermodalism usually refers to the carriage of trailers and containers by trains, with delivery to and from train terminals by truck, but can also refer to the use of barges or open ocean ships to transport containers, which are then moved by train or truck. Several innovative technologies have been implemented, including sealed containers that can be moved by train, barge, or truck; roadrailers (truck trailers that can ride directly on train tracks); piggybacking (putting truck trailers on railcars); and double-stack containers (putting two levels of truck-size containers onto railcars). Intermodal loadings on freight trains grew at an average annual rate of 4.9 percent from 1970 to 1990.[96] By 1991 their movements accounted for over 10 percent of all freight ton-miles.[97]

As noted above, freight energy use grew nearly twice as rapidly as freight volume. An important factor in the increase in freight energy use over the past few decades has been the rise in truck use (since trucks are second only to airfreight in energy intensity). From 1970 to 1990, heavy truck energy use rose at a 4.1 percent annual rate, or 125 percent for the period.[98] Heavy trucks began the period by accounting for 9.8 percent of total transportation energy, and ended it accounting for 15.6 percent.[99] Over these 20 years, there was only a modest improvement in truck fleet fuel economy (miles per gallon), with combination trucks improving from 4.8 to 5.5 mpg and larger single-unit trucks (with more than two axles or four tires) improving from 6.8 to 7.3 mpg. In addition, the fuel economy of automobiles increased more than three times as quickly as that of combination trucks during this period.[100]

Countervailing factors yielded small gains in truck fuel economy during the past two decades. Factors that contributed to improved fuel economy included technical improvements and increased trip lengths. Technologies implemented in recent years include electronic engine controls, demand-actuated cooling fans, intercoolers, aerodynamic improvements, low-profile radial tires, and multiple trailers. Market penetration of these technologies varies, although some, such as cab-top air deflectors, are found in almost all heavy trucks.[101] Increased average trip length—from 263 miles in 1970 to 389 miles in 1989—has also improved fuel economy due to the inherent efficiency advantage of longer trips.[102]

Factors hindering increased truck freight fuel economy included increased highway speeds,

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96 Loadings defined as the number of trailers and containers loaded on trains. Association of American Railroads, op. cit., footnote 54, p. 26.

97 Interstate Commerce Commission, Office of Economics, *Transport Statistics in the United States—Railroads, Part 1* (Washington, DC 1991), p. 27.

98 Davis and Strang, op. cit., footnote 8, p. 2-18. Excludes 2-axle, 4-tire trucks.

99 Ibid.

100 That is 2.2 percent/yr versus 0.7 percent/yr, from Ibid., pp. 3-23, 3-42. Data are for fleet averages. Miles per gallon is not an ideal indicator of efficiency for trucks because it fails to reflect changes in truck size, loads earned, and other variables. Data on Btu per ton-mile, which do account for some of these variables, are scarce; however, existing data show much the same pattern as miles per gallon (i.e., very slight improvement over the last 20 years).

101 Due in part to these technical improvements, certain classes of trucks showed relatively rapid improvements in fuel efficiency. See, for example, Energy and Environmental Analysis, "Analysis of Heavy Duty Truck Fuel Efficiency to 2001," report prepared for the U.S. Environmental Protection Agency, September 1991, p. 2-24.

102 Mileage data from Eno Transportation Foundation," Inc., op. cit., footnote 66, p. 71. Much of the increase in trip length occurred from 1970 to 1980 and may have been due in part to shifts from trains; trip length increased little after 1980 due in part to the growth in intermodal freight movement.

changes in the truck fleets, and the long lives of truck engines. In general, higher speeds are less efficient due to greater wind resistance.[103] Average vehicle speed on both urban and rural roads has been steadily increasing.[104] Also, in 1987 States were allowed to increase speed limits to 65 mph on certain highways; since then, many States have done so. Over the last 20 years, larger trucks (which use more energy per mile, but less per ton-mile) have accounted for a growing fraction of the total truck fleet. And the average heavy truck engine is rebuilt several times (in contrast to automobile engines, which are rarely rebuilt) and may travel well over a million miles before being retired.[105] This leads to very slow penetration of new technologies that cannot easily be retrofit to existing engines. For example, less than 10 percent of the current truck fleet have electronic engine controls.[106]

While truck energy use was rising rapidly, rail energy use actually declined by 15 percent[107]--despite a 35 percent increase in ton-miles. Three key factors contributing to the gain in rail efficiency are:

1. Increase in average trip lengths—from 515 miles in 1970 to 751 miles in 1991.[108] Longer trips are more energy efficient due to fewer stops and greater sustained speeds.[109]
2. Operations and communications improvements. Improved routing, scheduling, and overall operations reduced empty car-miles, allowed for better matching of locomotives and loads, and minimized stops and starts.
3. Technical improvements, including reduced locomotive idling speeds, improved sizing of auxiliary loads, improved wheel-slip detection, greater use of flange lubricators, weight reduction, and aerodynamic improvements.[110]

In addition, the fraction of total railcars occupied by trailers and/or containers (i.e., intermodal shipments) has grown very rapidly since 1970, but it is not clear how this has affected the energy efficiency of the rail system.

During the period 1970-90, water-based freight transport had a moderate growth in ton-miles, much of it coming from increased movement of coal, farm products, and chemicals.[111] This mode also showed a small improvement in energy intensity: Btu per ton-mile improved at an average annual rate of 0.7 percent from 1970 to 1989. Both technical and operational factors contributed to this improvement:

- improved engines, with greater use of fuel management computer systems;
- improved matching of barges and tugs;
- improved operations aided by computers;

103 For example, increasing speed from 55 to 70 mph more than doubles the power required.

104 U.S. Department of Transportation, Research and Special Programs Administration, *National Transportation Statistics, Annual Report*, DOT-L 'N NTSC-RSPA-92-1 (Washington, DC June 1992), p. 62; U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics 1991*, FHWA-PL-92-025 (Washington, DC: 1992), p. 202.

105 H. Sachs et al., *Heavy Truck Fuel Economy* (Washington, DC: American Council for an Energy-Efficient Economy, January 1992), p. 3.

106 Based on a sample of medium- and heavy-duty truck fleets. Abacus Technology Corp., op. cit., footnote 52, p. 3-6.

107 Davis and Strang, op. cit., footnote 8, p. 6-26.

108 Association of American Railroads, op. cit., footnote 54, p. 36. One contribution to this increase was the closing of smaller and less utilized stations.

109 With most longer trips, a smaller percentage of the trip will be under congested urban conditions that degrade energy efficiency.

110 Abacus Technology Corp., op. cit., footnote 52, pp. 2.1-2.6

111 U.S. Army Corps of Engineers, *The U.S. Waterway Transportation System: A Review* (Ft. Belvoir, VA: April 1989), p. 13.

- improved channels and locks; and
- use of larger barges and tugs.

Final] y, air freight has grown rapid] y during the past two decades, yet still accounts for a very small fraction of total freight ton-miles and total freight energy use. By one estimate, the energy efficiency of commercial aircraft (predominantly passenger transport, but including freight transport) has doubled since the early 1970s. Technical and operational factors contributing to this include improved aerodynamics. more efficient engines, and reduced aircraft weight.[112]

FORECASTING TRANSPORTATION ENERGY CONSUMPTION

Projections of future transportation energy consumption can play a powerful role in shaping policy by identifying emerging problems, pinpointing areas for energy savings, and providing a context within which to judge alternative policy options. For example, forecasts of continued rapid growth in travel demand, showing that reasonable levels of mobility cannot be maintained by "business as usual, " could provide an impetus for radical transportation policies that involve increasing urban residential densities and otherwise reversing the decline of central cities, On the other hand, forecasts that travel growth will slow drastically from previous levels would allow policymakers to proceed comfortably with technology-based solutions to urban congestion and pollution, and to avoid considering more drastic solutions.

This section examines the factors that will affect transportation energy consumption and describes some existing forecasts of transportation energy use. The basic focus is on energy use under normal market conditions (e.g., without major new government programs or changes in the underlying regulatory structure).

General Considerations—Factors That Will Affect Transportation Energy Consumption

Light-Duty Vehicles–Travel Demand

Both components of light-duty vehicle energy use—travel demand, measured as vehicle-miles traveled (vmt). and energy efficiency, meusured as vehicle fuel economy in miles per gallon-have grown robustly during the past 15 years, largely canceling each other out in terms of changes in overall fuel use. Over the next few decades, the rate of change of both factors is likely to decrease.

Light-duty vmt is widely expected to continue to rise. though not as rapidly as before. The rate of increase in light-duty passenger vmt between 1970 and 1990 was very large—about 3.3 percent per year. with auto travel growing at a somewhat slower rate (2.6 percent per year) and light truck travel growing at a much higher rate (6.9 percent per year).[113] (This represents all 2-axle, 4-tire trucks. not just trucks for personal use; for 1989, such trucks totaled 457 billion miles traveled, whereas personal trucks were only 290 bill ion miles.)[114] And the rate of increase in total light-duty travel became higher during 1982 -88—3.9 percent per year.

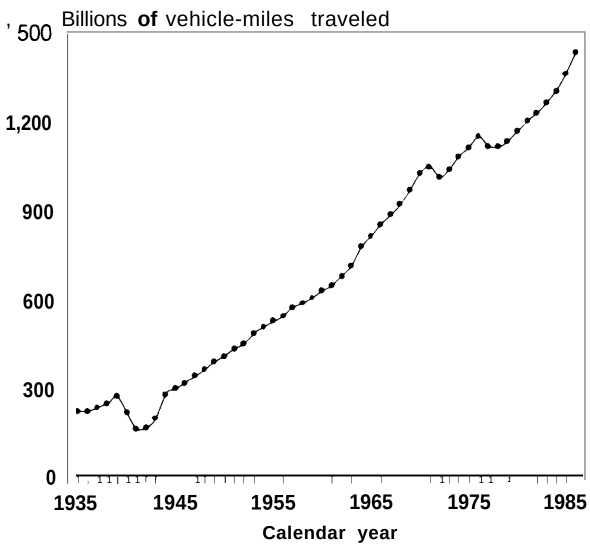
As shown in figure 2-2, the rise in vmt over the past several decades has been almost constant, because expected "saturation points" in auto ownership and travel demand did not occur. Initial assumptions that vehicle saturation would occur at one vehicle per household were surpassed in the United States in the 1930s. Then, a proposed satu-

[112] D. Greene, "Energy-Efficiency Improvement Potential of Commercial Aircraft," *Annual Review of Energy and the Environment*, vol. 17, 1992, pp. 537-573.

[113] Davis and Strang, op. cit., footnote 8, table 3.2.

[114] S.C. Davis and P.S. Hu, *Transportation Energy Data Book*, ed. 11, ORNL-6659 (Oak Ridge, TN: Oak Ridge National Laboratory, January 1991).

FIGURE 2-2: Growth in Passenger Auto Vehicle-Miles Traveled, 1936-89



SOURCE Office of Highway Information Management

ration point of one vehicle per worker was surpassed in the mid-1960s. Expected saturation of one vehicle for each licensed driver was surpassed in 1983.5 And for the past 30 years, vmt per vehicle has remained at about 10,000 per year. driving total U.S. vmt upward at the rate of expansion of the fleet.[116] The year-by-year increase in travel faltered only twice, and then for very brief periods when gasoline supply problems were coupled with very sharp price increases.

More than half of the increase in vmt over the past 15 years can be attributed to an increase in the number of adults of driving age. The remainder was due to increased driving per licensed driver and a greater proportion of licensed drivers in the population (the latter due largely to the increased number of women in the workforce).

As noted, the future growth rate for vmt is widely expected to be lower—and possibly much lower—than the 3.3 percent per year rate of the 1970-90 period. Although the Office of Technology Assessment agrees that a decreased growth rate does appear to be likely, there is considerable room for argument about the extent and likelihood of the decrease. On the one hand, the stability of vehicle mileage trends in the past argues for caution in projecting a significant decrease; on the other hand, demographic factors do seem to argue for such a decrease. Some factors that will affect future vmt are discussed below.

Women in the workforce

During the past few decades, the growing share of women working, and therefore needing to commute, has contributed significantly to rising levels of light-duty vehicle travel. The percentage of adult working women rose from 37 in 1969, to 48 in 1983, and to 56 in 1990.117 Of those working, the percentage with driver's licenses rose from 74 in 1969 to 91 in 1983. By 1990, women made up 46 percent of the total workforce, up from 27 percent in 1947.1 Further increases in the share of women working will continue to affect the demand for transportation services during the next few decades, but probably at a slower rate because the current percentage of working women is high. However, fully 74 percent of adult males are employed,[119] compared with 56 percent of adult females. Although it is hard to foresee the proportion of women working soon reaching 74 percent, the gap in employment rates between men and women of 18 percent does indicate a potential for continuation of the past trend.

115 P.D. Patterson, "Analysis of Future Transportation Petroleum Demand and Efficiency Improvements," paper presented at the IEA Energy Demand Analysis Symposium, Paris, France, Oct. 12-14, 1987.

116 Ibid.

117 Hu and Young, op. cit., footnote 71, table 1.

118 C A Lal e, "Future Growth of Auto Travel in the U. S.: A Non-problem," *Energy and Environment in the 21st Century,* paper presented at the Massachusetts Institute of Technology Conference, Mar. 26-28, 1990.

119 Hu and Young, op. cit., footnote 71, table 1.

The fact that women, working or not, still do not drive nearly as much as men **(9,500** miles annually per licensed female versus 16,500 miles per year per licensed male [120]) appears to leave open the possibility that future shifts in lifestyles among women could drive vmt at a higher rate than predicted. However, a substantial part of the vmt gap between men and women appears to be caused by the social custom of men being the primary drivers for recreation, family, and social travel.[121] Were this custom to change. vmt would be redistributed but not increased. A further examination of the reasons for the vmt gap between men and women drivers would be useful in illuminating the potential for closing this gap. One interesting area for examination is that women incomes are still significantly lower than men's, and travel increases with income,[122] which implies that if women's incomes rise in comparison with men's, their travel will increase. Also, it is likely that a higher percentage of women than men work in nonspecialized service jobs relatively close to home, with correspondingly shorter commuting trip lengths. In 1990, women commuting in urban areas traveled an average of 8.35 miles in autos and 7.38 miles in passenger vans, versus 10.79 and 13.11 miles, respectively. for men.[123] Over time. if the status of women's jobs becomes closer to that of men, women commuting trips should grow longer.

Number of adults

The growth rate in adults of driving age will slow as the baby boom passes. After 2010, however. the rate of increase will depend on future birth rates, which are uncertain. A recent surge in birth rates points out the danger in assuming that trends will continue. Also, potential fluctuation in immigration rates introduces an important uncertainty.

To compare expected growth rates of driving-age adults with former rates of growth, the number of driving-age adults grew at 1.7 percent a year from 1970 to 1986, and the average 1988-2010 rate expected by the Bureau of Census is 0.7 percent per year.[124] *Given the importance of the increase in number of driving-age adults to past vmt increases, this expected decline in the growth rate of adult drivers is probably the largest single factor in predictions of lower vmt growth rates.*

The aging of the population has an effect on vmt as well. The ratio of young drivers to those of retirement age is expected to decline by 23 percent from 1991 to 2010,[125] yielding a 3 percent decline in vmt according to Energy Information Administration projections. However, it seems unlikely that drivers of retirement age in 2010 will exhibit the same travel behavior relative to younger drivers as today do because they will have grown up accustomed to high (auto) mobility; so this expected drag on vmt growth is probably overstated.

Vehicle load factor

A substantial portion of previous increases in vmt can be attributed to the increased number of households with multiple vehicles (in 1969, 31 percent of households had two or more autos; in

[120] Ibid., table 17.

[121] Lave, op. cit., footnote 118.

[122] For example, for households with four or more members, annual vmt per household rises steadily with income, from 6,067 vmt for annual household incomes less than $10,000 to 23,879 vmt for incomes greater than $40,000. U.S. Department of Transportation, Federal Highway Administration, *1983-1984 National Personal Travel Survey, Volume 2, Personal Travel in the U.S.* (Washington, DC: November 1986).

[123] 1990 National Personal Transportation Survey data provided by Elaine Murakami, Federal Highway Administration.

[124] Reno, op. cit., footnote 3.

[125] U.S. Department of Commerce, Bureau of the Census, "Current Population Reports," Series P-25, No. 1018, *Projections of the Population of the United States, by Age, Sex, and Race: 1988 to 2080* (Washington, DC: January 1989), cited in U.S. Department of Energy, Energy Information Administration, *Assumptions for the Annual Energy Outlook 1993*, DOE/EIA-0527(93) (Washington, DC: January 1993).

1990, **58** percent did[126]) and the consequent decrease in trip sharing among household members. According to the National Personal Transportation Survey, the load factor for passenger cars was 1.9 in 1969 and 1.6 in 1990. Thus, the 1969-90 decrease in load factor by itself accounted for a 16 percent increase in vmt during this period. Although vehicle load factor could continue to decline, the rate of decline is likely to be less since the value cannot go below 1.0. This could slow the rate of vmt increase.

Availability of vehicles

Since the lack of access to a vehicle strongly constrains personal travel in most areas. vmt growth is fed by increases in vehicle availability. Because many adults own multiple vehicles, the near unit y of the ratio of personal vehicles to driving-age adults [127] does not imply that all driving-age adults have access to a vehicle; many adults remain whose personal vmt would increase if they obtained such access. Nevertheless, the fraction of potential drivers without access to vehicles is much smaller now than 20 years ago, and the potential for growth in vehicle access—and increased vmt from this growth-is thus much lower. Also, an unknown fraction of these "no-vehicle” adults cannot drive (because of illness or disability) or, perhaps because they live in high-density inner cities, have little need of a vehicle. On the other hand, although data are lacking, there likely are many vehicles whose condition does not allow them to provide a full measure of mobility to their owners; if these vehicles were replaced with newer, more reliable ones, the vmt of their owners might increase.

Possible driving time saturation among high-mileage drivers

Employed men between 25 and 54 years of age drive more than any other large group--about 18,000 miles per year. This represents an average of 1.5 hours per day spent driving. Although “common sense” about saturation of driving has been wrong before, it is at least possible that this group may be nearing saturation. One important area of uncertainty is whether a recent trend in auto design, making the vehicle interior a more hospitable environment (comfortable seating, excellent climate control, superb music systems, availability of telephone communication, etc.), will increase the likelihood of drivers’ spending more time on the road. Another uncertainty is whether predicted increases in traffic congestion (see below) will outweigh possible continued increases in average (uncontested) speeds. If congestion finally begins to drive average speeds down, this will increase the amount of time required to drive a constant vmt. This implies that the already large amount of time spent on driving will have to increase just to maintain current levels of vmt and that large increases in vmt would put extraordinary time pressure on drivers. On the other hand, continued increases in average speeds will have the opposite effect.

Changing economic structure

The growth in part-time work and shift of the economy toward more services may lead to increased driving by bringing more individuals into the workplace and increasing delivery requirements. The potential for delivering certain types of services, especially information, electronically may eventually substitute for some transportation, but thus far such trends have not been observed.

Traffic congestion

The increasing congestion of metropolitan areas will alter travel patterns, Congestion will decrease the fuel efficiency of those trips that are made; discourage other trips (or shift them to public transportation or to the electronic media where pos-

126 Hu and Young, op. cit., footnote 71, table 5.

127 According to Lave (C. Lave, University of California, Irvine, "The Spread of the Automobile Demon: What Can We Do?" unpublished report, 1992), the ratio was 0.95 in 1989.

sible); encourage some people to work closer to home or move closer to work; and encourage businesses to move to the less congested fringes, increasing travel requirements. The net effect on fuel demand is unpredictable, although growing congestion is likely to act as a brake on vmt growth.

Development patterns

There is a strong correlation between vmt and development patterns, particularly urban density: residents of dense inner cores, for example, tend to drive and travel less than residents of low-density fringe areas. Although increasing traffic congestion might promote some movement of residences and businesses as noted above, few analysts expect important *national* changes in the current suburban pattern of U.S. development.[128] One important development pattern to watch is the potential for persons working in the suburbs to move into rural areas, with substantial increases in commute distances as well as longer trips to shopping and other services.

Conclusion

In OTA's judgment, the most predictable aspects of the above factors affecting future light-duty vmt are as follows: the lower number of persons reaching driving age (although high immigration rates could offset somewhat the passage of the baby boom), the likely slowdown of the effects of women entering the workforce and adults of driving age gaining new access to vehicles, the likelihood that vehicle load factor will not decrease as rapidly as it has in the past, and the continuing spread of suburban development. The first three factors act to slow vmt growth, although the effect of a slowdown in women entering the work force is uncertain; there is still room for the character of women's jobs to change substantially. with the potential for significant increases in the length of their commuting trips. The last factor will contribute to vmt growth. Claims that the number of vehicles per driving-age adult is close to saturation should be viewed with some skepticism in light of the fate of past claims of vehicle saturation and uncertainty about the ability of many registered vehicles to deliver full accessibility y to driving (especially given the aging of the fleet). Further, many determinants of transportation demand (e.g., gasoline prices, personal income, vehicle characteristics) are likely to change in hard-to-predict ways over the next few decades, and we do not fully understand how demand will respond to changes in these determinants.[129]

The uncertainty associated with the various factors affecting travel demand probably allows a range of feasible vmt growth rates of 1.5 to 3 percent, *without* considering the potential for future oil price shocks. An unexpected large increase in gasoline costs, or supply problems. could cause the growth in personal travel demand to fall below these levels or even to become negative for a time. A period of price stability and continuation of improvements in vehicle designs would make the high end of the range more plausible. Although OTA believes that this is a lower-probability outcome, the 3.3 percent increase in total vehicular traffic between July 1991 and July 1992,[130] which followed a year of vmt stagnation (perhaps recession-driven), forces caution in predicting that the long-term trend in vmt growth, which had been stable so long, will now turn downward.

Light Duty Vehicles—Fuel Economy

As discussed earlier, the fuel economy of the light-duty fleet has grown substantially, slowed only by a shift in consumer preference for light

[128] Reno, op. cit., footnote 3.

[129] E.L. Hillsman and F. Southworth, "Factors That May Influence Responses of the U.S. Transportation Sector to Policies for Reducing Greenhouse Gas Emissions," *Transportation Research Record No. 1267, Global Warming: Transportation and Energy Considerations 1990* (Washington, DC: Transportation Research Board, 1990).

[130] Federal Highway Administration, *Traffic Volume Trends, July 1992* (Washington, DC: U.S. Department of Transportation), data summary.

trucks, which are less fuel-efficient than automobiles. New auto fuel economy grew **5.3** percent annually from 1974 to 1988, from about 14 to 28 mpg (U.S. Environmental Protection Agency rating). New light-truck fuel economy grew more slowly, from 18.2 mpg in 1979 to 21.3 mpg in 1988.[131] The on-road fuel economy of the total fleet grew from 13.1 mpg in 1974 to about 18.4 mpg in 1988.[132]

As discussed in *Improving Automobile Fuel Economy: New Standards, New Approaches,*[133] future market-driven fuel economy is not likely to grow rapidly despite the continuing spread of technologies that could allow substantial improvements (see box 2-B for a brief description of the available technologies). The primary cause of reduced potential for rapid increases in fleet fuel

BOX 2-B: Fuel Economy Technologies for Light-Duty Vehicles

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

Aerodynamic drag reduction primarily Involves reducing the drag coefficient by smoothing out the basic shape of the vehicle, raking the windshield, eliminating unnecessary protrusions, controlling airflow under the vehicle (and smoothing out the underside), reducing frontal area, and so forth

Front-wheel drive is now in wide use. Shifting from rear-to front-wheel drive allows mounting engines transversely reducing the length of the engine compartment, eliminating the transmission tunnel, which provides Important packaging efficiency gains in the passenger compartment, and eliminating the weight of the propeller shaft and rear differential and drive axle

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

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

Intake valve control involves a shift from fixed-tnterval intake valve opening and closing to variable timing based on engine operating conditions, to yield improved air and fuel feed to cylinders and reduced pumping loss at low engine loads

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

(continued)

[131] Davis and Hu, op. cit., footnote 114.

[132] Ibid., table 1.7.

[133] U.S. Congress, Office of Technology Assessment, *Improving Automobile Fuel Economy: New Standards, New Approaches,* OTA-E-504 (Washington, DC: U.S. Government Printing Office, October 1991).

BOX 2-B: Fuel Economy Technologies for Light-Duty Vehicle (cont'd.)

Accessory improvements Include adding a two-speed accessory drive to more closely match engine output to accessory power requirements plus design Improvements for power-steering pump alternator and water pump

Four- and five-speed automatic transmissions, and continuously variable transmissions by adding extra gears to the automatic transmission Increase fuel economy because engine efficiency drops off when the operating speed moves away from its optimum and the added gears allow the transmission to keep the engine closer to optimal speed

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

Throttle body and multipoint fuel injection which are in wide use offer Improved control of the air-fuel mixture and allow the engine to continually adjust this mixture for changing engine conditions Multipoint also reduces fuel distribution problems

Roller cam followers by shifting to a rolling mechanism, reduce friction losses (Most current valve **lift** mechanisms are designed to slide along the camshaft)

Low-friction pistons and rings decrease friction losses by improving manufacturing control of tolerances reducing ring tension and improving piston skirt design

Improved tires and lubricants represent a continuation of longstanding t rends toward improved **oil** and tires with lower rolling resistance

Advanced engine friction reduction includes the use of Ilght-weight reciprocating components (titamum or ceramic valves composite connecting rods, aluminum lifters, composite fiber-renforced magnesium pistons) and improved manufacturing tolerances to allow better fit of moving parts

Electric power steering is used primarily for cars in the minicompact, subcompact and compact classes

Lean burn Improves an engine's thermodynamic efficiency and decreases pumping losses This requires a new generation of catalysts that can reduce nitrogen oxide in a "lean' environment

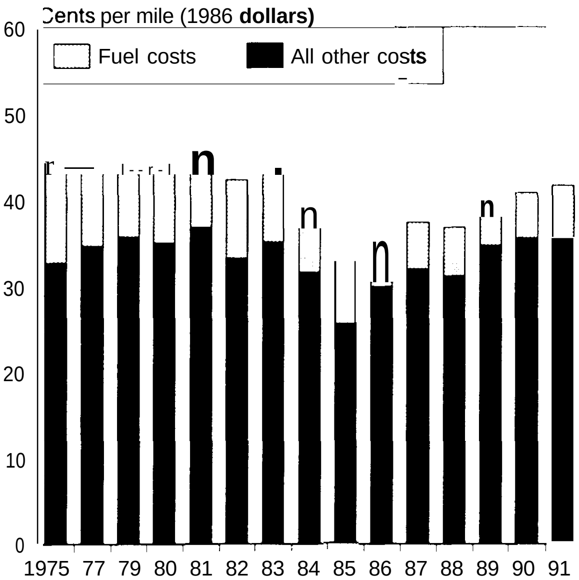
Two-stroke engines unlike conventional engines have a power stroke for every ascent and descent of the piston thus offering a significantly higher output per unit of engine displacement reduced pumping loss smooth operation and high torque at low speeds and allowing engine downsizing fewer cylinders (reduced friction losses) and significant weight reduction Also they operate very lean with substantial efficiency benefits (if nitrogen oxide problems are solved) Compliance with stringent emissions standards is unproven

Diesel engines (compression-ignition engines) are a proven technology and are significantly more efficient than gasoline two-valve engines even at constant performance new direct Inject Ion turbocharged diesels offer a large fuel savings Although the baseline gasoline engine will Improve in the future a portion of the Improvements especially engine friction reduction may be used beneficially for diesels as well Use may be strongly limited by emission regulations and consumer reluctance

Electric hybrids involve combining an electric motor and battery with another power source in one of multiple combinations Examples Include using a constant-speed engine (Internal combustion or turbine) as a generator to recharge the battery during longer trips with electric motors driving the wheels and the battery providing all power for shorter trips and a fuel cell or engine/generator to provide power for the electric motors with a battery that allows temporary boosts for acceleration or hill climbing (to reduce the required size of the fuel cell or engine)

SOURCE Office of Technology Assessment 1994

FIGURE 2-3: Auto Fuel Costs vs. Total Costs



SOURCE Oak Ridge National Laboratory

efficiency is lack of strong market pressure for such increases. With lower gasoline prices (and lower expectations for price increases), relatively high *nonfuel* vehicle operating costs, and the average fuel economy of most new vehicles already in the 20 to 35 mpg range. fuel costs have become a smaller fraction of total costs (figure 2-3) and fuel efficiency has declined dramatically in importance as a factor in choosing a new vehicle. If cost-effective efficiency improvements are available, the overall cost savings over vehicle lifetimes of any efficiency gain will be a small fraction of the total costs of ownership and operation.[134]

Other factors likely to restrain increases in fleet fuel efficiency include the following:

- **Growth in the use of light trucks for passenger travel.** Light-truck vmt grew at a rate that was more than five times that of autos between 1970 and 1985; during this period, auto vmt grew 38 percent while light truck vmt tripled.[135] (As noted earlier, this seems to be total 2-axle, 4-tire truck travel, not personal light truck travel).
- **A growing attraction among purchasers of new automobiles to more powerful (and thus less fuel-efficient) automobiles.** An important consequence of this consumer preference has been that drivetrain improvements (such as engines with four valves per cylinder and turbochargers), with the potential to either increase fuel efficiency (at least in part by reducing engine displacement) or boost horsepower from previous levels, have been introduced in configurations that emphasize power increases rather than fuel savings. The performance increases of the 1980s, signified by a reduction in 0- to 60-mph acceleration time of 2.3 seconds from 1982 to 1990, have caused a more than 8 percent decline in fuel economy-more than 2 mpg—from what it would have been at 1982-level performance.[136]
- **Additional luxury and safety equipment on new cars.** Equipment such as power seats, sunroofs, and power locks and windows may gain additional market share and can add significant weight to the vehicle. Four-wheel drive may add 150 to 200 pounds per vehicle and decrease fuel economy by 12 to 15 percent. Safety equipment such as air bags (30 to 45 pounds) and antilock brakes (30 to 45 pounds) add further weight.
- **More stringent emission standards, especially for nitrogen oxides.** Meeting the new Tier 1 Federal standards on exhaust and evaporative hydrocarbons and nitrogen oxides may create a fuel economy penalty, although there is controversy about the likelihood of such a penalty. The California Air Resources Board claims

[134] See, for example, J. Goldemberg et al., *Energy for a Sustainable World* (Washington, DC: World Resources Institute, September 1987).

[135] Patterson, op. cit., footnote 115.

[136] K. Hellman, U.S. Environmental Protection Agency, Ann Arbor, MI, personal communication, 1990.

that the new Federal standards, and even more stringent California standards, can be met with no reduction in fuel economy.[137] In contrast, Energy and Environmental Analysis, Inc., which has extensive experience in fuel economy analysis, projects an average 1 percent fuel economy penalty from Tier 1 standards.[138]

- **Slower replacement of the automobile fleet, so that technological improvements introduced into the new fleet will take longer to diffuse into the total fleet.** Whereas in 1969 autos more than 10 years old accounted for only about 7 percent of vmt and fuel consumed, by 1977 these older vehicles accounted for about 13 percent of vmt and fuel, and by 1983 for almost 20 percent of vmt and 23 percent of fuel.[139] Continuation of this trend will slow fuel economy improvements in the fleet.
- **Changes in levels of congestion, highway speeds, and the share of urban driving, all of which impact on-road fuel economy.** Estimates of future fuel use must account for the gap between fuel economy as tested by the U.S. Environmental Protection Agency (EPA) and the actual fuel economy obtained during driving. EPA adjusts its new auto test values downward by 15 percent to account for this gap—reflecting an assumed 55 to 45 percent split between urban and highway driving, a 10 percent gap between tested and actual city fuel economy. and a 22 percent gap between tested and actual highway fuel economy.

Recent work by a U.S. Department of Energy contractor estimates the actual gap for the entire on-road fleet to be about 15.2 percent for automobiles and 24.5 percent for light trucks.[140] All else equal, increased levels of congestion, an increasing share of urban travel. and higher highway speeds would cause this gap to increase.[141] Trends in congestion and urban-rural travel clearly imply that the first two conditions will occur; and recent trends toward a higher percentage of vehicles traveling at more than 55 mph and a relatively short-term upward trend of average highway speed may indicate a future increase in this latter variable. The contractor projected a minimum gap of 21.2 percent for automobiles and 29.5 percent for light trucks by 2010, with substantial potential for a much larger gap in this time frame with slightly different assumptions.[142] These estimates should be treated with caution, however. Much of the new "urban" travel will likely occur in less congested suburbs. and ""city" fuel efficiencies may not apply. Further. EPA regulations requiring on-board diagnostics, cold temperature carbon monoxide controls, and improved evaporative emission controls will tend to reduce the tested and on-road gap.[143]

Air Passenger Travel

Passenger travel in commercial aircraft has been the United States most rapidly growing transport mode, with revenue passenger-miles increasing at the very high rate of 6.47 percent a year between

[137] James Lerner, California Air Resources Board, Sacramento, CA, personal communication, Oct. 8, 1993.

[138] K.G. Duleep, Energy and Environmental Analysis, Inc., Arlington, VA personal communication, Nov. 18, 1993.

[139] U.S. Department of Energy, *Assessment of Costs and Benefits of Flexible and Alternative Fuel Use in the U.S. Transportation Sector. Progress Report One: Context and Analytical Framework*, DOE/PE-0080 (Washington, DC: January 1988).

[140] J.D. Maples, University of Tennessee Transportation Center, Knoxville, "The Light Duty Vehicle MPG Gap: Its Size Today and Potential Impacts in the Future," draft, November 1992. Another source estimates an 18.7 percent gap for automobiles and 20.1 percent gap for light trucks (M.M. Mintz et al., Argonne National Laboratory, "Differences Between EPA-Test and In-Use Fuel Economy: Are the Correction Factors Correct?" *Transportation Research Record*, No. 1416 (Washington, DC: National Academy Press, October 1993).

[141] Estimated loss in fuel economy for each mile-per-hour increase in speed between 55 and 65 mpg is 1.78 percent, according to an Oak Ridge National Laboratory study (Maples, op. cit., footnote 140).

[142] Ibid.

[143] J. German, U.S. Environmental Protection Agency, Ann Arbor, MI, personal communication, Sept. 30, 1993.

1970 and 1985.'44 At the same time, however, a combination of improved technical efficiency and advances in operations essentially doubled overall efficiency (measured in Btu per revenue passenger-mile) during the same period, so that actual energy use rose only at 1.68 percent per year. During the past few decades, commercial aviation has captured a growing share of intercity travel, primarily from automobiles, and it is likely to continue to do so even in relatively short hauls of a few hundred miles unless major new competitive systems (e.g., high-speed rail) are initiated.

In the past, the amount of air travel has appeared to be extremely sensitive to overall economic conditions and ticket prices. High economic growth rates appear to accelerate air travel; thus travel forecasts will vary depending on assumptions about GNP growth rate. If historic trends continue, any increase in growth of GNP will be accompanied by an increase in air travel that is about twice as large, in percentage terms. Similarly, an increase in ticket prices will be met by a decrease in travel demand on the order of half as large. Although ticket prices vary for many reasons, the price of jet fuel is a major influence, so travel demand will be sensitive to oil prices.

The second component of aviation energy use, fuel efficiency, will continue to increase. Most airlines are renewing their fleets (although the financial difficulties experienced recently by many airlines will slow the rate of renewal), and the new airplanes are substantially more efficient. Near-term technologies used to enhance fuel efficiency include advanced electronic controls, higher pressure ratios and turbine entry temperatures for engines, and use of composite materials that reduce airframe weight. Future technologies include continuing improvements in compressor and turbine efficiency, more extensive use of composites and other advanced materials, use of new engines such as the ultrahigh bypass turbofan and the propfan, and use of active controls for aerodynamic surfaces, to minimize drag.[145] Because fuel prices have been relatively low, there is some doubt about the likely speed of introduction of some new technologies (e.g., the propfan). Box 2-C provides a more complete description of available aircraft fuel efficiency technologies.

Aside from buying aircraft with greater technical efficiency, airlines can improve overall fuel efficiency by improving operations and continuing current trends toward larger aircraft. Relieving airport congestion is a major concern. Although some new airports will be built, expansion of airport capacity is *not* expected to be a primary strategy for relieving congestion over the next few decades.[146] Instead, most attention will go to operational modifications; for example, improvements in air traffic control systems can allow reduced spacing of takeoffs and landings and increased use of parallel runways.

An important determinant of fuel efficiency will be the distribution of aircraft trip lengths. Limitations on airport construction and forecasts of growing air traffic congestion may lead to efforts to substitute other modes-such as high-speed trains—for shorter trips. However, the recent history of commercial aviation has seen the industry capturing market share in shorter-length trips, and it is virtually unchallenged in trips of longer length (more than 500 miles). Shorter trips decrease efficiency by increasing the percentage of fuel used for taxiing, idling, and takeoff and landing, activities whose fuel use is independent of travel distance; preventing the use of larger,

144 M. M. Mintz and A.D. Vyas, *Forecast of Transportation Energy Demand Through the Year 2010*, ANL ESD-9 (Argonne, IL: Argonne National Laboratory, revised April 1991).

145 Ibid.

146 Ibid.

BOX 2-C: Fuel Economy Technologies for Commercial Aircraft

Advanced engine types. The current-generation engine penetrating the fleet today is the high-bypass *turbofan,* with heat-resistant materials that allow high turbine relet temperatures and new compressors that allow higher pressure. *Ducted ultrahigh-bypass (UHB) turbofans* yield efficiency Improvements of 10 to 20 percent *Propfan engines* deliver an additional 10 percent Improvement over UHB turbofans

Lightweight composite materials. With the exception of a few new business jets, commercial aircraft use new composite materials sparingly Extensive use of these materials can reduce airframe weight up to 30 percent without sacrificing structural strength

Advanced aerodynamics. This involves optimization of airflow using a combination of computer-designed changes in wing shapes, ultrasmooth surfaces, and "active" flow control concepts that suck air into the wings Other concepts use variable wing shapes and new fuselage designs

SOURCE D L Greene, "Energy Efficiency Improvement of Commercial Aircraft Ar?nua/Review of *Energy and the Environment* VOI **17 1992 pp 537-573**

more efficient aircraft; and generally preventing the attainment of high load factors because high trip frequency is necessary to compete successfully with other modes. ' 47

Freight Transport

The production and consumption of goods determines the demand for freight transport services, and indirectly the energy needs of the freight transport system. Although it is very difficult to forecast production and consumption, most analysts predict relatively slow growth for basic commodities. For example, coal production, which accounts for the bulk of both train and barge movements, is projected to grow at only 1.3 percent per year. On the other hand, higher-value-added goods, such as construction materials and processed foods, are expected to grow more rapidly—l.5 to 4 percent per year (table 2-5), A separate analysis predicted little or no growth for basic materials production in the United States through the year 2000.48

These projected trends—slow growth in commodities, more rapid growth in higher-value-added goods-suggest that in the future, as in the past. demand for train and barge freight movements will grow slowly, whereas demand for truck and air freight movements will grow more rapidly. However, even with extremely rapid growth of 10 percent per year for airfreight, the energy required for air freight movements will still be a fraction of that required by trucks. **Trucks will be the dominant freight transport energy consumer in the next** 20 **years.**

Commercial trucking

In 1989, trucks accounted for 29 percent of freight movements (measured in ton-miles) and used 83 percent of the energy expended for these freight shipments (table 2-2). Although the former percentage is low by European standards, the large U.S. land mass and extensive long-distance shipment of raw materials (coal, iron ore, grains) by unit trains and barges signify that truck transport actually competes very well in the interstate freight arena. Trucking dominates local distribution, of course.

The reasons for this competitiveness include the dispersed and shifting location of many products that require long-distance shipping (e. g.,

[147] A.B. Rose, *Energy Intensity and Related Parameters of Selected Transportation Modes: Passenger Movements*, ORNL-5506 (Oak Ridge, TN: Oak Ridge National Laboratory, January 1979).

[148] Williams et al., op. cit., footnote 94.

TABLE 2-5: Projected Growth in Commodities (annual average growth rate)

Commodities[a]		Goods[b]	
Coal production	13	Construction materials	3-4
Crude 011 production	-10	Appliances	2
Oil products consumption	10	Processed foods	
Agriculture production	18	Fruits and vegetables	2
Chemical production	31	Bakery items	15-2
Mining production	-01	Candy	2-35

[a] For 1990 to 2010 Coal and 011 are in Btu per year Agriculture chemicals and mining are in constant dollars U S Department of Energy, Energy Information Administration *Annual Energy Outlook 7993,* DOE 'E IA-0383(93) (Washington DC January 1993), p 81, U S Department of Energy, Energy information Administration *Energy Consumption and Conservation Poten-t/a/ Supporting Analysis for the National Energy Strategy,* SR/NES/90-02 (Washington DC December 1990) p 126
[b] For 1993 to 1997-98 u S Department of Commerce International Trade Administration *U S Industrial Outlook 1993* (Washington DC 1993), various pages

wood), the dispersed locations to which the products (farm products) are shipped, and established truck-oriented distribution systems (petroleum products, processed foods). Trucking also benefits from an infrastructure built largely with money collected from automobile fuel taxes; although trucks pay fuel and use taxes, these taxes do not cover their proportional share of infrastructure costs.[149] Nevertheless, there is room for future shifts in freight modes, stemming from competition with more efficient rail operations that integrate with local trucking systems or from changes in the basic economics of trucking operations (higher fuel prices, higher road taxes to account for actual infrastructure maintenance costs). On the other hand, continued shifts in the U.S. economy toward service industries and higher-value-added products, with more focus on just-in-time distribution systems, may favor the flexibility of trucking over other freight transport modes and add to its share of overall freight shipment. However, at the same time these shifts in the economy may cut down the total volume of freight shipment (light engineering is less freight intensive than steel and auto manufacturing, and services are generally less freight intensive than manufacturing).

Generally, future growth in truck transport levels is expected to follow trends in economic activity, and forecasts attempt to match estimates of truck ton-miles carried to estimates of the growth of specific portions of the U.S. economy. If the U.S. economy continues its shift toward less heavy manufacturing and more services, with resulting overall freight volumes growing more slowly than the rate of GNP growth, trucking volumes may still keep pace with GNP, at the expense of other modes.

The overall energy efficiency of truck shipping depends heavily on factor-s besides simply the technical efficiency of the vehicles. These include load factors (including the incidence of empty backhauls); driver behavior; road congestion; changing speed limits, especially on rural interstate; and shifting truck mixes, including use of tandems.

Freight truck fuel efficiency, as measured in miles per gallon. has improved only gradually during the past few decades: at an annual rate of 0.4 percent per year for single-unit trucks and 0.7 percent per year for combination trucks. Furthermore, efficiency growth stagnated during the 1980s—for the period 1982-90. single-unit truck

[149] Congressional Budget Office, *Paying for Highways, Airways, and Waterways* (Washington DC: May 1992).

efficiency grew at only 0.3 percent per year, and heavy truck efficiency at 0.5 percent per year.[150] As discussed above, these aggregate efficiency indicators reflect a number of factors, including shifts in average truck size, changes in types of freight moved, and increased speed limits.

The range of factors both hindering and promoting freight truck fuel efficiency, discussed earlier, will likely continue to yield slow improvement. Commercially available technologies, such as aerodynamic improvements and electronic engine controls, will gradually increase their market penetration. Improved operations, aided by better communications between trucks and their headquarters, could increase load factors and allow more efficient routing. On the other hand, as long as fuel prices are low, trucks will likely find time savings from higher speeds out weighing the energy penalty; average highway speeds may continue to climb. Also, some projections of increases in urban congestion have been startling; if these projections are correct. future congestion could have a substantial negative impact on efficiency.[151]

It is important to note that although truck fuel efficiency is expected to improve quite slowly, a number of technological and operational improvements are available that could yield dramatic improvements in efficiency (see boxes 2-D and 2-E). The combined effects of some of these options can be estimated through the performance of trucks that use these technologies. Several manufacturers have used long-distance demonstration runs to both test and demonstrate new energy-efficient technologies. These demonstration runs combine improved technologies, highly trained drivers, and optimal running conditions (such as maintaining 55 mph). The results, summarized in table 2-6, show that commercially available trucks obtained energy efficiency 50 to 70 percent above that of the current fleet, while prototype technologies achieved efficiencies over twice that of the current fleet. These results must be applied with caution; they do not measure what could be obtained from technological improvements alone. Nevertheless. they do provide a useful upper bound for the savings potential. If all heavy trucks were able to achieve the level of energy efficiency obtained from these tests of the best commercially available technologies, energy use would drop by about 0.9 quads. or 15 percent of total freight transport energy use.[152] Achieving the energy-efficiency level of the prototype truck would be quite difficult on today roads, as it makes use of spoilers with very little ground clearance.

Alternative Forecasts

This section presents and discusses the forecasts of the Energy Information Administration (EIA) for the period 1990-2010, from its "' 1993 Annual Energy Outlook, "[153] as well as alternative forecasts from other organizations when they present significantly different projections of energy consumption or other variables affecting c(msumption.

The 1993 Annual Energy Outlook (AEO93) examines seven scenarios of the future: a baseline scenario, two scenarios examining the effects of higher and lower oil prices ($38 and $18 per barrel, respectively, in 2010 versus the baseline of $29 per barrel (bbl)—all in 1991 dollars), two

[150] Davis and Strang, op. cit., footnote 8, pp. 3-40, 3-42. Data are fleet average miles per gallon and exclude 2-axle, 4-tire trucks.

[151] Note that moderate highway congestion, in slowing average speeds below high "free-flowing" levels, could improve fuel efficiency. However, once congestion thresholds are reached, relatively small increases in traffic can slow average speeds to 30 mph or less, or even to stop-and-go levels, which are extremely wasteful of fuel. Federal Highway Administration congestion estimates project large costs from wasted fuel.

[152] Best commercially available trucks are 62 percent more efficient than existing fleet (see table 2-6, average of 51 and 72 percent); therefore replacing fleet will reduce energy use (1-[1/1.62]) or 38 percent. Heavy trucks account for about 51 percent of truck energy use (table 2-3), trucks use 4.9 quads per year (table 2-2); therefore savings = 4.9 x .38 x .51 = 0.9 quads.

[153] Energy Information Administration, op. cit., footnote 10.

BOX 2-D: Fuel Economy Technologies for Commercial Trucks

Aerodynamics. Modifying the shape of the truck and trailer can yield significant reductions in energy use by reducing air resistance. The primary aerodynamic improvement used on heavy trucks today is the cab-mounted air deflector, which began to be installed in the 1970s. Since then, a number of improved aerodynamic devices have been used, including various devices to seal the space between the truck and the trailer, front air dams, and improved rooftop fairings. The simpler devices can often be retrofit to existing trucks and, according to one analysis, offer rapid (less than 2-year) paybacks. [1] Aerodynamic improvements to trailers include side skirts to minimize turbulence underneath the trailer and rear "boattails" to smooth airflow behind the trailer The energy savings of these devices are difficult to measure, since airflow is difficult to model accurately and field tests are complicated by the need to measure small effects while controlling for confounding factors such as wind speed, temperature, and driver behavior, Aerodynamic Improvements to tractor-trailers are also limited by the need to connect quickly and simply to trailers of different designs and sizes, to tolerate road surface uncertainties, and to meet size regulations,

Improved tires. Radial tires have largely replaced bias-ply tires, except for special applications such as off-road use (bias-ply tires have stronger sidewalls and are thus more resistant to puncture). By one estimate, replacing all 18 bias-ply tires on a full-size tractor-trailer with radials results in a 10 percent reduction in fuel use in miles per gallon [2] A more recent tire innovation is "low-profile" radial tires, which weigh less than standard radials and thereby save energy, Just now becoming commercially available are "low rolling resistance" tires, which use new compounds and designs to reduce rolling resistance. These new tires are claimed to offer a potential energy savings of 4 percent relative to low-profile tires[3] and 75 percent relative to conventional radials [4] Finally, fuel savings can be achieved by tailoring tires to specific types of service, powertrains, and roads, including the use of smaller-diameter tires for low-density cargo

(continued)

[1] H Sachs et al , *Heavy Truck Fuel Economy* (Washington, DC American Council for an Energy -Efficient Economy, January 1992), p 16

[2] Bridgestone Tire Co., *Guide to Large Truck Fuel Economy for the 90's* (Nashville, TN 1992), p 7

[3] "Tomorrow's Tire Today, " *Fleet Owner,* September 1991, P 48

[4] Kenneth Farber, representing Michelin Personal Transportation Vehicle Workshop, presentation to White House Conference on Global Climate Change, Washington, DC, July 1,1993 Current market share of low rolling resistance radials was said to be5percent

scenarios examining the effects of higher or lower economic growth rates (2.4 and 1.6 percent per year, respectively, versus the baseline of 2.0 percent per year), and two scenarios examining the effects of high or low domestic gas and oil recovery (40.2 versus 31.9 quads recovered, respectively, compared with 33.8 quads in the baseline scenario).[154] None of the scenarios is policy-driven in the sense that all assume that little change will occur in government policy to affect energy supply and demand. That is, the scenarios assume no major new conservation initiatives, such as more stringent fuel economy standards or tax incentives for purchase of fuel-efficient autos, and no important changes in access to energy supplies. (A modest exception is assumed passage of licensing reform legislation for new nuclear reactors in the high-economic-growth case.)

[154] High and low recovery rates are based on the probability distribution of technically recoverable oil and gas reserves in the United States as estimated by the U.S. Geological Survey. The baseline case is the median of the distribution, whereas the high and low cases are based on the 5th and 95th percentiles, respectively.

BOX 2-D: Fuel Economy Technologies for Commercial Trucks (cont'd.)

and of very wide single tires to replace dual tires. However truck tires, unlike automobile tires are often re-capped when worn low-profile and low rolling resistance technologies which cannot be Incorporated into recapped tires will largely be limited to sales of new tires

Improved transmissions. Electronic transmission controls measure vehicle and engine speed and other operating conditions allowing the transmission to optimize gear selection and timing thus keeping the engine closer to optimal conditions for either fuel economy or power than is possible with hydraulic controls This technology offers about a 4 percent improvement in fuel economy.

Greater use of diesel engines. Compression-ignition engines, or diesels, are a proven technology and are significantly more efficient (about 12 percent for heavy trucks) than gasoline two-valve engines even at constant performance, new direct injection turbocharged diesels offer additional fuel savings.

Improved engines. A variety of new engines are becoming available to freight trucks. *Turbocompound engines* are technically ready but have not been commercialized because of low fuel prices. *Low-heat-rejection diesels* are compression-ignition engines that run at very high temperature and do not use energy-draining cooling systems. *Gas turbines* harness fuel energy by using the burning fuel's kinetic energy to spin a turbine rather than drive a piston. Both engine types require the development of mass-producible materials with higher heat resistance than currently available (structural ceramics or heat-insulating composites). Estimated fuel savings for low-heat-rejection diesels are as high as one-third over modern diesels.[5]

Electronic engine controls. Electronic engine control systems can monitor and adjust fuel consumption, engine speed, idle time, road speed, and other factors. They can also provide extensive feedback data to drivers on energy use. They were developed largely to meet new emissions requirements, but they have energy-efficiency benefits as well. They are currently available on some long-haul heavy trucks.

SOURCE M M Mintz and A D Vyas Forecast of Transportation Energy Demand Through the Year 2010 Argonne National Laboratory Report ANL F SD-9 revised April 1991

[5] R Kamo Adiabatic Diesel-Englrw Technology in Future Transportation *Energy* vol 12 No 10 11 1987 pp 1073 1080 cited in D L Greene et al Transportation Energy to the Year 2020 *A Look Ahead Year 2020* Transportation Research Board Special Report 220 (Washington DC National Academy Press 1 988)

The baseline scenario accepts mainstream ideas about oil prices and economic growth. First, the scenario assumes that a combination of plentiful oil supply, gradually increasing world demand, and Saudi restraint will maintain prices in the $20/bbl range for a few years and then gradually push prices upward, to $29/bbl (1991 dollar-s) by 2010, with a gradual increase in gasoline retail costs. Second, it assumes that slower growth in the U.S. labor force for the next few decades (a projected rate of about 1 percent per year versus 2.1 percent annually from 1970 to 1 990) will restrain the growth in real output of goods and services, but that the U.S. economy will remain sufficiently competitive in world markets to keep growing at the moderate rate of 2.0 percent per year. The alternative price scenarios reflect. on the low side, a combination of aggressive conservation, significant competition among Organization of Petroleum Exporting Countries

BOX 2-E: Operational Strategies To Improve Truck Fuel Efficiency

Speed. Several studies have examined the effects of higher speed on energy consumption One field test found a fuel efficiency penalty of 22 percent from increasing speeds from 55 to 65 mph.[1] Other costs associated with increased speed were reported as well, including a 10 percent decrease in miles to engine overhaul These costs, however, must be traded off against time savings For a 1,000-mile trip, traveling 55 instead of 65 mph in a new tractor-trailer will save 278 gallons of fuel but will take an extra 28 hours At $1 25 per gallon the fuel savings are equivalent to a time cost of $12.40 per hour If driver salaries or the time value of the cargo exceed this, then it may be financially prudent to drive 65 mph [2]

Idling. Truck drivers often idle their engines for long periods—to supply heat or air conditioning for the cab, to keep fuel heated and free-flowing, to avoid starting difficulties, and because starting is thought to be hard on the engine Fuel consumption at idle varies, but a typical rate is O 5 gallons per hour.[3] In addition there are other detrimental side effects of idling, including oil degradation and Increased engine wear due to water condensation.[4] The technical alternatives to idling include using auxiliary cab heaters and air conditioners, fueled by diesel or electricity, and fuel and engine block heaters, which are also available at low cost [5] Concerns over starting are certainly valid, however, if batteries are in good condition a truck should have no difficulty starting Claims that starting is hard on the engine are unproven and have no apparent engineering basis Unfortunately there are no reliable estimates of total fuel consumed by excess Idling, so savings potential is unknown

Routing and operations. Advanced communication and computer technologies have already improved truck operations, and further Improvements are likely Some truck fleet operators are using commercially available software packages to determine optimal loading and routing.[6] A few large fleets are using onboard computers and/or satellite communications to track fleets and provide up-to-date information to drivers.[7] As the costs of such systems decline and customers increasingly require up-to-date information

(continued)

[1] American Trucking Associations, The Maintenance Council 55 vs 65 *An Equipment Operating Costs Comparison* (Alexandra VA 1987), p 7

2 Assuming 6 44 mpg at 55 mph and 546 mpg at 65 mph as found by ibid Extending the analysis to include effects on engine life has little effect on the results Many drivers are paid by the mile and not by the hour, in these cases the time penalty for slower speeds is paid by the driver (who must work longer hours for the same pay) and not by the owner

[3] "Electronic Diesels and Other Ways to Improve Fuel Economy, *Commercial Carrier Journal,* April 1993, p 96

4 Argonne National Laboratory, "Don t Idle Your Profits Away! October 1986. P 3

[5] Ibid

6 Abacus Technology Corp, "Rail vs Truck Fuel Efficiency,' report for the Federal Railroad Administration April 1991 p 2-12

[7] R Schneidermann, "Tracking Trucks by Satellite" *High Technology Business*, May 1989 p 24

(OPEC) members to expand production capacity, and high non-OPEC production, perhaps because of a revival of production capacity in the former Soviet Union.[155] On the high side, the alternative price scenarios reflect more global economic growth and less conservation than expected (boosting world oil demand), coupled with lower supply. The alternative-economic-growth scenarios reflect differing assumptions about the rate of labor force growth and productivity: 1.2 percent annual growth in the labor force and 1.2 percent annual productivity growth (versus a baseline of 1 percent product iv it y growth) for the high economic growth scenario, and 0.8 percent labor force

155 Given the Continuing political turmoil in the Confederation of Independent States (CI S), the DRI forecast expects CIS production to be significantly delayed by negotiations and startup problems.

BOX 2-E: Operational Strategies To Improve Truck Fuel Efficiency (cont'd.)

on the status and location of their goods, these systems will become more prevalent The energy savings will come from Improved routing reduced empty or partially filled truckloads due to better Information on availability of loads and trucks, and more efficient operations at transfer points

Reduced empty backhauls. Although the data are uncertain, about 10 percent of long-distance truck-miles are empty [8] Reasons for empty backhauls Include equipment limitations (e g , an automobile carrier cannot carry other cargo) and natural traffic Imbalances (e g , urban areas consume more than they produce) Regulatory restrictions once prohibited private companies from carrying cargo for others, however, many of these restrictions were removed by the Motor Carrier Act of 1980 It may be possible for Improved communication and information tools to allow for better matching of loads and trucks, thereby further reducing empty backhauls

Increased size and weight. Allowable truck size and weight are controlled by both State and Federal law The Surface Transportation Assistance Act (1 982) prohibits States from setting a maximum gross weight of less than 80,000 pounds for travel on or near interstate highways. In addition, States are required to allow trailers 48 feet long, or double trailers 28 feet long and 102 inches wide The Intermodal Surface Transportation Efficiency Act of 1991 prohibits States that do not already do so from allowing longer trucks on or near Interstate highways Currently some but not all States allow longer trucks, however, the variations in State rules make it difficult for longer trucks to operate on Interstate long-haul routes

SOURCE Off Ice of Technology Assessment 1994

[8] Estimate by OTA staff based on various sources

growth and 0.8 percent productivity growth for the low-economic-growth case. The gas and oil supply scenarios have little effect on the rate of economic growth or energy use from 1990to2010 compared with the base case.[156]

Other forecasts predict moderate growth in the economy and world oil prices similar to the AEO93 baseline scenario. The annual rate of change in GDP for the Gas Research Institute Baseline Projection 1993 (GRI93)[157] is identical to the AEO93 (2 percent) whereas the DRI/McGraw Hill Spring/Summer Energy Forecast (DRI)[158] assumes a 2.2 percent GDP growth rate. The Argonne National Laboratory's Transportation Energy and Emissions Modeling System (TEEMS)[159] uses the DRI macroeconomic submodel for its forecast, so assumptions are similar.[160]

AEO93 projects moderate but steady growth in transportation energy use across all scenarios: baseline growth is 1.26 percent a year, with a range of 0.9 to 1.6 percent annually for the other

[156] However [here, $ a 10 percent increase in imported petroleum (1.26 million barrels a day, mmbd) in the low oil and gas recovery scenario and an I I percent decrease in imported petroleum (1.35 mmbd) in the high oil and gas recovery scenario. Total consumption of energy differs by 0.5 quadrillion Btu (quads) between the high and low recovery scenarios and the reference case, or less than 0.5 percent of total consumption.

[157] P. D Holtberg et al., *Baseline Projection Data Book: GRI Baseline Projection of U.S. Energy Supply and Demand 102010,* vol.1 (Washington, DC. Gas Research Institute, 1993).

[158] DRI McGraw -Hill, *Energy Review* (Lexington, MA: spring/summer 1993).

[159] Mintz and Vyas, op. cit., footnote 144.

[160] I bid., pp. 8-9.

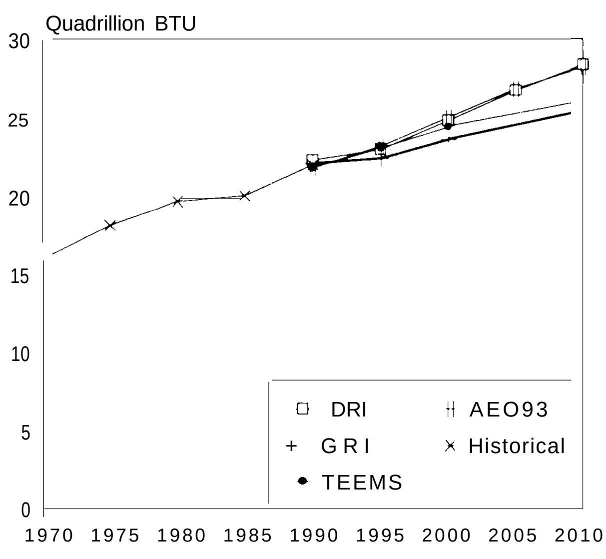
TABLE 2-6: High-Efficiency Heavy Trucks

Truck	Gross weight (lbs.)	Fuel economy Mpg	Fuel economy Percent over existing fleet
Existing fleet	33,000 and over	5 3	—
Kenworth T600A	72,400	8 0	51
Peterbilt 377A/E	76700	91	72
Kenworth prototype	72050	114	115

SOURCES Existing fleet average from S C Davis and M D Morris, *Transportation Energy Data Book,* ed 12, ORNL-671 O (Oak Ridge TN Oak Ridge National Laboratory, March 1992), p 3-46 Truck efficiencies based on cross-counrty demonstration runs using trained drivers See J McNamara, "Kenworth Road Test Raises Fuel Economy Target," *Transport Topics,* Dec 10, 1990, **p 12, and** T Moore, "Peterbilt Introduces Aero Conventional," *Fleet O-wrier* November 1991 p 10

scenarios. Over the 20-year forecast period, this means that transportation energy use will grow from the 1990 level of 22.50 quads. slightly more than 10.5 million barrels per day (mmbd), to 26,86 to 31 quads, about 12.9 to 14.9 mmbd (a 19.0 to 37.8 percent increase) by 2010. The baseline2010 figures are 28.93 quads (13.9 mmbd) total, a 28.5 percent increase (see figure 2-4[161]).

FIGURE 2-4: Total Energy Use of the U.S. Transportation Sector



SOURCE Off Ice of Technology Assessment based on Energy Information Administration historical data and various forecasts

DRI forecasts growth in energy use almost identical to the AEO93 baseline case (i.e., 1.2 percent per year to 28.22 quads, or 13.3 mmbd, in 20 10-or an increase of 27 percent). However, its components (types of fuels, vehicle-miles traveled, and fuel efficiency) are at different levels of growth. DRI forecasts a higher annual total energy growth rate in the second 10 years than AEO93 (1.30 versus 1.09 percent) despite a decrease in the growth rate of highway motor fuel use. AEO93 forecasts a higher energy growth rate than DRI in the first 10 years (1.35 versus 1.18 percent) with a similar decline in highway fuel use. GDP and total vmt projections are similar in the two forecasts. with much of the difference coming from AEO93's more optimistic forecasts of fuel efficiencies.

GRI forecasts a low growth rate in energy use at 0.68 percent a year. The total transportation sector energy use in 2010 is 25.46 quads (11.86 mmbd), a 14.5 percent increase from 1990 and 12 percent less than the AEO93 forecast. Much of this difference comes from a projected **decrease** in motor gasoline consumption over the next 20 years despite a robust growth in motor vehicle vmt. Assumed fuel efficiency ratings are higher not only for passenger cars, but also for light-duty trucks, whose use all models project will continue to grow at a faster rate than passenger car use, with lower fuel efficiency gains.

[161] All charts referencing AEO93 projections will use the baseline scenario.

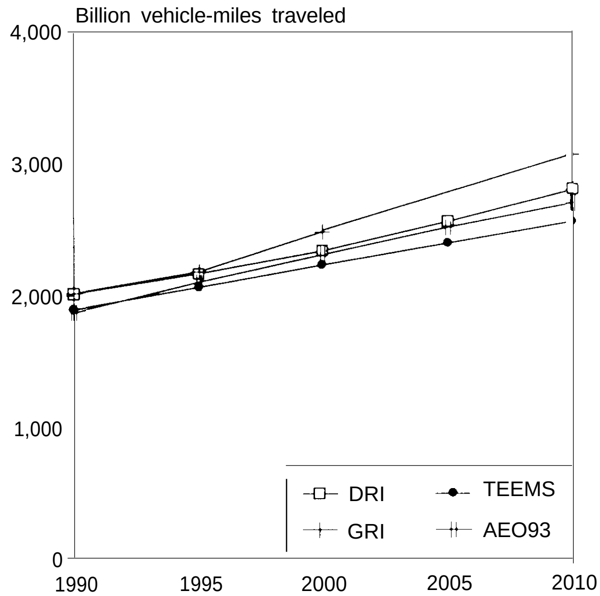
TEEMS forecasts a total energy annual growth rate of less than 1 percent, with a sharp decrease in the second decade of the projection (1.15 to 0.67 percent). Total transportation energy use increases from 21.86 to 26.19 quads (1 2.2 mmbd), an increase of slightly less than 20 percent from 1990 and 9.5 percent lower than AEO93's 2010 total. Part of this 9.5 percent difference can be explained by EIA's higher 1990 estimate of energy consumed by heavy-duty trucks. Another important reason is a lower expected growth rate in air transportation for the TEEMS model (1 .05 percent) than for the AEO93 model (1.9 percent).

In the AEO93 forecast, motor gasoline remains the dominant fuel, but its use increases far more slowly than diesel fuel, predominantly for freight trucks, and jet fuel for aircraft. In 1990, motor gasoline, diesel fuel, and jet fuel made up 91 percent of transportation energy. The projected baseline growth for transport use of these fuels from 1990 to 2010 is 0.8, 1.7, and 1.9 percent per year, respectively, so that diesel share grows from 17 to 18.7 percent, a gain of 1.59 quad (0.74 mmbd). Jet fuel grows from 14 to 15.8 percent, a gain of 1.44 quad (0.67 mmbd), whereas gasoline's share **decreases** from 60.3 to 55 percent, although it gains 2.33 quads (1.08 mmbd). These differences in growth occur primarily because AEO93 foresees a decrease in the annual rate of vmt growth for light-duty highway vehicles, a modest but steady increase in fuel efficiency for these vehicles, a sharp increase in the annual growth rate for air passenger travel and freight shipments, and brisk growth in truck freight transport.

Vehicle-Miles Traveled and Fuel Efficiency

Due to light-duty vehicles' large share of energy use in the transportation sector, forecasting vmt is an important component in forecasting the total

FIGURE 2-5: Light-Duty Vehicle-Miles Traveled for Passenger Autos and Light Trucks



SOURCE Office of Technology Assessment, based on American Automobile Manufacturers' Association data and various forecasts

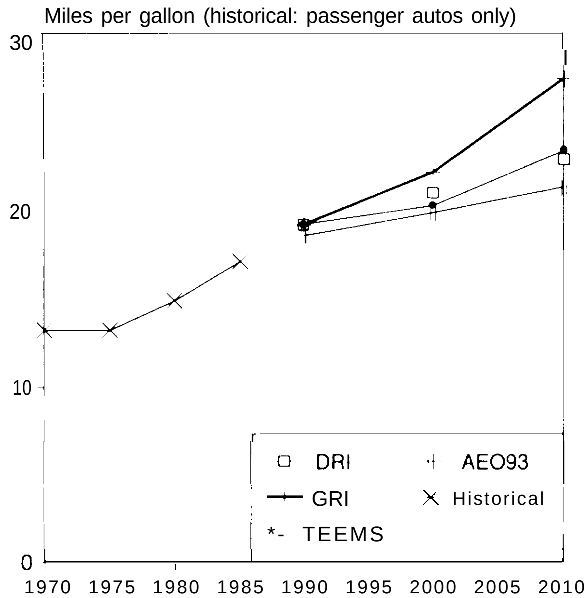
sectoral energy use in 2010. In 1990, light-duty vehicles made up about 34 percent of total U.S. petroleum consumption and 14 percent of the entire energy consumed by the United States.[162]

In the AEO93 baseline scenario, travel for light-duty highway vehicles grows at a much slower pace than in the past, about 1.7 percent per year (see figure 2-5), whereas the fuel efficiency of the light-duty fleet[163] grows at about 0.7 percent annually, compensating for less than half of the growth in travel demand (see figure 2-6). This yields a 1 percent annual growth in energy consumption over the next 20 years compared with 1.36 percent over the last 20 years. These parameters do not change much in the other scenarios: for

162 Motor Vehicle Manufacturers Association, *Facts and Figures '92* (Detroit, MI:1992), p. 82.

163 This value is an estimated average on-the-road efficiency rating for all cars and light trucks. The EPA rating for projected mpg for new cars is adjusted according to assumptions (coefficients) in each model for projected changes in fuel prices (e.g., AEO93 estimates that a 10 percent Increase in fuel prices yields a 6 percent improvement in fuel efficiency over time due to manufacturer product changes and consumer response) and inefficiencies such as increased congestion.

FIGURE 2-6: On-the-Road Fuel Efficiency of the Light-Duty Vehicle Fleet



SOURCE Off Ice of Technology Assessment based on Oak Ridge National Laboratory historical data and various forecasts

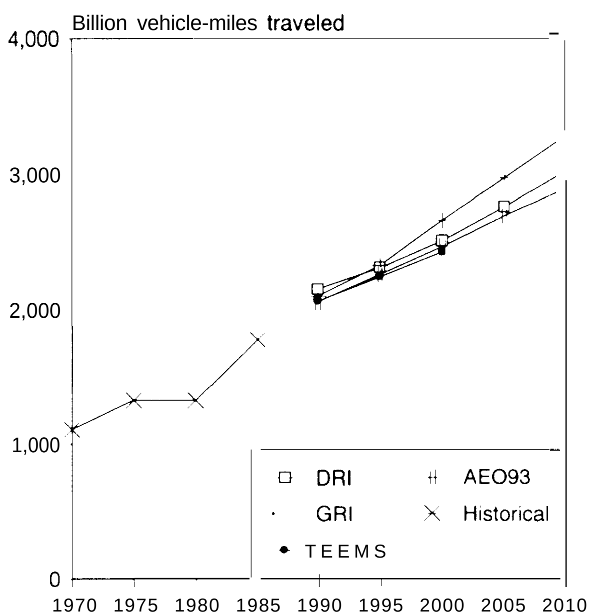
example, in the high economic growth scenario, light-duty travel grows at a pace of only 1.9 percent per year, still well below historic levels. The largest variation in fuel use occurs with low oil prices, with a 1.8 percent annual growth in travel and only a 0.5 percent annual compensating increase in fleet fuel efficiency; in this scenario, transportation use of gasoline grows at 1.3 percent a year, leading to an increase of 1.82 mmbd by 2010, a 50 percent gain from the baseline case.

Several of the alternative forecasts looked at both total and personal vehicle vmt (see figure 2-7). The forecasts rely on economic choice calculations based on fuel efficiency, real costs per mile, and real disposable income. Predictive variables come from either fleet-based or driver-based characteristics.

DRI

The DRI forecast uses a fleet-based model to calculate vmt. The mode] uses projected vehicle purchases and scrappage-rate assumptions, based on projected real costs per mile and real disposable income, to obtain a vehicle mix for the light-duty fleet in nine census-defined regions of the United States. The DRI total highway vmt forecast is almost identical to AEO93. The average annual vmt growth rate is 1.7 percent, but the total is higher due to a difference in definition of light-duty vehicles. The AEO93 model forecasts a decrease in the annual light-duty vmt growth rate in the second decade of the forecast, presumably due to a drop in the U.S. economy's growth rate (an important predictor of vmt growth in all of the models) and increased oil prices. The DRI model forecasts an increased vmt growth (1.84 percent) in the years 2000-10 despite a forecasted decrease in economic growth. Projected fuel efficiency increases by 0.9 percent a year with a slight decrease in the second decade. This results in a slightly lower motor fuel consumption in 2010 than projected in the AEO93 forecast.

FIGURE 2-7: Total Highway Vehicle-Miles Traveled



SOURCE Off Ice of Technology Assessment based on American Automobile Manufacturers Association historical data and various forecasts

Gas Research Institute

The GRI forecast uses the DRI base vmt model and adjusts some of the coefficients to reflect differing assumptions (mostly in the area of fuel efficiency and natural gas-fueled vehicle share). GRI forecasts higher fuel efficiency and one of the highest increases in total highway vmt of any of the models. The total highway vmt is expected to grow an average of 2.28 percent per year over the next 20 years to 3,288 billion vmt. Total fleet mix is expected to be 30 percent light-duty trucks, accounting for 35 percent of the total vmt in 2010. The vmt for light-duty vehicles is expected to grow at a slightly lower rate of 2.12 percent annually. Most of the excess increase in vmt (compared with other models) is offset by the higher projected increase in light duty vehicle fuel efficiency. which is expected to grow by 1.79 percent annually, from 19.2 to 27.4 mpg, or slightly less than a 43 percent increase. Given the physical limits of efficiency improvements for present-day automobile engine configurations and even conservative estimates of increased congestion, most of this increase must come from changes in consumer preference. With the moderate consumer reaction to fuel price increases in the last 20 years, the trend toward a higher percentage of older vehicles in the fleet mix, and projected moderate fuel prices,[164] it would appear difficult for the vehicle fleet to achieve this great an increase in fuel efficiency over such a short time frame. GRI projects transportation use of natural gas to increase at 3.6 percent a year, from 0.7 to 1.4 quads.[165] This represents a slightly more than 28 percent increase in natural gas vehicle use to almost 0.5 quad between 1990 and 2010. The AEO93 projects an increase in vehicle gas use from negligible to 0.15 quad during the same period.

Transportation Energy and Emissions Modeling System

TEEMS combines fleet-based and driver-based models. It uses changes in disaggregate household vmt data (driver-base) to project fleet mix by vehicle usage and scrappage rates (fleetbase) similar to the DRI model. Economic and fuel price variables are based on the DRI macromodel of the U.S. economy. TEEMS projects the lowest annual growth in total highway vmt of the forecasts examined, 1.55 percent. The model forecasts a lower annual growth rate in the second 10 years than in the first 10, in conjunction with a decrease in the annual growth rate of GDP from 2.6 to 1.93 percent. The 20- year annual growth rate of light-duty vmt is also the lowest of models at 1.49 percent, or 20 percent less than the AEO93 model growth rate. The model predicts that most of the fuel efficiency (and emissions) gains of highway vehicles will be offset by increased congestion and the large number of older, less efficient vehicles that remain on the road. Fuel efficiency increases at an annual rate of only 0.56 percent in the first decade and 1.43 percent in the second[166] for a 20-year annual rate of slightly less than 1 percent, from 19.2 to 23.4 mpg.

Air Travel

AEO93 projects that travel for air passengers and freight combined will grow much faster than any other mode, and much faster than the growth rate of the economy—at 3.9 percent per year for the baseline, and as much as 4.8 percent annually for

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[164] Fuel and oil costs were slightly more than 13 percent of the total per-mile costs to operate a car. This percentage is expected to continue to decline, making fuel prices less predictive of light-duty vehicle fuel efficiency. See Davis and Strang, op. cit., footnote 8, p. 2-40.

[165] This includes pipeline compressor use of natural gas for throughput of natural gas in the lower 48 States. The amount is 0.7 quad in 1990 and increases to 0.9 quad in 2010.

[166] Presumably due to rising fuel costs.

the high-economic-growth case. Aircraft efficiency will also increase at a brisk pace—1.5 percent per year (in terms of Btu per passenger) in all of the scenarios—but not nearly fast enough to offset the growth in travel demand.

Transportation Energy and Emissions Modeling System

The TEEMS model projects a similar annual rate of increase in revenue passenger miles—3.37 percent, but greater aircraft efficiencies than the AEO93 projection, for an overall increase in jet fuel demand of 1.05 percent per year or about a 23 percent increase over the 20 years.

DRI

DRI projects the highest annual rate of increase in revenue passenger-miles for commercial jets[167] (3.82 percent per year) and lower efficiency gains (1. 15 percent per year), for an overall increase in jet fuel demand of 1.42 percent a year or about a 32.5 percent increase over the 20-year period.[168]

Rapid fuel efficiency gains are likely through lighter composite materials, advanced electronic controls to optimize fuel burn under given flight conditions, and an increase in the number of seats per aircraft.[169] However, even at a rapid rate of growth, air transport will make up a relatively small portion of the transportation sector's energy use.

Discussion and Analysis

There is a remarkable unanimity among the various models that highway vmt will increase at a much lower rate during the period 1990-2010 than during the previous decades; all models use vmt rates of less than 2 percent per year. As noted, the most important factor behind these projections is the forecasted decline in growth of driving-age adults as the baby boom passes. This factor alone represents more than half of the decline in growth rate in the EIA forecast and presumably is equally critical in the alternative forecasts. There is less unanimity about efficiency increases, although the majority of the forecasts are relatively optimistic about fuel economy, with the GRI forecast being remarkably optimistic. Similarly, all forecasts project growth in air travel at levels considerably lower than the recent 6 to 7 percent annual rate, with EIA projecting 4.8 percent for the high-economic-growth scenario, and less than 4 percent for the baseline scenario. *All of these factors tend to push passenger transportation energy consumption growth in the same direction, to lower-than-historic levels.*

OTA considers the EIA projection of transportation energy growth—a baseline increase of about 29 percent over 1990 levels by 2010-as likely to be an underestimate, if there are no changes in energy policy. In particular, OTA is skeptical that vmt growth will fall below 2 percent a year for the period and that light-duty fleet fuel economy will increase as much as EIA projects.

Freight

There have been several efforts to forecast freight transport energy use. The results of three models are presented, one of which is a very simple extrapolation of past trends used to pinpoint key areas of disagreement.

Argonne National Laboratory provides forecasts of energy use through 2010 for both freight and passenger transport. Results of the Argonne model show freight transport energy use growing by 2.3 quads from 1990 to 2010-with 1.8 of these due to increased consumption by trucks and 0.4 due to trains (table 2-7). This model projects very rapid (3.3 percent) annual growth in train

167 Includes freight and passenger demand.

168 DRI also starts off with a higher baseline level of jet fuel demand (0.6 quad) than TEEMS.

169 However, there are physical limitations to aircraft size due to current airport configurations. The lack of completely new airports completed or in the final permitting process in the past 10 years (Stapleton being the exception) will limit the size of aircraft over the next 20 years.

ton-miles, more than double the historic (1970-90) growth rate.[170] The model also projects moderate (1 percent) annual average improvements in freight truck intensity--even though historical improvements, as discussed above, were considerably smaller.

The AEO93 forecast shows a 2.4-quad increase in freight transport energy use (1990-20 10), with 1.5 of this from trucks and 0.6 from marine (table 2-8). (The EIA model, unlike the Argonne model, includes international movements under "Marine.") The increased demand for freight truck movement is relatively modest in this mode]- 1.9 percent per year, compared with 2.5 percent for the Argonne model. Other researchers have noted that EIA's growth rate for freight truck travel is surprisingly low, whereas truck efficiency improvement is rapid.[171] The EIA analysis also implies that oil prices have little or no effect on freight transport energy use. The projected improvement in freight truck energy intensity, for example, is the same at a 2010 oil price of $18 per barrel as at $38 per barrel (1991 dollars).[172]

TABLE 2-7: Argonne Forecast of Freight Transport Energy Use (quads/year)

Mode	1990	2010	Change (percent per year)
Truck	525	707	15
Train	053	095	30
Marine	034	038	06
Air freight	005	006	16
Pipeline	068	070	03
Total	**6.84**	**9.15**	**1.5**

SOURCE Argonne National Laboratory, *Forecast of Transportation Energy Demand Throughout the Year 2010* ANL ESD-9 (Argonne IL November 1990 revised April 1991) p 3

TABLE 2-8: AEO Forecast of Freight Transport Energy Use (quads/year)

Mode	1990	2010	Change (percent per year)
Freight	506	657	13
Rail	049	059	09
Marine	139	202	19
Pipelines	068	081	09
Total	**7.62**	**9.99**	**1.0**

SOURCE U S Department of Energy Energy Information Administration *Annual Energy Outlook 1993* DOE EIA-0383(93) (Washington DC January 1993) p 96

The assumptions and results of the Argonne and EIA models can be examined by comparing them with the results of a simple extrapolation of past trends. As discussed above, it seems likely that past trends (notably increasing demand for higher-value-added goods, moderate growth in basic commodity" movements, and continued moderate penetration of energy-efficient technologies) will continue. Therefore a simple extrapolation of past trends is a useful reference case.

The results of such an extrapolation are shown in table 2-9. This calculation uses historical trends in demand (ton-miles per year) and energy intensity (Btu per ton-mile) to forecast energy use. For example, to calculate train energy use in 2010. demand for train movements and train energy intensity in 2010 are calculated first by assuming that historical (1970-90) rates of change continue in the future (1990-2010). Demand and intensity in 2010 are then multiplied to yield energy use.

This simple extrapolation. in comparison with the Argonne and EIA models, shows much higher growth in freight truck energy use—3.4 percent annually versus 1.5 and 1.3 percent annually, This

[170] This increase is due to rapid expected growth in coal movements from western mines to eastern and southern powerplants

[171] D. Gately, "The U.S. Demand for Highway Travel and Motor Fuel," *The Energy Journal*, vol. 11, No. 3, 1990, pp. 59-73.

[172] Energy Information Administration, op. cit., footnote 10, pp. 6, 150, 168.

TABLE 2-9: Simple Extrapolation of Freight Transport Energy Use

Mode	Energy use (Quads/yr) 1989	2010	Growth: Percent per year	Growth: Quads (1989-2010)
Truck	4.9	9 8	+3 4	4 9
Rail	0.4	0 3	-1 2	-01
Water	0 3	0 4	+1 4	01
Air	01	0 2	+4 5	01
Pipeline	0 3	0 4	+2 1	01
Total	**5.9**	**11.1**	+3.0	5.1

SOURCE. Off Ice of Technology Assessment, 1994

is due in part to the extrapolation of past trends in truck freight energy intensity, which was relatively flat from 1970 to 1990.[173] In the absence of major technological or policy changes, there is little reason to expect past trends to change.

Given the uncertainty both in the historical data and in future economic conditions and oil prices, these forecasts should be interpreted with care. One can, however, be reasonably confident about major trends shown by all three efforts-that truck energy use will continue to be much higher than that of the other modes, and that air freight will continue to be a trivial energy consumer despite the rapid growth in demand for air freight movements that is forecasted.[174]

173 As discussed above, truck energy *efficiency* (miles per gallon) improved very slowly In the past 20 years. Data on *intensity* (Btu per ton-mile) are uncertain, but show a similar pattern. In addition to the factors discussed above—such as increased highway speeds—intensity was probably influenced by decreases in cargo density, which led to trucks filling up their cargo areas before reaching (heir weight I imits. This would increase intensity, as measured by Btu per ton-mile, but is not a decrease in efficiency.

174 A fourth analysis, not discussed here, also found that truck energy will continue to dominate freight transport energy use and that air freight will continue to bea small energy user. See Union of Concerned Scientists, *America's Energy Choices* (Cambridge, MA: 1992), technical appendix, p. D- 10.

Is the U.S. System Energy-Efficient? A Comparison With Europe

3

In arguing about the potential for improving U.S. transportation energy efficiency, it is tempting to point to Western Europe as a model. Although average Western European "per capita" income levels are similar to those in the United States, the average citizen of a European OECD (Organization for Economic Cooperation and Development) country uses far less energy for travel than an average U.S. citizen. In 1990, citizens of Great Britain, West Germany, France, and the Scandinavian countries used about 30 to 40 percent as much and the average Italian citizen about one-fourth as much energy as U.S. citizen s.[1] This large disparity may not seem surprising given the similar (although inverted) disparity in energy prices-in 1990, European gasoline prices averaged about three times those in the United States, and Italian prices four times as much—but there may be additional reasons for the energy use differential.

US. POTENTIAL TO MOVE TOWARD EUROPEAN TRANSPORT ENERGY LEVELS

The large differences between European and U.S. per capita transport ation energy use raise two obvious questions. First, do the differences reflect primarily differences in efficiency; that is, are the Europeans just doing a better job than Americans are of supplying the same basic transportation services? In other words, should we be trying to emulate the European model? Second, to the extent

[1] Data obtained from L. Schipper and N. Kiang, International Energy Studies, Lawrence Berkeley Laboratories, in advance of publication in Oak Ridge National Laboratory, *Transportation Energy Data Book*, ed. 14 (Oak Ridge, TN: forthcoming).

that energy use differences reflect differences in efficiency, would shifts in U.S. energy and transportation policy toward European norms--e.g., high taxes on fuels and vehicles, and zoning restrictions designed to maintain high residential densities—lead to significant reductions in U.S. energy consumption toward European levels?

These questions are sometimes answered in the affirmative without any analysis to back them up. For a number of reasons, the correct answer might be "no" or "not entirely," and these reasons must be thoroughly explored before a definitive answer is given. As an example, for the first question, the differences in energy use could represent in part differences between Europe and the United States in geography and demography or in the quality and quantity of transportation services each supplies to its residents. It is well known that levels of energy consumption in less-developed countries are well below those of the United States, but the reasons have everything to do with the level of services and nothing to do with efficiency (the efficiency of systems in less-developed countries is generally far less than that of the United States). As for the second question, matching policies may not yield matching results. The extensive transportation infrastructure of the United States may create a status quo that limits the shifts in energy consumption achievable with feasible policies. Also, some of the differences between the United States and Europe may be caused less by policy differences than by differences in history and culture, and so cannot be undone by policy. For example, most European cities are substantially older than U.S. cities, and built for foot and animal traffic rather than for automobiles. Their greater residential density and lower travel requirements are due *at least in part* to this history. In fact, some analysts claim that European transportation is moving inexorably toward the U.S. model, despite the great differences in policy.

This chapter addresses the questions raised above, drawing on the work of several researchers who have examined and compared U.S. and European energy use. In doing so, the differences between U.S. and European energy use today are addressed, and the trends examined; the latter examination adds a critical dimension to the discussion.

The analysis is preliminary and exploratory, not definitive. The very critical question of comparative mobility is not addressed. Even though Europeans use far less energy for travel, do they still enjoy mobility—measured not in miles or kilometers per year but in the ability to access recreational, social, cultural, and employment opportunities—at levels similar to those enjoyed by Americans? Although this question is at the core of a fair energy comparison, any quantitative analysis would be extremely subjective, and adequate data are lacking. Nor can the relative roles of governmental policies and other influences in shaping transportation energy use be distinguished clearly, because of the great complexity of the systems involved and the lack of "controls" in evaluating the effects of changes in policies.

In this brief examination, comparisons with various countries are made, because the sources consulted do not all use the same ones. However, all comparisons include West Germany, the United Kingdom, France, and Italy, which together account for a major share of European transportation demand and energy consumption.[2]

PASSENGER TRANSPORT ENERGY IN THE U.S. AND EUROPE TODAY

Table 3-1 presents some basic statistics comparing passenger transportation energy use values and indicators for five European countries and the United States. As noted above, U.S. per capita transportation energy consumption is far higher

[2] For example, among 11 European countries—Austria, Belgium, Denmark, Finland, France, West Germany, Italy, the Netherlands, Spain, Sweden, and the United Kingdom—France, West Germany, Italy, and the United Kingdom accounted for 78 percent of passenger vehicle travel in 1985, about 636 billion vehicle-miles out of a total of 819 billion miles. Source: J. Darmstadter and A. Jones, "Prospects for Reduced CO_2 Emissions in Automotive Transport," Resources for the Future, ENR90-15, August 1990, table 6.

TABLE 3-1: United States–Europe Passenger Transportation Comparison, 1990

	Autos (per capita)	Gas price (1990$)	Auto fuel economy (mpg)[a]		Passenger miles (per capita)	Energy use (10^6 Btu per capita)	Car share (percent of passenger-miles)	Air share (percent of passenger-miles)
			New[b]	Fleet, on-road				
United States	**0.598**	**1.04**	**25.3**	**18.6**	**13,500**	**54**	**86**	**10.2**
France	0.413	3.40	36.3	28.0	7,800	16	83	1.3[d]
Italy	0.430	4.27	34.3	31.5[c]	7,400	14	80	0.9
Sweden	0.419	3.34	28.5	23.7	7,800	21	80	3.1
United Kingdom	0.352	2.55	32.0	25.0[c]	7,000	19	87	0.8
West Germany	0.499	2.72	30.0	23.5	6,900	21	84	0.8

a Includes light trucks used for personal travel.

b U.S. Environmental Protection Agency test values or equivalent

c 1988 data

d Includes domestic flights only, so European values are artificially low

SOURCE Lawrence Berkeley Laboratory

than that in European countries-n average, about three times higher. As demonstrated by the table, differences in per capita travel account for the major share of the overall energy differences: Europeans travel a bit more than half as much (in distance) as Americans do each year, and this difference accounts for about one-half of the per capita difference in energy use. The remainder of the energy difference is accounted for by differences in the relative share of different modes of transportation, load factor, and vehicle efficiency. Americans travel somewhat more in private autos, and far more in energy-intensive airplanes, than do Europeans, who make far greater use of buses and trains. Mass transit has about a 15 percent modal share—measured as a percentage of *passenger-miles*-in Europe versus about 3 percent in the United States.[3] European automobile fleets are more efficient than the U.S. fleet, partly because Americans purchase large numbers of light trucks for personal travel, and partly because American automobiles are larger than their European counterparts.[4] These differences do yield important differences in the energy efficiency of U.S. and European travel—Americans use about 4,000 Btu/passenger-mile versus about 2,100 Btu/passenger-mile in France, 1,900 in Italy, 2,700 in Sweden and the United Kingdom, and 3,000 in West Germany.

One interesting and perhaps surprising conclusion that can be drawn from table 3-1 is that despite the huge disparities in total energy use, European travel is nearly as automobile-dominated as U.S. travel—in both regions, the great majority of passenger travel is by automobile. However, statistics for *total* travel mask somewhat the automobile's utter dominance in the United States for trips of a few hundred miles or less, where its share is in the middle 90s compared with the European auto share of about 80 percent.

Also, the statistics in table 3-1, which are exclusively in terms of total travel distance, mask the role of bicycling and walking in European travel. In urban settings, where the European cities' high densities place work, services, and recreational activities within close reach of residential areas, and where careful attention has been paid to nurturing these modes, bicycling and walking play an important role in total tripmaking. Table 3-2 presents somewhat dated but still revealing estimates of modal split for the United States, Canada, and Western Europe, with shares measured as a percentage of total *trips*.[5] Whereas bicycling and walking accounted for only 11.4 percent of U.S. urban trips in 1978, these modes typically accounted for 30 to 50 percent of urban trips in Western Europe around the same time. Presumably, many of these trips, if they were being made in U.S. cities, would be longer in distance and would be made by auto.

Further insight can be gained by focusing specifically on auto owners in the United States and Europe. U.S. and European auto owners are far

[3] L. Schipper and S. Meyers, with R. Howarth and R. Steiner, *Energy Efficiency and Human Activity: Past Trends, Future Prospects* (Cambridge, United Kingdom: Cambridge University Press, 1992).

[4] With the global market in automobiles, there are few technological differences in automobiles in Europe and the United States; efficiency differences are due primarily to differences in average size and power, with emissions, safety equipment, and luxury features (power accessories, four-wheel drive) playing a role as well. One exception is the important role of diesel engines in Europe.

[5] J. Pucher, " Urban Travel Behavior as the outcome of Public Policy: The Example of Modal-Split in Western Europe and North America, " *Journal of the American Planning Association*, autumn 1988, table 1. Data on total travel are difficult to obtain and are viewed with suspicion by some analysts (Lee Schipper, Lawrence Berkeley Laboratory, personal communication).

TABLE 3-2: Modal Share of Urban Passenger Transportation (percentage of total trips)

		Mode					
Country	**Year**	**Auto**	**Public transport**	**Bicycle**	**Walking**	**Motorcycle + moped**	**Others**
United States	**1978**	**82.3**	**3.4**	**.7**	**10.7**	0.5	2.4
Austria	1983	385	128	85	312	37	53
Canada	1980	740	150	◄	110		►
Denmark	1981	420	140	200	210		30
France	1978	470	110	50	300	60	10
Great Britain	1978	450	190	40	290	20	10
Italy	1981	306	260	◄	434		●
Netherlands	1984	452	48	294	184	13	10
Sweden	1978	360	110	100	390	20	20
Switzerland	1980	382	198	98	290	13	19
West Germany	1978	476	114	96	303	09	11

SOURCE J Pucher Urban Travel Behavior as the Outcome of Public Policy The Example of Modal -Split in Western Europe and North America *American Planning Association Journal* autumn 1988

closer to each other than are U.S. and European citizens in general: European auto owners travel by auto 60 to 80 percent as much as Americans,[6] versus about 48 percent for all citizens.[7]

If the reasons for the substantial disparities between travel volumes and energy use in the United States and in Europe were fully understood, one could better identify policy prescriptions that might move U.S. transportation toward the European model. Unfortunately, there are too many interrelated variables to construct a precise model relating transportation outcomes to country conditions, and logic and qualitative examination of the data must suffice. For example, it seems clear that the disparity in gasoline prices must be a major factor in the different driving propensities of U.S. and European auto owners, but it is equally clear that other factors play an important role as well. Among these are differences in the physical system, for example, the amounts of parking space and roadway and the speeds possible on these roads. The United States has two to four times as much road per capita as Europe;[8] 80 percent more parking spaces per 1,000 workers than Europe:[9] and traffic speeds in major urban areas that average about 27 mph versus only about 19 mph for major European cities.[10] Thus, for urban driving, European drivers can go only 70 percent as far as American drivers in the same amount of time.

The reasons the United States has a more automobile-oriented physical system are complex. In part, this is due to the following:

- specific U.S. policy decisions to set up a dedicated gasoline sales tax for road construction (whereas the higher European taxes are earmarked largely for the general treasury) and to construct the Interstate Highway System;

[6] L. Schipper et al., "Fuel Prices, Automobile Fuel Economy, and Fuel Use for Land Travel: Preliminary Findings From an International Comparison," *Transportation Policy*, forthcoming.

[7] This is assuming all European citizens travel 50 percent as much as Americans, using an 83 percent auto share versus the U.S. 86 percent share.

[8] Pucher, op. cit., footnote 5, table 5, 1982 data.

[9] P.G. Newman and J.R. Kenworthy, *Cities and Automobile Dependence: A Sourcebook* (Aldershot, England: Gower Publishing Co., 1989).

[10] Ibid.

- a U.S. tax code that encourages single-family home ownership and suburban sprawl through mortgage interest deductions,[11] and that defines the provision of free employee parking as a deductible business expense (more than 80 percent of U.S. work parking is free, a major subsidy of automobile use[12]);
- a U.S. approach to zoning that often favors low-density development; and
- a failure to subsidize mass transit during the 1950s and 1960s, when U.S. transit ridership fell to less than half its pre-World War II level.[13]

As Pucher has pointed out, even the huge subsidies of the 1970s failed to substantially boost mass transit ridership, at least in part because most of the capital subsidies went toward building a few new and very expensive rapid rail systems that did little to boost nationwide transit growth.[14]

Another reason is the U.S. decision to keep taxes on gasoline very low in comparison with European levels. The availability of inexpensive fuel has promoted a rapid increase in auto use that has continually pushed expansion of the highway system, while providing little incentive to use mass transit and thus little incentive to expand transit services.

The auto orientation of most American cities also has quite a bit to do with simple timing:

Many American cities evolved in a twentieth-century, postautomotive period where a combination of abundant land, a new transport mode, and cheap fuels all pointed to unique patterns of living and transport. By contrast, the concentrated urban configuration of many European cities was firmly locked into place many years--if not centuries---earlier It seems no accident that those American cities---namely the older ones along the Eastern seaboard, like Boston, New York, and Philadelphia-which most closely resemble European cities are also the ones in which public transportation survives as an enduring tradition.[15]

The importance of timing in determining urban form ought not to be taken as absolute, however. As Pucher points out, many American cities were densely developed and massively dependent on mass transit during the early part of this century, and then underwent a loss in density and a shift to auto orientation and suburbanization that accelerated after 1945.[16] Further, some European cities (Rotterdam, Nuremburg, Frankfurt) were extensively rebuilt after World War II, and others have large sections that were incorporated into their urban areas and built up during the automobile era.

Two prominent differences between the U.S. and Europe that might affect travel are the marked differences in residential density characteristic of U.S. and European cities and the very large U.S. land mass. Intuitively, a large land mass may be thought to signal a likelihood of high travel rates; actually, however, the data for countries of different size seem not to bear this out.[17] On the other hand, high densities do appear to depress travel rates, probably because they allow potential destinations-cultural, recreational, employment,

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[11] It is important to note here that the form of encouragement is less an actual *favoring* of single-family homes over other forms than the general lessening of costs for all housing, which then allows personal preferences for single-family housing to more easily outweigh cost considerations in housing decisions.

[12] Pucher, op. cit., footnote 5.

[13] Ibid.

[14] Ibid.

[15] J. Darmstadter et al., Resources for the Future, *How Industrial Societies Use Energy: A Comparative Analysis* (Baltimore, MD: Johns Hopkins University Press, 1977).

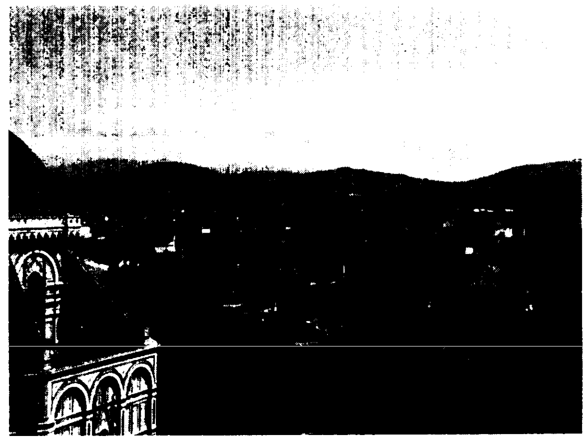
[16] Pucher, op. *cit.*, footnote 5.

[17] Darmstadter et al., op. Cit., footnote 15.

and so forth-to be within easy reach.[18] Also, as discussed in chapter 5, high residential densities are more easily served by public transportation, and the characteristically low U.S. urban densities (generally less than 8 per acre, compared to about 20 per acre in Europe[19]) make dependence on the auto virtually certain.

Another factor that may influence automobile use is the relative ease with which driving-age adults can gain access to a vehicle. The United States makes it far easier, in both a financial and an administrative sense, to gain such access. State governments levy only an average 5 percent tax on new autos (in 1982), versus from 14 percent (Germany) to 186 percent (Denmark) in Europe, and U.S. requirements for obtaining driver's licenses are minimal compared with the stringent (and expensive in terms of training) requirements throughout Europe.[20]

Differences in demographic characteristics between the United States and Europe are also important to differences in travel characteristics. As discussed in chapter 2, characteristics such as age distribution, number of women in the workforce, and so forth are important determinants of U.S. travel volumes. For example, high participation of women in the workforce has driven up U.S. passenger travel both by necessitating more work-trips and by giving more women financial access to automobiles. To the extent that women workforce participation may be higher in the United States than in Europe, this would contribute to the disparity in per capita travel distances. Although this topic is not pursued further here, it deserves a closer look.


MICHAEL GLUCK

High residential densities of European cities promote walking, bicycling, and transit use and reduce travel distances

Because of its continuing influx of immigrants, the United States has a lower proportion of its population over age 65 than do Western European countries.[21] This difference may explain at least a small part of the lower European annual person-miles of travel, because the over-65 population travels less than any other age group. For the United States, males over 65 take about 2.2 trips per day versus 3.5 for males ages 20 to 29 and 3.3 trips for males ages 30 to 39.[22]

Other factors that may contribute to Western Europe's lower tripmaking propensity are as follows:

- its greater degree of urbanization than the United States (in 1985,92 percent of the United Kingdom's population was urban, and most other Western European countries had more

[18] Ibid, Newman and Kenworthy, op. cit., footnote 9.

[19] Ibid.

[20] Pucher, op. cit., footnote 5. Since data on European rates of licensing have not been obtained, we cannot assert that the differences in licensing procedures and costs actually reduce these rates.

[21] U.S. Department of Transportation, *National Transportation Strategic Planning Study* (Washington, DC: March 1990), ch. 6.

[22] A.E. Pisarski, *Travel Behavior Issues in the 90's* (Washington, DC: Federal Highway Administration, July 1992), fig. 27.

than 85 percent of their populations in urban areas; in contrast, 74 percent of the U.S. population lived in urban areas[23]);
- its tendency to have a larger share of total country population in a single major city;[24] and
- the tendency of its populations to be less mobile in their decisions about where to live (many long-distance personal trips in the United States are made to visit distant family members). The importance of these factors deserves further examination.

As might be expected, the pattern of higher automobile orientation in the United States compared with Europe is not absolute. One anomaly in the pattern is the widespread European practice of awarding company cars to employees. About one-third of all new cars in West Germany and Sweden, for example, are company cars, as are more than half of the new cars in the United Kingdom.[25] Also, commuting costs are tax deductible in many European countries,[26] cutting drastically the real costs of driving. The existence in Europe of these market incentives in *favor* of auto travel may be part of the reason some transportation energy trends in Europe are beginning to converge with those in the United States.

For intercity travel, U.S. travelers use airplanes far more than Europeans do, and they use far less rail. There are a number of reasons for this: deliberate European policies to limit the number of flights and keep fares high; the more favorable geographic distribution of major European cities for rail travel (i.e., they tend to be a few hundred miles apart—far enough to discourage many drivers but short enough to allow high-speed rail to compete with air in door-to-door travel time); and European support for a network of efficient and high-speed rail systems.

TRENDS IN U.S. AND EUROPEAN PASSENGER TRANSPORT ENERGY

It is clear from the above discussion that, in many respects, the current European passenger transportation system is an attractive model for the United States to emulate *if reducing energy intensity is a high-value goal.* One potential counterargument to this conclusion is that European mobility may be lower than that in the United States. If it is, emulating the European model either will fail to reduce energy use as much as expected, if current levels of mobility are maintained, or will create an unacceptable decline in the average U.S. resident mobility and quality of life. This argument is not addressed here, except to note that it is unwise to assume that the lower level of European *travel* necessarily translates into a similarly lower level of European *mobility* (i.e., access to social, economic, recreational, and cultural opportunities). Another counterargument is that examining European transportation during one brief interval misses an important dynamic: Europe is rapidly becoming more like the United States in its auto orientation,[27] despite its high gasoline prices, dense cities, and superb transit, so that emulating its example will result in few energy savings. This thesis is examined here.

A comparison of changes in transportation energy use over time in the United States and Western Europe yields results that, at first glance, appear to support the proposition that the U.S. and European transportation systems are converging. Despite a lower population growth rate than in the United States, total European transport energy

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[23] U.S. Department of Transportation, op. cit., footnote 21.

[24] Ibid.

[25] L. Schipper et al., "Fuel Prices, Automobile Fuel Economy, and Fuel Use for Land Travel: Preliminary Findings From an International Comparison," *Transport Policy*, vol. 1, No. 1, 1993.

[26] L. Schipper and G. Ericksson, "Taxation Policies Affecting Automobile" Characteristics and Use in Western Europe, Japan, and the United States," forthcoming, proceedings of the Asilomar Workshop on Sustainable Transportation, University of California-Davis, 1993.

[27] See, for example, C. Lave, "Cars and Demographics," *Access*, University of California at Berkeley, fall 1992.

growth over the past few decades has been much faster than U.S. growth: from 1973 to 1988, U.S. transportation energy grew by 13 percent, while Western Europe's grew by 55 percent.[28] A good portion of this differential, however, is due to the rapid improvement of U.S. automobile fuel economy during this period. European cars, in contrast, improved technologically but not in terms of fuel economy[29] because they became larger and more powerful. Also, Europe is starting from a much lower base of transportation energy use, so its higher growth rates are less impressive.

Because the primary reason for the U.S.-European differential transportation energy use is the difference in total travel per capita, rather than differences in mode or efficiency, the critical values for examining a potential U.S.-European convergence in per capita transportation energy consumption are changes in the travel per capita over time. Of the major European nations, most show growth rates of passenger travel per capita significantly higher than those in the United States. For example, for 1970 to 1987, passenger-miles per capita (p-m/c) grew by 53 percent in France, 61 percent in Italy, 41 percent in Sweden, 49 percent in the United Kingdom, and 40 percent in West Germany-a weighted average of 47 percent—versus 22 percent in the United States.[30] Even with per capita annual travel distances so much lower in Europe than in the United States, the difference in the European and U.S. rates of more than two to one is significant,

Focusing specifically on automobile travel reveals an even stronger gap in travel growth between the United States and Europe. From 1970 to 1987, per capita passenger travel by auto grew by 57 percent in France, 69 percent in Italy, 37 percent in Sweden, 67 percent in the United Kingdom, and 50 percent in West Germany-an average of 59 percent—versus only 16 percent in the United States.[31] What is happening here is that while auto travel is growing considerably more rapidly in Europe than in the United States (again, this is made less surprising by Europe's much lower starting level), U.S. air travel is growing so rapidly (over 7 percent per year for 1982 to 1989) that it is pulling up total U.S. passenger travel growth rates closer to Western European levels.

Much of the rapid growth in auto travel in Western Europe is due to high growth rates of vehicle ownership. In the 13 Northern and Western European nations,[32] per capita auto ownership increased 6.4 percent per year during the period 1965-75 and 3.2 percent per year during the 1975-87 period, whereas U.S. growth rates were 2.5 and 1.0 percent per year, respectively.[33]

Another trend that is important to the future U.S.-European transportation energy differential is the change in public transport (rail and bus, not counting school buses) usage. Between 1965 and

[28] Schipper and Meyers, op. cit., footnote 3.

[29] S.C. Davis and M.D. Morris, *Transportation Energy Data Book*, ed. 12, ORNL-6710 (Oak Ridge, TN: Oak Ridge National Laboratory, March 1992), table 1.7.

[30] L. Schipper et al., "Energy Use in Passenger Transport in OECD Countries: Changes Between 1970 and 1987," *Transportation, the International Journal*, April 1992.

[31] Ibid.

[32] Austria, Belgium, Denmark, Finland, France, West German}, Ireland, Italy, Netherlands, Norway, Spain, Sweden, and the United Kingdom.

[33] J Darmstadter and A. Jones, Resources for the Future, "Prospects for Reduced CO_2 Emissions in Automotive Transport," ENR90-15, August 1990.

1985, U.S. passenger use of public transport fell from 4.7 to 1.2 percent of total passenger-miles,[34] whereas the public transport share of a sample of European nations fell from 26.6 to 17 percent.[35] In terms of actual passenger-miles, U.S. public transport ridership was fairly stable:

- Rail transit[36] ridership has fluctuated by about 20 percent over the past two decades, but was virtually identical in both 1970 and 1989 at 12.3 and 12.5 billion passenger-miles, respectively.[37] It has been rising over the past few years.
- Both transit and intercity bus ridership has been stable, with a combined total passenger-miles of 43.4 billion in 1970 and 44.8 billion in 1987.[38]

On the other hand, although it has decreased in modal share, European mass transit increased its ridership substantially during the same period. According to Lave,[39] during the 1965-87 period, bus and trolley travel in the European OECD nations increased by about 60 percent, and rail travel increased by more than 20 percent (although automobile travel increased by more than 160 percent in the same period, thus greatly increasing its modal share).

Thus, European mass transit, which started from a much higher per capita passenger base than the United States, continues to increase its ridership whereas U.S. mass transit has essentially stagnated (see chapter 2); the European lead in per capita ridership is growing. Although European transit may appear to be converging with the U.S. situation from the perspective of *modal share,* it appears extremely unlikely to "bottom out" at a share similar to that in the United States. Even at some theoretical "travel saturation" point, if it is ever reached and if there is no change in relative U.S.-European transportation policies, European transit should still have substantially higher per capita passenger-mile ridership than U.S. transit. In addition, total per capita travel should be substantially lower, because of the much higher density of European cities (see discussion on effects of urban form in chapter 5) and the higher costs of travel. Thus, the Office of Technology Assessment concludes that future mass transit operations in Europe will likely maintain a much higher modal share than in the United States, although the gap between the two will shrink somewhat.

For intercity travel, although rail retains a much higher modal share in Western Europe than in the United States, air has gained at the expense of rail. For example, in 1975, rail and air had equal shares of Western Europe's intercity passenger market; in 1986, rail share was half that of air.[40] Continuing growth of air travel in Europe would bring intercity energy efficiencies closer to those in the United States. However, the new and expanding high-speed rail network in Europe could change the trend toward air.

U.S. AND EUROPEAN FREIGHT TRANSPORT ENERGY USE

Freight transport is heavily influenced by the nature of countries' economies (i.e., what they produce, and where they produce and consume it), as well as their size and physical geography. Because the United States and Western Europe are quite dissimilar in size, geography, and production

34 Ibid The estimated share of public transportation varies from source to source. Note, for example, that the estimated 1989 share of bus and rail, not counting school bus rides, is 2.2 percent in S.C. Davis and M.D. Morris, op.cit., footnote 29, table 2.12, versus the 1.2 percent cited in Darmstadter.

35 Ibid. The nations included are Belgium, Denmark, Finland, France, West Germany, Italy, Norway, and the United Kingdom.

36 Not including commuter and intercity rail.

37 Davis and Morris, op. cit., footnote 29, table 6.13.

38 Ibid., table 3.30.

39 Lave, op. cit., footnote 27.

40 U.S. Department of Transportation, op. cit., footnote 21.

characteristics, their freight systems have many differences *over and above those that result from different policy choices.*

The United States has more than five times the land area of six Western European nations (the former West German y, United Kingdom, France, Italy, Sweden, and Norway) and produces large quantities (relative to total production) of bulk commodities that must be shipped long distances, both to internal markets and to coastal ports for export. As a result, the volume of freight hauling (measured in ton-miles) in the United States, relative to the size of its economy, is three times that of Western Europe.[41] Note, however, that this result leaves out "foreign" shipments between individual European countries and thus ignores shipments of longer lengths (and some that are quite short) that would be included in U.S. data.

U.S. shipping of bulk commodities over long distances allows heavy use of highly efficient pipeline, rail, and ship modes, as opposed to Europe's heavy dependence on trucking. In 1989, rail accounted for 32 percent of total U.S. shipping, or 40 percent of all nonpipelined shipping; ships for 26 percent of total, and 32 percent of nonpipelined shipping; and trucks for only 23 percent of total, and 28 percent of nonpipelined shipping.[42] Pipeline shipping itself accounted for 19 percent of the total. In sharp contrast, in 1988, trucks accounted for 63 percent of nonpipelined shipping in Western Europe, rail only 18 percent, and ships 19 percent.[43] And trucks' domination of European freight shipments is increasing over time, up from 54 percent in 1973, with rail absorbing the loss of modal share.[44] This increase is due to a combination of adoption in Europe (and the United States) of Japanese-style "just-in-time" delivery of materials and components for manufacturing, greater production of high-value-added products that require fast and flexible delivery, and growth of the European road network as auto usage grows.

The combination of the large differences in modes and some differences in the energy intensity of each mode leaves the United States with a (nonpipeline) freight energy intensity about 40 percent lower than Europe's[45]---due primarily to the relatively high intensity on a Btu per ton-mile basis of truck shipment. Although European trucking is less energy intensive than U.S. trucking, by about 15 percent, trucking in general is several times more energy intensive than other freight modes. For example, in the United States, *not counting differences in types of cargo carried,* trucking is almost nine times more energy intensive than shipping, and about eight times more intensive than railroads.[46]

CONCLUSIONS

The United States uses three to four times the transportation energy per capita used by Western European nations, primarily because Europeans travel less, choose more efficient modes, and maintain higher efficiencies in each of the modes. Several factors likely influence European travel rates, which average half as much as U.S. travel rates on a per capita basis:

- lower private vehicle ownership (influenced by very high vehicle purchase prices because of taxes, fewer roads, and other factors, but also affected by the later start of Europe auto "explosion");
- high fuel costs:
- much greater urban density and centralization;
- a better mix of residential and housing development than U.S. cities; and

[41] Schipper and Meyers, op. cit., footnote 3.

[42] Davis and Morris, op. cit., footnote 29, table 2.14.

[43] Schipper and Meyers, op. cit., footnote 3.

[44] Ibid.

[45] Based on data in table 4.4 in Schipper and Meyers, op. cit., footnote 3.

[46] Davis and Morris, op. cit., footnote 29, table 2.14.

- demographic factors such as the percentage of women in the workplace, age distribution, and family mobility.

Europeans choose mass transit more consistently than people in the United States both because European cities tend to have good systems and because lack of parking, high fuel costs. high residential density, and a road system that is somewhat sparse by U.S. standards make transit look more attractive. Finally, European automobiles are more efficient than U.S. autos, primarily because they are smaller and have fewer luxury features (e.g., air conditioning, power windows, automatic transmission).

Travel and energy trends in Europe show some convergence with conditions in the United States, and some analysts claim that Europeans will eventually catch up to Americans in their travel and energy use. They contend that automobile dominance is so powerful a force that it will tend to overwhelm differences in fuel costs and other factors between the United States and Europe. Certainly, part of the U.S.-European difference in auto travel reflects the fact that Europeans started their period of rapid growth in auto ownership later than the United States. There are strong reasons to believe, however, that European and U.S. "equilibrium points ''-conditions when travel and energy use remain stable over time—are not identical, and that Europeans will continue to travel less and use less energy than Americans, although the difference between the two systems certainly will narrow. One reason for this belief is that arguments that Europe simply is at an earlier stage than the United States in growth in auto dominance ignore the differences in travel and energy that appear among alternative conditions of urban development *within the United States.* As long as European cities are more dense than U.S. cities, and less "auto-oriented" (e.g., have fewer miles of roadway per capita), they will continue to have fewer trips made and a higher reliance on public transportation. Another reason is that European growth in auto ownership and auto travel in general is a less impressive refutation of the importance of high travel costs in affecting energy use than it appears. Namely, this is because some of this growth is associated with European *subsidy* of auto travel in the form of large-scale use of company cars and tax deductions for commuting, and Europe starts with a much lower base so higher growth rates translate into much lower absolute values of growth. Part of the difference in travel volumes and energy use is due to differences in demographic factors; it is not clear to what extent these factors might converge or diverge in the future.

To a large extent, what this argument boils down to is whether the differences in U.S. and European travel patterns are due more to differences in policy or differences in history, geography, income (both now and over the past few decades), and demographics. If policy is the dominant determinant, then shifting U.S. policy toward European-style high gasoline prices, land use controls, etc., could move the United States toward European-style transportation patterns. However, an important caveat is that much of our transportation and land use infrastructure is in place and mature, so that moving toward European norms will be slow. If factors other than policy are more important, massive policy shifts may be somewhat futile, and European travel patterns may also move gradually in the U.S. direction. Questions such as this can sometimes be resolved by statistical analysis, investigating which variables are more significant determinants of the energy outcomes under investigation. Pucher, for example, claims that relative gasoline and transit price differences among Nations-which are primarily determined by policy—are better statistical determinants of auto ownership and urban auto-transit modal shares than are differences in income .[47]

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[47] J Pucher .. Capitalism Socialism, and Urban Transportation: Policies and Travel Behavior in the East and West, " *American Planning Association Journal*, summer 1990.

However, Pucher readily admits that the combination of data problems, multicollinearity between variables, and a limited sample size makes statistical analysis suspect in this case.[48] Further, his analysis does not examine a host of other potentially significant variables that deserve close examination. Nevertheless, he is convinced that the data are strong enough to show that differences in transportation prices are indeed a strong determinant of travel behavior.

To sum up, it appears that if the United States were to make a concerted effort to copy the European model *but without some of its auto-subsidizing features,* it would stand a good chance of substantially improving overall travel efficiency and reducing travel volume from levels that would otherwise be achieved. But the United States is unlikely to match current European levels of energy use.

European freight transportation, unlike personal travel, is not more efficient than its U.S. counterpart, although its volume in ton-miles in proportion to total economic activity is much lower than in the United States. The types of goods transported and the physical conditions are sufficiently different from those in the United States that there seem to be few lessons easily extracted from a comparison of the two systems.

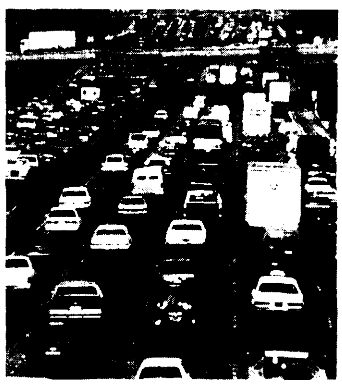
[48] Ibid.

Why Intervene? Externalities, Unpriced Inputs, Problems Needing Solutions 4

In a "pure" free market economy, decisions about resource use and conservation are left to market forces, with resource price being the signal that guides production and consumption decisions. In the transportation sector, for example, oil price is a critical determinant of the number and type of trips that consumers make and the efficiency of vehicles that automakers produce and consumers buy.

WHY GOVERNMENTS MIGHT WANT TO ACTIVELY PROMOTE ENERGY CONSERVATION IN TRANSPORTATION

However, a completely free market economy does not exist in transportation. Instead, governments throughout the world intervene—and intervene strongly—in consumer and manufacturer decisions about the use of oil in transportation. Generally, governments throughout the world have chosen to control provision of the basic infrastructure for transportation—roads, bridges, tunnels, airports, and so forth. Although some basic infrastructure is allowed to be private (some airports, occasional private toll roads, and some railroads), this is more the exception than the rule. In addition, governments intervene directly in transportation markets. For example, some governments have chosen to restrict the purchase of private automobiles, generally because they consider their countries too poor to afford to import gasoline. With the notable exception of the United States, most countries in the Organization for Economic Cooperation and Development (OECD)—which includes Western European nations, Japan, Australia, New Zealand, Canada, and the United States—have



chosen to levy high taxes on gasoline, raising its price to several times the "free market" price. [1] In the United States, government intervention in transportation oil use includes:

1. moderate fuel taxes, primarily to finance road construction and capital subsidies of transit systems;
2. fuel economy standards for automobiles;
3. disincentives to auto use (including parking restrictions, high-occupancy vehicle lanes, etc.) in State air quality implementation plans; and
4. operating subsidies for public transit.

U.S. government interventions are defended on a number of grounds. First and most widely accepted is the argument that some interventions (e.g., taxes on gasoline, which fund roadway construction) merely constitute user charges. Other grounds for existing and possibly increased intervention include:

1. correction for existing subsidies and pricing, and
2. external costs.

Correction for an Existing Network of Subsidies and Inefficient Pricing

Government intervention in the current market may be promoted as a correction to a web of past and ongoing subsidies and inefficient pricing mechanisms that have distorted the U.S. transportation market. Both public and private travel are subsidized. For example, on a percentage basis, U.S. operating subsidies for transit are among the highest in the developed nations at about 57 percent,[2] and capital subsidies for some systems are 100 percent. The United States also provides direct subsidies to private automobiles through payments for some roadway capital construction and maintenance from general funds, tax treatment of parking expenses that promotes free or low-cost parking for many workers and shoppers, and other means. In addition, some analysts claim that the Federal tax exemption for mortgage interest promotes low-density development patterns that favor private vehicles over public transit.[3] And U.S. tax policy creates cross-subsidies between different modes; for example, automobiles and light trucks pay a large share of the costs of highway repair through fuel taxes, whereas heavy trucks cause most of the damage.[4]

Aside from subsidies, inefficient pricing also distorts transportation decisions. For example, retail establishments commonly absorb the price of parking into their business costs, rather than charging customers--even though the customers eventually "pay" through higher prices.[5] Consequently, the apparent cost of transportation is reduced, encouraging more tripmaking than if travelers had to account for the full costs of their travel.

Externalities

Intervention may also be justified by the argument that transportation users are imposing costs on others that they do not consider in their travel decisions, and therefore travel more than is optimal for society. Theoretically, if these external costs ("ex-

[1] OECD tax policy on gasoline and vehicles appears to be primarily a matter of governments viewing these products as an excellent source of revenue for a broad range of societal functions, with a desire to restrain oil use and traffic congestion also a factor.

[2] American Public Transit Association, *1990 Transit Fact Book* (Washington, DC: September 1990).

[3] Note however, that the mortgage interest deduction applies to all residential properties, including rentals (lowering costs for owners, allowing lower rents). It "'promotes" lower density development (rely to the extent that by lowering costs of housing generally, it allows a greater choice of housing to the average citizen; the km-density option must be preferred for it to be promoted by greater choice.

[4] U.S. Congress, Congressional Budget Office, *Paying for Highways, Airways, and Waterways: How Can Users Be Charged?* (Washington, DC: May 1992).

[5] paradoxically, prices at large suburban stores with free parking may be lower than at urban stores that require no special parking facilities, because of the economies of scale and wide market reach of the suburban stores, As discussed in the following section, this is a benefit of auto-oriented travel not often considered in evaluating the social cost pricing of travel.

ternalities") could be added to the price of travel, travelers would make more economically efficient choices.

Some analysts define externalities as costs that are caused by a *class* of activity, such as all motor vehicle travel or all auto travel, and imposed on everybody else or on society as a whole. This is useful in examining the costs and benefits of motor vehicle or auto travel, but it is too narrow a definition if the concern is whether such travel is overused because drivers are not accounting for the costs they impose on others. For the latter concern, externalities also include costs that individual drivers impose on others and do not account for, *even if the others are also drivers.* **Thus,** drivers deciding to travel during peak periods may recognize clearly the congestion costs they incur, but they do not take account of the costs they impose on other drivers. Were they forced to, some might choose to drive lessor to drive at nonpeak periods. Some critical transportation externalities are:

1. *Environmental and safety impacts.* Federal requirements for emission controls on new automobiles, inspection and maintenance requirements on the entire fleet, and other pollution control measures have reduced the potential air pollution impacts of oil use in transportation. There remain, however, substantial environmental impacts whose costs are not included in the price of gasoline and diesel fuel, in vehicle prices, or elsewhere in the market price of transportation. These impacts stem from remaining air emissions, including emissions of carbon dioxide and other "greenhouse" gases, as well as from oil leaks and spills, sprawling patterns of development associated with auto dependence, and other sources. The existence of these externalities and others, such as vibration damage to roadside structures and safety risks to pedestrians, implies that oil consumers do not pay the full societal cost of their oil use and thus consume too much—potentially justifying governmental action to raise oil prices or otherwise reduce consumption.
2. *Energy and economic security.* A substantial portion of the world's oil production and export occurs in unstable areas and is managed (though with intermittent success) by a cartel-like organization, and the U.S. transportation system combines near-total dependence on oil with an inability to rapidly substitute alternative fuels. U.S. dependence on imports for half of its oil supply therefore creates a risk to the U.S. economy from supply disruptions. Current oil prices do not include the cost of U.S. military expenditures to protect the oil supply in politically unstable areas or other security costs. To the extent that energy security would improve (and security costs decrease) if U.S. oil imports declined, government measures to reduce consumption (and increase domestic supply) can be justified. However, an important caveat is that any effect of oil use reductions on energy security will be highly nonlinear--small reductions are unlikely to have any effect on energy security. As a result, charging a premium on oil prices for energy security effects will yield the desired decrease in security costs only if oil use is reduced enough to make a real difference in U.S. energy security and military strategy.

   Another societal effect of U.S. transportation dependence on petroleum-not a true security effect—is the extent to which this oil use affects world oil prices. A large drop in U.S. oil consumption would lower world oil prices, yielding a strong benefit to the U.S. economy and to individual consumers, but this effect is not considered in individual oil use decisions.
3. *Congestion.* As noted above, congestion costs can be considered an externality to the extent that drivers during congested periods impose costs on all other drivers sharing the road but do not account for these costs in their decisions to drive. Congestion also adds to environmental and energy security external costs, because stop-and-go driving both wastes fuel and generates more pollution per mile than free-flowing driving.

Society's beliefs about these problems and externalities. and policy makers' understanding of them, are critical to formulating and initiating successful policy intervention in the transportation system. Unless there is a strong consensus that the problems faced by the U.S. transportation system are truly critical and *must be* solved, and that externalities and inefficient pricing will prevent the market from solving them, the U.S. public is unlikely to support much additional intervention—because the transportation system is so crucial to quality of life, and because many proposed policy interventions seek significant changes (either in cost or in system structure) in an automobile-oriented system that is firmly entrenched in American society. Further, selecting optimal intervention mechanisms is unlikely unless policy makers understand the complex and varied interactions between different policy instruments and the full range of problems and externalities.

Policy makers must recognize also that the automobile may offer society external *benefits* that ought to be considered in any attempt to adjust the market. The economies of scale achieved by auto-oriented superstores, the social integration and mobility offered by widespread automobile availability, and the special mobility offered in rural areas all have societal benefits (and perhaps costs) as well as private benefits. Unfortunately, there is little understanding of such potential benefits of the private automobile; as a result, attempts to evaluate and redress problems with auto externalities have tended to focus exclusively on costs.

Finally, policy makers who wish to "correct" the amount of transportation demanded by travelers and shippers by accounting for inefficient pricing, subsidies, and externalities should remember that the other "goods" in consumers' market baskets—housing, food, entertainment, education, and so forth-do not operate in a free market environment either and, to differing degrees, share the transportation sector's pricing and subsidy distortions and also generate externalities. It maybe that *all* forms of consumption are somewhat underpriced in the U.S. economic system. Correcting transportation prices—presumably by raising them, if transportation's combination of external costs, subsidies, and inefficient pricing mechanisms outweighs any external benefits-should improve the efficiency of the allocation of transportation demand among competing modes and move *overall* transportation demand closer to an economically efficient level. Failure to correct pricing in the other sectors may, however, compromise some of the efficiency gains that would otherwise flow from correcting transport pricing.

This chapter describes and evaluates the various externalities, pricing inefficiencies, and embedded subsidies that distort the market for transportation energy. It also--qualitatively and tentatively-describes some potential benefits of today's auto-dominated system. Analysis of these issues is relatively new, data are scarce, and there is no consensus in the scientific community about the magnitude of transportation externalities and subsidies. In spite of this lack of consensus, however, the United States has spent many billions of dollars in subsidies to various transportation systems and is preparing to spend many additional billions of dollars during the next few decades, based on the supposition that free market forces will not by themselves create a satisfactory transportation system. It seems obvious that a better understanding of the externalities, inefficient pricing systems, and embedded subsidies would be valuable to the process of designing U.S. transportation policy.

AUTO BENEFITS

Critics of the U.S. automobile-dominated transportation system generally try to explain the strong preference for autos as a natural response to a system of skewed incentives—government subsidies of many auto costs, widespread provision of free parking (and government tax policy that rewards such provision), failure to incorporate "external" costs (air pollution, noise, etc.) into fuel prices, and land use policies and tax incentives that favor single-family home ownership and low-density development. Some cite additional causes such as the alleged auto and oil industry sabotage of public transportation systems and relentless advertising of the joys of auto ownership.

These forces no doubt do play an important role in the strong dominance of automobiles in the

U.S. transportation system, but they do not constitute the whole story. Many of the incentives probably should be viewed not only as causes of U.S. auto orientation but also as *results* of it: they are a natural response of voters and voter-responsive legislatures to the public's desire to accommodate an automobile-oriented system. More important, the European example. discussed in chapter 3, demonstrates that the combination of an incentive system that taxes gasoline very highly (enough to incorporate at least a significant portion of external costs), a set of land use policies that favor-s urban over suburban development, and the nurturing of an extensive system of public transportation still does not prevent the automobile from becoming the dominant transportation mode. Something else besides monetary and land use incentives appears to be propelling the automobile's dominance of personal travel. In other words, automobile use clearly is perceived by many as having real benefits *other than those created by artificial incentives* in comparison to the use of alternative modes or to the option of not traveling. These benefits are primarily "internal" or private benefits that accrue directly to drivers and passengers (e.g., low door-to-door travel time, comfort, flexibility) and "external"' benefits that accrue to society as a whole or groups other than drivers (e.g., more locational options for owners of small businesses).

Many proposals for reducing transport energy use and environmental damage involve reducing the automobile's share of personal travel or reducing the total volume of travel. Effective strategies cannot be devised, however, without understanding the nature of the attachment that Americans have to their cars. Such understanding might help identify ways to weaken the attachment in the future. Further, understanding the broader societal benefits of automobile use is essential for policymakers who wish to incorporate full social costs and benefits into transportation decisionmaking, perhaps by folding these costs and benefits into the market price of travel (through charges on gasoline, vehicles, vehicle-miles traveled, or other measures). This section discusses available research about U.S. attitudes toward automobiles and the private benefits associated with the automobile orientation of the U.S. transportation system. Unfortunately, our understanding of the external benefits of automobile use is extremely weak, because judgments about the value of the factors that generate these benefits—such as differences in urban structure and retail store location and character —are highly subjective in nature.

Attitudes Toward Automobiles

Research by J.D. Power and Associates can help illuminate the character of Americans attachment to their automobiles. In its survey research, Power has determined that U.S. car drivers can be broken down into six attitudinal groups (their shares of all drivers are in parentheses):

1. functionalists, who want sensible, fuel-efficient transportation (11.8 percent);
2. gearheads, who are car lovers and true enthusiasts (16.7 percent);
3. negatives, who view cars as necessary evils that they would love to do without (15.8 percent);
4. epicures, who want stylish, elegant automobiles (25.9 percent);
5. purists, who like cars but are very skeptical of all claims (4.2 percent); and
6. road haters, who are fearful of anything but normal driving (25.5 percent).[6]

An interesting conclusion from this list is that if functionalists are included, 53.1 percent of drivers (functionalists, negatives, and road haters) appear to be amenable to giving up their vehicles or greatly reducing their driving if a viable alternative is offered. Of course, the important question left unanswered by this survey is, what constitutes a viable alternative for those who are not attached to their autos. The perceived advantages of automobiles—such as virtually door-to-door service, generally shorter travel times, privacy. and com-

[6] J.D. Power and Associates, "Finding Customers May Be Just a Matter of Attitudes," *The Power Report*, newsletter, June 1991.

fort—present a formidable challenge to potential alternatives unless auto users begin to perceive important disadvantages in the use of their vehicles.

"Internal" or Private Benefits

Autos are the overwhelming choice of short-distance travelers in the United States because of a number of advantages over their transit competition. In particular, automobiles generally provide faster service than mass transit, primarily because they offer virtually door-to-door service, whereas transit requires multiple links. A typical auto-based trip involves a short access walk, no waiting to transfer to the auto, a relatively direct trip, and a short access walk at one's destination. In contrast, atypical transit-based trip may involve a significant walk or drive to reach a bus stop or train station; a wait of at least a few minutes; quite often, more than one transit trip interspersed with waiting periods (and the total transit phase may include two or more transit modes); and a walk or drive to reach the destination. When transfers are involved, the transit route is quite often more circuitous than an auto route (although a rapid rail route occasionally will be less circuitous than a highway route).

In addition to time savings, autos generally offer better protection from the elements, greater comfort (especially during peak periods when transit seats are at a premium), and greater protection from crime (although certainly not better overall safety). Autos also offer freight-carrying capacity, which allows consolidation of shopping trips that would be difficult or impossible by mass transit as well as access to stores that, by combining many services into one location, allow great time savings (especially for the frequent chore of food shopping). Further, automobiles offer travel flexibility (in terms of choice of time of day and destination) that would be extremely difficult to obtain in a transit-oriented system, thus expanding the universe of social, cultural, and recreational opportunities.

Automobiles also offer longer-distance family travel, especially for larger families, that is less expensive than public transportation and far more flexible in choice of destination, time of travel, and ability to change routes and destinations.

An automobile-oriented transportation system allows low-density residential development patterns that are often criticized as wasteful of land, inefficient in their use of energy, and sterile in their access to cultural opportunities and their segregation by economic class. However, the residents of these developments, who must be heavy users of the automobile system, may reap substantial benefits from these patterns. Cul-de-sac development may guarantee inaccessibility to efficient transit services and inefficient road use when measured simply as the length of road needed to provide access to services, but it offers a low-speed and lightly traveled environment in the immediate area. Moreover, although separation of commercial and residential development demands longer trips and the use of automobiles, whereas mixed development could allow walking and bicycling as substitutes, it also avoids the traffic concentration and aesthetic intrusion that commercial development may make on residential areas. Although there may be a heavy price to pay for these amenities, policy makers cannot ignore the reality that they are highly valued.

Benefits to Society

Automobile use has created many problems for modern society, and these problems form the core subject of attempts to understand and measure auto "externalities." It is unlikely, however, that the type of mobility the automobile offers, and the land use patterns that heavy reliance on autos tends to engender, yield only costs to society, Although the American "love affair" with the auto is now generally the subject of derision, use of the

[7] Food shopping still consumes a great deal of time in some industrialized countries where the retail network consists mainly of small specialty shops.

automobile offers benefits to society that must be considered in any “full cost accounting” that seeks (o fold the external effects of a technology (environmental, social, etc.) into its market costs. The brief discussion that follows is not meant to extol the virtues of the automobile, but instead to suggest that as a transportation tool, the automobile "ain’t all bad. ”

Many of the external costs of automobiles, although sometimes hard to measure quantitatively, are quite easy to describe and understand qualitatively—air pollution and its health, ecosystem, and material impacts; noise pollution; land use preemption; and so forth. Benefits tend to be more subjective. For example, the ready availability of automobiles, and of an extensive road and parking network, allows remarkable travel flexibility at any time of day or night. Perhaps a transit-oriented system could approach this flexibility by combining fixed route transit with demand-based service available in nonpeak hours, but this has not been demonstrated. Such flexibility allows a degree of spontaneity in tripmaking that is a strong private benefit but must also be of value to society. Further, increased access to a range of cultural, recreational, and educational opportunities represents both a private (as noted above) and a public benefit: the social and economic integration promoted by this access.

The retail shopping and service base that develops in an automobile-oriented system is different from what would develop in a transit-oriented one. So-called superstores that attain considerable economic benefits from their large scale—and pass these benefits on to customers-cannot exist unless they can draw from a wide geographic area.[8] Further, these stores depend on shoppers who can make a shopping trip a major purchasing expedition, which would be impractical without private “freight transport” home, especially for larger items, Such superstores would be much less feasible with a transit-oriented transportation system. Their economic efficiency benefits society, although the existence of these stores may influence factors other than efficiency, such as the general availability of a diversity of products and services, that also bear on their net value to society.

The move to an automobile-dominated transportation system has been synonymous with a societal movement away from the home (and family) as the focus of social interaction. The extent to which the auto has been the major cause, partial contributor/enabler, or innocent bystander to this movement is unclear, but it seems likely to have played a significant role. It is normal in our society, for example, for both children and adults to use evenings for education, exercise at clubs, and numerous other activities outside the home that would be more difficult without auto mobility, even with the higher density of a transit-based area (given the reality of urban safety, how many children would be allowed to visit friends at night if mass transit, walking, and a wait at a bus stop were necessary?). Whether the movement from the home as center of social interaction should be viewed as a cost or benefit to society is a philosophical question, but it is clear that some will consider it a positive contribution to personal growth and social integration and well-being, whereas others will feel it has had a strong negative influence on family values.

Automobile transportation provides special benefits in rural areas, where mass transit services are impractical. It allows social interaction that would be impossible without private transport and (coupled with truck freight services) enables the employment in light industry that has allowed large numbers of Americans to live outside cities, despite the vast decline in agricultural employment.

Note that the major differences in mobility between auto- and transit-dominated systems undoubtedly occur during off-peak times, when transit cannot maintain high-frequency service *and*

[8] Although higher residential densities associated with a transit-oriented area allow more customers to be available to a store within a set radius or area, this is unlikely to compensate for the market afforded by an auto-oriented suburban location.

the time advantage of autos becomes particularly large. Aside from the expansion of nighttime non-work activities engendered by the temporal flexibility of an auto-oriented system, flexibility in work schedules has been promoted: second and third shifts may be more practical in such a system. This has both private and social benefits: private in terms of obtaining employment that better fits people's schedules, and public in terms of increased economic productivity. It also has costs: not all employees take second- or third-shift jobs voluntarily, and the ability to schedule multiple shifts might alter the balance of jobs away from daytime and toward nighttime in ways that could be efficient for employers but destructive for private and societal values.

Critics of the automobile tend to portray the low-density land use patterns that have accompanied automobile growth as uniformly negative in terms of their public impacts: in other words, they argue that suburban or exurban development occurs only because it yields some direct benefits to those who live there, and that this type of land use exacts high costs from society in general. The idea that these land uses are a legitimate alternative, that society may benefit from the availability of suburbs as one option available among choices of lifestyle, is rejected. Instead, suburban development is regarded by its critics as a despoiler of urban life and a primary cause of the inner-city decay and loss of tax base affecting so many U.S. cities.

There obviously is much that is subjective in such an evaluation. Although low-density, suburban development clearly has important negative environmental and social impacts, it is worth asking whether limiting future development to higher densities will really yield large benefits. The answer undoubtedly lies in the extent to which suburban development can be tied to the problems of today's cities. If this development is a cause of current urban problems, and if a radical shift to higher density development and strict limits on suburban growth would clearly improve central-city life, then perhaps the critics are right and suburbs offer no benefits to society other than those reaped by their inhabitants. If the current problems of the cities have other causes, however—if suburban development is not really the proximate cause—then the availability of a low-density option increases the diversity of choice and provides benefits to society, which then must be balanced against the costs.[9]

INEFFICIENT PRICING: SUBSIDIES, EXTERNALITIES, HIDDEN COSTS

How does one go about evaluating the magnitude of subsidies, hidden costs, and external costs associated with transportation? This section presents a framework for examining these costs and a series of estimates for most categories of costs.

Introduction and Viewpoint

A number of studies have attempted to estimate the "total costs" or "full social costs" of motor vehicle travel or of transportation in general, in order to explore the extent to which drivers may fail to pay such costs and, in response, "consume" too much travel. Most of these studies conclude that motor vehicle travel is substantially underpriced in the sense that drivers are paying considerably less than the total costs of their driving:

> Commuters going to work in major central business districts in the United States in their own motor vehicles directly pay for only about 25 percent of the total cost of their transport. The other 75 percent is typically borne by their employers (e.g., in providing "free" parking), by other users (in increased congestion, reduced safety, etc.), by fellow workers or residents (in air or noise 'pollution," etc.) and by governments (passed on to the taxpayers of one genera-

[9] An extreme negative view of suburban development is not, of course, the only point-of-view expressed by advocates of denser land uses. Many would instead claim that suburban sprawl is, in many areas, the *only* option open to new home purchasers rather than an option that increases housing diversity. In regions where this may be the case, "densification" of land use would add to options by adding a middle ground of medium density development, as well as strengthening the urban core by infill development.

tion or another in ways that usually bear no relationship to auto use).[10]

However, these studies use a variety of accounting systems to identify unpaid costs, and it is difficult to compare their results.

The Office of Technology Assessment (OTA) asked Mark DeLuchi of the Institute of Transportation Studies, University of California at Davis, to evaluate the social costs of motor vehicle use *and how they are paid,* focusing particularly on those costs that have market prices or, if unpriced (e.g., free parking at shopping malls), that can be priced by comparing them to similar priced costs.[11] Although part of the reason for the automobile's dominance of U.S. transportation results from past subsidies, this study focuses on 1990 costs, since new policy initiatives must take the current transportation infrastructure as a starting point.

Evaluating the full social costs of motor vehicle travel is a relatively new and contentious field of analysis. DeLuchi's work, which follows and builds on earlier studies, will not be the last word on this issue. Further, several of the cost areas, for example, potential damages from global warming and national security costs, remain highly uncertain. Thus, OTA presents DeLuchi's work as a valuable contribution to the field, but does not endorse the specific values in each cost category. On the other hand, we believe the work to be sufficiently robust to endorse DeLuchi conclusion that a significant fraction of social costs is not efficiently paid by motor vehicle users. Inclusion of these costs into motor vehicle charges, and restructuring of payments so that those who incur the costs take them fully into account in their travel decisions, would likely reduce the total amount of motor vehicle travel and shift some of it to other times or locations.

There are, of course, other, competing evaluations of both the total social costs and specific external costs of transportation. Some of these evaluations, e.g., those of the Congressional Research Service, are discussed briefly in the other sections of this chapter. A variety of studies are discussed by Hanson.[12] OTA will soon publish a study reviewing different estimates of the environmental externalities of electricity generation.

The definition of a particular cost of driving as paid or unpaid, or as efficiently or inefficiently priced, has much to do with the *purpose* of the accounting. Analysts concerned primarily with ensuring that automobile users pay for the costs of auto use, to avoid subsidizing automobiles, focus their analysis on whether auto users *as a class* pay their full costs. For example, although congestion causes some societal costs (more pollution, lost productivity), its primary cost is lost time, and this is borne primarily by the drivers and passengers on congested roads (although it also impacts freight costs). Thus, in terms of equity among such alternative travel modes as auto, rail, and air, road congestion is largely an internal cost of auto travel. In contrast, when police services on highways are paid out of a community's general funds while the rail transit system pays for transit police and charges a higher fare as a result, auto users receive an inequitable subsidy.[13]

In terms of economic efficiency, to ensure that a good is not under-or overconsumed, it is more important to worry about an individual decisionmaker (i.e., potential purchaser), not a class; *what matters is whether or not individual decisionmakers recognize and pay an appropriate price for what*

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[10] E.W. Johnson, "Taming the Car and Its User: Should We Do Both?" *Aspen Quarterly,* autumn 1992, based on a presentation by J. Meyer, Harvard University.

[11] DeLuchi's report will be available separately, but the key results are summarized here.

[12] M.E. Hanson, "Results of Literature Survey and Summary of Findings. The Nature and Magnitude of Social Costs of Urban Roadway Use," paper prepared for U.S. Department of Transportation, Federal Highway Administration, 1992.

[13] To complicate this issue further, however, rail transit systems obtain much of their revenues from public funds.

they receive. In the case of congestion, each new driver who enters a busy road is delayed and thus pays a price in lost time, but also inflicts costs on drivers already on the road, costs that the new driver does not bear.[14] That new driver is paying *average* costs rather than marginal costs. This is very similar to new customers on an intensively used electrical grid that must add expensive new capacity to accommodate them; although the new capacity may be more expensive than the older part of the system, thus raising costs for all users, new users make their decision to use electricity by accounting only for a fraction of the additional costs that they create.[15] In other words, the "appropriate price" from an efficiency standpoint is *marginal* cost, not average cost.

Aside from paying the wrong price (e.g., equal to average rather than marginal costs),[16] auto users may not recognize the price they are paying because it is hidden. Free parking at shopping malls is not really "free" because its costs are included in the price of goods at the mall. Thus, drivers may pay much of the cost of this parking, but they are unlikely to take account of it in deciding whether to visit the mall. Free parking for shopping is also an example of a societal subsidy of automobile travel, because everybody who shops at the malls bears part of the parking costs even if they walk or use transit.

Also, individual auto users may not be paying the right price because they create nonmarket costs that they do not fully bear: air pollution, global warming, loss of energy security through their oil use, pain and suffering inflicted on others from accidents, and congestion delay costs. These are the so-called externalities--nonmonetary damages inflicted by auto users on others and not considered in driving decisions.

In summary, to ensure efficient use, individual drivers must pay and account for the marginal costs to society that they create when they choose to drive. Problems arise when others—including other drivers—pay these costs; when drivers pay the costs but not in a way that they recognize and account for in their decisionmaking; when the price is not the marginal price, so drivers do not realize the full impact of their decision; or when those who pay the costs cannot choose the amount of good or service that they pay for and consume.

Table 4-1 provides a classification of the different costs of motor vehicle use, according to basic cost categories, whether (or not) they are monetary costs, whether they are paid for by those who cause them, and so forth. In essence, the classification scheme focuses on whether, or to what extent, an item is efficiently priced at the marginal social cost of supply. The sum of all of the costs in table 4-1 represents the social cost, or total resource (welfare) cost, of motor vehicle use. Another way to put this is that the social cost of motor vehicle use is *what would not have been incurred had there been no motor vehicle use.* Only the costs in the first column of the table are efficiently priced; all others are priced either inefficiently, indirectly, or not at all.

The logic behind this classification scheme, or behind any other, does not work well with every type of cost, and users of this analysis will argue with the placement of some costs, For example, there is room for argument about the extent to which motor vehicle users actually account for some costs (e.g., their probability of getting into an accident and being injured or killed) in their travel decisions. Also, because some types of costs have components that are paid by users and other components paid by nonusers (or efficient] y

[14] In this sense traffic congestion is an externality, at least from the standpoint of the individual driver,

[15] This problem has become less common than it was, because pollution controls have raised the cost of electricity from many older powerplants. and new capacity using natural gas is relatively inexpensive.

[16] in the case of congestion costs. Prices of other travel goods and services may be wrong because they are poorly related to marginal costs in some other manner (e. g., the price may be subsidized).

TABLE 4-1: Classification of the Costs of Motor Vehicle (MV) Use

Efficiently allocated	Not efficiently allocated				Efficiently allocated
Items accounted for by users in MV ownership and use decisions	Items *not* accounted for by users in MV ownership and use decisions				Items accounted for by users in MV ownership and use decisions
Efficiently priced items each user and no nonuser is charged, and price probably equals marginal cost	Inefficiently priced items each user and no nonuser is charged but price probably does not equal marginal cost	Implicitly, inefficiently or Indirectly priced items nonusers as well as users pay, and the MV cost is buried in tax or price of other commodities		Unpriced items	Price is r70t relevant, because there is no transaction (but marginal value = marginal cost)
■ Those who pay for these items choose the amount that they pay for and consume ■ If you do not own and use MVs, you do not pay these MV costs ■ The party responsible for the cost always pays all of it		■ Those who pay for these items cannot (or can but do not) choose the amount of the item that they pay for and consume ● Even if you don t own and use MVs, you still might pay these costs ■ The party responsible for the cost often pays little or none of It			● Accounted for and borne entirely by MV users
Monetary costs				**Nonmonetary costs[a]**	
1 *Motor vehicles, fuel, parts, and service, excluding taxes and fees* Usually included in estimates of the cost of owning and operating MVs ■ New and used MVs (excluding sales taxes and charges on producers) ■ Interest payments for MVs ■ Fuel and oil (excluding taxes and fees) ■ Maintenance, repair, washing, renting storage, towing ■ Parts, tires, tubes, accessories ■ Automobile Insurance ● Parking away from home (excluding parking tax) Usually not included ■ Vehicle safety and smog inspection[c] ■ Accident costs paid for by responsible party but not covered by auto insurance lost productivity,[d] medical, legal, property damage[e]	2 *Public Infrastructure and services covered by the following use charges (see column 4 for list of costs)* Usually Included m estimates of the cost of owning and operating MVs ■ FHWA-classified road-user taxes and fees fuel taxes, road tolls[h] commercial road-user fees vehicle registration fees, driver's license fees (excludes fees dedicated for nonhighway purposes) ■ Portlons of fuel tax dedicated to nonhighway purposes ■ Investment income from the Highway Trust Fund ■ Charges levied on producers and included in selling price of goods (e g , for vehicle certification tests, Superfund cleanup, and oilspill cleanup) ■ Sales taxes[i]	3 *"Hidden" private-sector costs* Unpriced parking[j] Local roads provided or paid for by the private sector, and Included in the price of structures or services ■ Accident costs[k] paid for by those not responsible and not covered by any auto Insurance lost productivity,[d] medical, legal, property damage[e] ● Monopsony price effects of using 011	4 *Public infrastructure and services, not fully covered by charges m co/-umns 1 or 2* ■ Highway construction, maintenance administration ■ Pollee protection ■ Fire protection ■ Judicial and legal services ■ Correctional system ■ Environmental regulation and protection ■ Energy and technology research and development ● Military defense of oil supplies ■ Strategic Petroleum Reserve ● Payment of costs of accidents lost productivity medical, legal, property damage[e] ● Other social services ■ Free or underpriced municipal parking ■ Differential tax treatment of energy producers (tax subsidies or penalties)	5 *"Classical" externalities* ● Air pollution ■ Global warming ● Water pollution ■ Solid waste ■ Noise and vibration inflicted on others ■ Social and aesthetic impacts ■ 011-price shocks ■ Traffic congestion inflicted on others ● Pain and suffering and deaths inflicted on others from accidents[m]	6 *Personal nonmarket costs of using MVs[b]* ■ Travel time (excluding delay Imposed by others, column 5) ■ Personal time spent working on vehicles and garages ■ Privacy, comfort, convenience, safety while driving (combine with travel time to make general attribute activities foregone while driving) ■ Pam and suffering and death from accidents (excluding that inflicted by others, column 5) ■ Noise and vibration (excluding that inflicted by others, column 5)

• Home garages and other residential parking.[f,g]	Usually not included: • Air-quality fees (paid with registration). • In-1ieu **property taxes (paid with registration)** • **Traffic fines.** • **Parking fines,** • **Parking taxes,**				

a Note that an externality is not defined as any nonmonetary (or nonmarket) damage, rather, an externality is one kind of nonmonetarydamage All nonmonetarydamages can be classified into three mutually exclusive and exhaustive categories relevant to policymaking First are externalities; those damages (air pollution, global warming, pain and suffering, etc) Inflicted by motor vehicle user A on party B and not accounted for byA These are the "classical" externalities of this table, and as indicated in table 5-9 the prescription for them is a dynamic Pigouvian tax on the perpetrator with no direct compensation of the victim The second category is those damages inflicted by motor vehicle user A on party B but accounted for by A as marginal cost of motor vehicle use These are appropriately internalized nonmoney damages, when an externally is properly taxed, it becomes this second type of damage (internalized) If there were any such internalized (formerly nonmonetized) damages, theywould be classified as user payments in columns 1 or2. However, the United States does not levy any "externality adders" or internalization taxes for nonmonetary damages of motor vehicle use (Note that in adding up the social cost, one would count either the internalization charge or the actual damage estimate-they represent the same thing-not both.). The third category is self -inflicted damages or costs by a motor vehicle user, for example, the nsk of hurting oneself in an accident of one's own causing These are the "personal" nonmonetized costs of column 6

b Personal costs—travel time, comfort, safety, and privacy while driving (activities foregone while driving), the nsk of pain and suffering and death, and pollution and noise (excluding those costs imposed by others) are included because they are considered "costs" in lay terms However, if one categorized these items in strict economic terms, with respect to supply and demand curves, then they most naturally are demand-side (use-value) rather than supply-side items, and therefore economic "benefits" rather than costs In any event, the notion of price, or efficient market allocation of resources, is not relevant, because these items are not exchanged, or traded in markets, they are "Imposed" by users directly on themselves The only economically relevant concern is that each user accurately assess these self-generated costs to himself Note that these same sorts of costs imposed on others do Involve interactions; they are externalities (if unaccounted for) and theoretically should be priced or taxed Externalities are included in column 5

c Includes only those payments made for inspections at privately run stations, not payments for government-administered programs, because the latter presumably are included in the Federal Highway Administration's reported receipts from imposts on highway users (column 2) Privately run inspection programs presumably charge marginal costs, whereas government programs may not

d Lost productivity can be disaggregated into the portion that the individual keeps (net wages) and the portion that the government keeps as income taxes. This seems like a conceptually unnecessary complication: the loss is the total productivity of the individual; the disposition of the income is (usually assumed to be) Irrelevant in a cost-benefit analysis

e Excludes the cost of repairing and replacing vehicles or roads because all of those costs, whether caused by accidents or not, are classified as expenditures on vehicles (column 1) or highways (columns 2 and 4) It therefore includes only the relatively small amount of damage to other property, such as buildings It is worth noting, though, that if in deciding whether to buy or use motor vehicles, people consistently underestimate their probable out-of-pocket payments (those not covered by Insurance) for repairing or replacing accident damage to their own or others' vehicles, then they will use motor vehicles more than is socially efficient (i e , more than they would if they possessed and acted on the right reformation)

f It is questionable whether these costs really are accounted for fully by motor vehicle users when they make motor vehicle ownership and use decisions

g Includes interest payments on the garage portion of the total cost

h Some road tolls, perhaps by coincidence, may be priced efficiently Similarly, some frees and producer charges may be efficient (set equal to marginal cost), probably by coincidence

i All but a small fraction of this probably should not be counted as a payment by motor vehicle users for motor vehicle use

j The text discusses the important differences between garages and unpnced parking

k Costs that the affected party (who is not at fault) pays out of pocket or through private Insurance other than auto Insurance Costs covered by the automobile insurance of the affected party (who is not at fault) are included under "automobile Insurance" in column 1 (All auto Insurance costs are in column 1, even though some of the costs covered by auto Insurance are attributable to accidents caused by others, because the relevant cost is not the cost of the items or services covered by Insurance but the cost of the Insurance policy itself, and the cost of the Insurance policy is borne by and attributable to the person who buys it) Costs paid by the responsible party also are included in column 1, under either "automobile Insurance" or "accident costs " Costs paid by the government are included in column 4 of this table

l A pecuniary externality, a transfer between consumers and producers, and hence not normally a true economic cost or benefit But if a particular class of producers (e g , foreign 011 producers) is excluded from the welfare analysis, then consumers' loss is not balanced by producers and is thus a real net welfare loss within the scope of the analysis

m Includes pain and suffering inflicted on pedestrians, cyclists, and other nonusers of motor vehicles, as well as other users of motor vehicles This also should Include the cost of the threat of accidents to other drivers, pedestrians, and cyclists, but no data are available on this cost

SOURCE M A DeLuchi, University of California-Davis, 1994 allocated components and inefficiently allocated components), these costs must be divided in unusual ways to fit this classification scheme (e.g., accident costs appear in three separate places according to who is responsible for the accident and whether the costs are monetary or nonmonetary). However, there is substantial value in pursuing this classification scheme, rather than simply adding up costs according to their physical nature. because the policy prescriptions for dealing with each category are different. Thus, knowing the magnitude of the costs in each class is necessary to inform policy choices. Policy options for dealing with the various categories of inefficiently priced or unaccounted-for costs are discussed in chapter 5.

An issue that is not dealt with explicitly in the classification scheme outlined in table 4-l is that of time: to what extent should costs be classified as "fixed" or "variable," and what should the relationship be between policy measures and the time horizon of the costs? This issue is dealt with in slightly more detail at the end of this section, but ignoring the time horizon implies that one is viewing travel behavior over the long term, during which changes in vehicle costs can have as signifi - cant a role as changes in fuel cost; and trying to separate short-term (variable) from long-term (fixed) costs implies that one is viewing travel behavior in the short term and attempting to change behavior by altering the traveler's perception of costs faced on a daily or weekly basis.

Two last but critical points: first, the estimate of social cost derived here is only an average cost. This much would be saved if motor vehicle use were eliminated, and thus an average value of the reduction in vehicle-miles traveled (vmt) can be calculated by dividing social cost by total vmt. We cannot be sure, however, that the marginal cost of a small reduction (in dollars per mile) would be the same as the average cost, and for some cost components, we know it is not. Since viable policies seek only to reduce motor vehicle use by a significant but small fraction-a 10-percent reduction would be optimistic--the average rate calculated from this social cost estimation may not yield the correct estimate for such a small reduction. On the other hand, in at least some scenarios of relatively large changes in motor vehicle use, the average rate of social cost reduction might be a serviceable approximation of the actual marginal rate.

Second, although OTA has substantial confidence in the estimates of monetary costs, the estimates of the cost of externalities warrant less confidence. In some areas (e.g., the cost of global warming impacts associated with a unit volume of carbon dioxide emissions), extremely large uncertainties exist, and these estimates should be considered tentative. In other areas (e. g., the cost of air pollution damages), estimated values are firmer, although they are not without controversy.

Detailed Results

Monetary Payments for Motor Vehicles, Fuel, and Other Items

The largest part of the social cost of motor vehicle travel is the private cost of new and used cars and trucks, gasoline and oil, maintenance costs, and the variety of other costs ('parking, insurance, inspection costs, etc.) that maintains the rolling stock of motor vehicles, Wages of freight drivers constitute a special category of costs that must be included to incorporate highway freight transportation properly into the accounting system. Table 4-2 lists the private payments for these items, which account for more than $800 billion of the total social cost of motor vehicle travel. All of the items listed in the table are bought and sold in markets that function more or less properly. Consumers face and account for the price of each of these items, and the price (presumably) equals the marginal supply cost. Thus, the items in this category are produced and consumed efficiently. An interesting point is that the Federal gasoline tax used to construct highways, as well as road tolls and vehicle registration fees, are not included here because the taxes, tolls, and fees are only loosely tied to the infrastructure and service costs they are designed to pay for.

TABLE 4-2: National Payments for Motor Vehicles, Fuel, Parts, Service and Wages of Freight Drivers, 1990 (billions)

Item	Low cost	High cost	Weight on cost
Passenger vehicles			
New and used cars and trucks (including embedded fees levied on producers; these are deducted en masse below)	$2217	$2217	1
Interest on debt for new and used cars and trucks	437	437	
Gasoline and 011 (including road-user taxes and fees, these are deducted en masse below)	1240	1240	1
Maintenance, repair, cleaning, storage, renting, towing, leasing	876	876	1
Parts, tires, tubes, accessories	257	257	1
Automobile Insurance	207	207	1
Parking (excluding taxes)	6 7	6 7	1
Vehicle Inspection fees	0 8	0 8	1
Accident costs not covered by insurance	157	180	1
Garages and residential parking, including interest on loans	100	201	1
Losses from parking lot robberies and larceny or theft from cars[b]	01	0 2	1
Subtotal	5567	5693	
Highway freight transportation			
ICC-authorized intercity trucks	7 5 4	7 5 4	1
Non-ICC intercity trucks	8 5 2	8 5 2	1
Local trucks	11 8	111 8	1
Intercity buses	0 2	0 2	1
Government-owned freight trucks	5 5	5 5	1
Less wages of drivers (counted as time cost, table **4-7)**[c]	1777	1777	-1
Subtotal	$1004	$1004	
Deduction for user taxes and fees counted separately in this analysis	(39 2)	(39 2)	1
Total	**$617.9**	**$630.5**	

[a] **The low end is based on** *4-percent* discount rate and the high end on 2 5-percent discount rate

[b] The estimate accounts for the likelihood that if there were no motor vehicle use, some larceny thefts from motor vehicles and some parking lot robberies would become larceny theft of other things and robberies in other places The estimate does not Include the value of theft losses of motor vehicles, parts, and accessories, because it is assumed theft victims buy replacements for these items, and replacement purchases are Included on total national payments for vehicles, parts, and accessories, estimated elsewhere in this table The estimate also does not include payments for legal assistance, security services, or security devices (to the extent that they are costs of motor vehicle use and not already included in other lines in this table) because these costs proved too difficult to estimate

[c] The wage cost of **drivers** is **a** money **cost, and** technically belongs in this table It is included in table 4 7 to give a complete picture of the cost of all travel time

KEY ICC = Interstate Commerce Commission.

SOURCE M A. DeLuchi, University of California-Davis, *1994,* based on Federal Highway Administration data

Monetary Payments by Users for Highways and Services

Highway users pay for a large share of highway infrastructure and services through a variety of user charges. The primary source of payments is the Federal gasoline tax, which is now 18.4 cents per gallon, coupled with license fees and toll charges. State sales taxes represent an accounting difficulty: should these taxes, amounting to $14.3 billion, be counted as user charges (and included here in the total of motor vehicle user payments), or should only the small portion of sales taxes (about 3 percent) spent on highways be counted? The latter was chosen because sales taxes are collected on virtually all goods, not just gasoline, Table 4-3 displays the motor vehicle user payments counted toward highway infrastructure and services, about $70 billion in 1990.

As noted above, these fees are not marginal cost prices, and most of them do not fully cover costs. For example, the Federal excise tax on gasoline is a charge per gallon of gasoline consumed, and it is

TABLE 4–3: Payments by Motor Vehicle Users for Highway Infrastructure and Services, 1990 (billions)

Item	Low cost	High cost	Weight on cost
FHWA tax, license and toll payments by highway users	$443	**$443**	1
Portions of the tax dedicated to nonhighway purposes (Including collection expenses)	113	**113**	1
Other Imposts used for highways	3 0	3 0	01
Investment income from Highway Trust Fund	1 0	1 0	1
Extra highway user payments in 1991, over 1990a	7 4	7 4	1
Fees levied on producers	0 2	0 2	1
Sales taxes	143	143	003
Air quality and in Iieu fees paid with vehicle registration (and not already counted)	0 6	0 6	1
Traffic fines	3.0	3 0	1
Parking fines	1 0	3 0	1
Parking taxes	0 7	0 8	1
Total	$70.3	$72.3	

a In December 1990, the federal gasoline tax was raised 5 cents/gallon, to 14 1 cents/gallon, of which 25 cents goes to reduce the Federal deficit (Federal Highway Administration, *Highway Statistics 1991, 1992)* There must also have been other Increases in user payments in 19!31 compared with 1990, because the extra revenue from the Federal tax does not account completely for all of the extra user payments in 1991 compared with 1990 As a result of these Increases, total user payments for transportation were about $7 billion higher in 1991 than in 1990 Gwen that this increase in payments has already occurred, it would be misleading if the baseline estimate did not account for it Consequently, the 1990 estimates have been adjusted so that the difference between cost and revenues is the same as in 1991, even though the baseline is nominally 1990 Note that the $7- billion difference between 1990 and 1991 is due mostly to differences in the rate of payment or expenditure per unit of vehicle use or ownership (the point of interest), rather than differences in total vehicle ownership or use In 1991 compared with 1990, total motor vehicle registrations were O 2 percent lower total vehicle miles traveled was 1 3 percent and total fuel gallonage taxed at prevailing rates was 1 6 percent lower (Federal Highway Administration, *Highway Statistics 7991, 7992)* These differences are small compared with the roughly 12 percent Increase in user payments from 1990 to 1991

KEY FHWA Federal Highway Administration

SOURCE M A DeLuchi, University of California Davis, 1994, on Federal Highway Administration data

designed to pay for highway infrastructure and maintenance. However, the amount of highway that a driver "consumes" depends on the type of highway (a freeway is orders of magnitude more costly per mile than a dirt road), the amount and kind of driving, the weight and other characteristics of a vehicle (a very heavy truck causes much more road damage, and necessitates a much heavier road, than does an auto), and other factors; the amount of gasoline consumed bears some relationship to these factors, but the relationship is a weak one.

Hidden Private Expenditures *for Motor Vehicles*

Table 4-4 displays those costs paid by the private sector for motor vehicle use that are ● *hidden" (not counted by motor vehicle users in their decisions about traveling). The largest expenditure is for parking: very few motorists pay for parking (according to the National Personal Transportation Survey, only about 1 to 2 percent of travelers during a typical travel day), but providers must still pay to build and maintain parking facilities. Estimates in the table represent both the "value" of parking, estimated by assuming that free parking would be charged at prevailing commercial rates, and the cost of parking, estimated by computing the likely actual expenditures needed to build, maintain, and operate parking facilities. Note that if all parking charged commercial rates, total parking demand would decline dramatically, and so might prices, as people carpooled, reduced tripmaking, and switched to other modes of transport to avoid charges. The "cost" estimate is considered the more accurate gauge of the social cost of free parking.

Another important hidden expenditure is the fraction of the monetary accident costs (property losses, medical costs, lost wages, etc.) of motor

TABLE 4–4: "Hidden" Private Sector Expenditures Related to Motor Vehicle Use, 1990 (billions)

Item	Low cost	High cost	Weight on cost
Value of free off street nonresidential parking at work (excluding parking taxes)	$3710	$6550	0
Value of free off street nonresidential parking for all other trips (excluding parking taxes)	6430	15230	0
Annual cost of off street nonresidential parking (excluding taxes), less payments for parking	4350	18520	1
Onsite roads provided by developers	500	1500	1
Monetary accident costs to those not responsible (and not covered by auto insurance)[b]	3260	3450	1
Monopsony cost of Importing oil	752	2162	1
Total	**$88.60**	**$256.30**	

[a] Roads built within the boundaries of the development, as opposed to roads outside the boundary (offsite roads, see table 4 5)
[b] The low end is based on a 4 percent discount rate estimate, and the high end on a 25 Percent discount rate

SOURCE M A DeLuchi, University of California Davis, 1994, on Federal Highway Administration data

vehicle use that is incurred by nonresponsible parties (both motorists and pedestrians) and not covered by automobile insurance,[17] more than $30 billion. These costs are considered hidden because the people who cause them do not pay for them and therefore do not consider them in travel decisions.

Another important but controversial hidden cost is the so-called monopsony cost of importing oil-the effect of the large U.S. import requirements on the world price of oil. A large reduction in U.S. oil imports presumably would lower world prices, saving all U.S. motorists a portion of their fuel bill (and providing savings for nontransportation users of oil, as well), but individual drivers do not take this potential savings into account. Calculating this cost demands estimating the sensitivity of world oil prices to U.S. oil demand, an uncertain and time-dependent value. A central value for this cost is about $15 billion, but the margin of uncertainty is very high.

Public Expenditures for Motor Vehicle Infrastructure and Services

Local, State, and Federal governments provide much of the infrastructure and services associated with motor vehicle use: highway construction, maintenance, and administration, police and fire protection, all aspects of the judicial system, and so forth. They pay for portions of accident costs not covered by insurance or private payments. And they pay for some aspects of national security associated with motor vehicle use of oil: military costs, and building and running the Strategic Petroleum Reserve. National security costs associated with relying on a fuel source whose primary reserves are located in politically volatile areas potential y represent the second largest governmental cost, after highway construction and maintenance. The range of expenditures is very large, however, because of accounting problems. Given U.S. commitments to the security of its political allies who also import oil, and given other U.S. interests as the remaining world superpower, would military expenditures to protect oil supplies necessarily be affected by large reductions in oil imports? Or how much of U.S. expenditures should be associated with its oil imports, and how much with the general importance of oil to world commerce, and thus to U.S. interests? Different answers to these questions yield very different estimates of U.S. military expenditures related to motor vehicle use. Table 4-5 lists these public expenditures.

[17] And not recovered by legal redress.

TABLE 4-5: Public Motor Vehicle Infrastructure and Services, 1990 (billions)

Item	Low cost	High cost	Weight on cost
Highway construction, maintenance, services, and administration (excluding costs of police and private investment in onsite local roads, but including collection expenses and private investment in offsite roads)	**$76.5**	**$765**	1
Pollee protection, including portion estimated by FHWA[a]	**79**	**765**	1
Fire protection	14	**32**	1
Court and judicial system[a]	40	100	1
Corrections[a]	25	**35**	1
Environmental regulation and government pollution control (e.g., sewers)	10	30	1
Energy and technology research and development	0.0	0.0	1
Military costs related to oil use	50	200	1
Strategic Petroleum Reserve construction, operation, and oil-holding costs	0.2	0.2	1
Monetary accident costs covered by the government (excluding pain, suffering, and lost quality of life)[b]	**4.4**	3.9	1
Other social services	0.0	0.0	1
Tax subsidies	00	3.0	1
Subtotal	$1030	$135.9	
Total: public infrastructure and services, net of Payments from table 4-3.	**$32.6**	**$63.6**	

a These estimates do attempt to account for the possibility that many criminal offenses that involve motor Vehicles and highways might occur anyway even if there were no motor vehicles and highways.
b The low end is based on a 4-percent discount rate and the high end on 2.5- percent discount rate

KEY FHWA = Federal Highway Administration.

SOURCE M A DeLuchi, University of California-Davis, 1994, on Federal Highway Administration data

Externalities

Table 4-6 presents some *rough* estimates of classic externalities associated with motor vehicle use. Although the term externality has many definitions, here externalities are nonmonetary damages imposed by motor vehicle users on others (including other motor vehicle users) without accounting for these damages. In other words, A affects B, but may not know it and, in any case, does not care. The monetary values for the externalities presented here are taken from the literature, with less evaluation than was applied to the monetary costs and expenditures in earlier tables. Typically, for most of these externalities, there are large uncertainties about both the physical magnitude of damages and the appropriate way to place monetary values on them.

Nonmonetary Personal Costs

Table 4-7 presents rough estimates of the nonmonetary personal costs of motor vehicle travel. The two important components of these costs are the value of travel time and the pain, suffering, and lost quality of life due to accidents for which the traveler is responsible. At an assumed cost of time of $4 to $7 per hour for motor vehicle occupants, travel time costs are huge; they are the single largest cost category in the entire set of social costs. The observed behavior of travelers makes it clear that they take significant account of travel time in their travel decisions; for example, travel time is a critical factor in choice of transport mode and one of the primary reasons why mass transit does so poorly in competition with auto travel. On the other hand, it is less clear that travelers take full

TABLE 4-6: Nonmonetary Costs ("Classical Externalities"), 1990 (billions)

Item	Low cost	High cost	Weight on cost
Pain, suffering, and lost quality of life inflicted on others, due to accidents	$132.1	$138.8	1
Macroeconomic costs of oil supply disruption	15.5	40,9	1
Mortality and morbidity effects of air pollution	40,0	200.0	1
Global warming due to fuel cycle emissions of greenhouse gases	2,5	25.8	1
Congestion travel time costs inflicted on others[a]	128.9	149,5	1
Leaking tanks, oil spills	1,0	3.0	1
oil refineries (environmental Impacts, excluding global warming)	1,0	6.0	1
Gasoline distribution (counted separately only if doing cost of gasoline use)	0.0	5.0	0
Agricultural losses	1.0	6.0	1
Material, visibility, and aesthetic losses due to air pollution	3.0	10,0	1
Noise inflicted on others	1,5	5.0	1
Total	**$325.5**	**$579.0**	

a This is a crude first approximation only, The breakdown between external Congestion cost and other travel time cost is conjecture

SOURCE M A DeLuchi, University of California-Davis, 1994, on Federal Highway Administration data.

TABLE 4-7: Nonmonetary Personal Costs, 1990 (billions)[a]

Item	Low cost	High cost	Weight on cost
Pain, suffering, and lost quality of life, due to accidents	$132.1	$138,8	1
Travel time, excluding external congestion costs[b]	855,4	992.0	1
Value of personal time spent working on cars and fixing and cleaning garages[c]	40,0	96,3	1
Pain, suffering, inconvenience, anxiety, and avoidance behavior due to crimes related to motor vehicle use	0.8	1.6	1
Personal noise costs[d]	0.0	0.0	1
Total	**$1,028.4**	**$1,228.7**	

[a] Personal nonmonetary costs are distinguished from nonmonetary externalities because of the different policy implications a Pigouvian tax on externalities (with no compensation for the victims), and a "reminder" to individuals about the personal costs that they inflict on themselves Technically, a small part of total air pollution damage, global warming damage, and other nonmonetary damage is actually borne by the party that generates it and thereby really is a personal nonmonetary cost rather than an externality However, for these damages, the personal cost is so much lower than the external cost that the distinction seems pedantic Only in the cases of accident costs, noise costs, and travel time is the distinction between personal and external costs of practical significance

b This is a crude first approximation only The breakdown between external congestion cost and other travel time cost is conjecture.

c Based on an estimated 8 to 11 minutes per person per day, and a $4-$7/Per Per hour time cost.

d No estimate has been made of the noise costs that motor vehicle users inflict On themselves.

SOURCE. M A DeLuchi, University of California-Davis, 1994, based on Federal Highway Administration data account of the potential for accidents, and the resulting injury costs, in their travel decisions. The recent sharp increase in consumer interest in vehicle safety, which has translated into vehicle purchase decisions beginning to focus on the presence of airbags, anti lock brakes, and other safety equipment, implies that safety is playing a strong role in *long-term* travel decisions: it is less clear to what extent safety influences short-term travel behavior.

Conclusions

Because different policy makers are more or less willing to incorporate nonmonetary costs into their decisions, and are more or less interested in equity among transportation alternatives versus economic efficiency, the numerical results of DeLuchi's analysis can be interpreted in a variety of ways.

The question of whether motor vehicle users as *a class* are paying most of the costs of their use is a good starting point. This is primarily a question of fairness, not economic efficiency.

First, if the focus is purely on monetary costs, motor vehicle users as a class pay openly[18] for most of the costs of motor vehicle use. In 1990, these payments ranged from $866 bill ion to $881 billion, while total motor vehicle use costs, including costs for free parking and the monopsony cost of imported oil, ranged from $988 billion to $1,200 billion; in other words, **motor vehicle users paid openly for** 73 **to** 88 **percent of the monetary costs of motor vehicle use.** Note that these costs include both "private" and "public'" costs.

Second, if all costs of motor vehicle use are considered, whether monetary or nonmonetary, including externalities such as the costs of oil supply disruption, global warming damages, and damages to vegetation and materials, but excluding the value of travel time, motor vehicle users "paid" about $988 billion to $1,019 billion in 1990, out of total social costs of $1,437 billion to $1,918 billion. In other words, **motor vehicle users paid openly for 53 to 69 percent of the social (public plus private) costs of motor vehicle use, both monetary and nonmonetary, excluding the value of time.** Further, to the extent that most of the accident costs listed as externalities are inflicted by users on other users, these could be added to the costs paid by users to yield a higher percentage of paid costs.

Third, because the costs of travel time (and other time spent in motor vehicles) are extremely high and paid entirely by motor vehicle users, adding time costs to the social cost equation leads to users' paying a much higher percentage of total costs. At average costs of $4 to $7 per hour for personal travel, the 1990 costs for motor vehicle travel time, excluding truck driver wages and external congestion costs, were about $718 billion to$911 billion. Thus, if all costs of motor vehicle use—monetary or nonmonetary (including travel time)—are considered, motor vehicle users "paid" about $1,716 billion to $1,930 billion out of total social costs of $2,155 billion to $2,937 billion. In other words, **motor vehicle users paid openly for 66 to 80 percent of the social (public plus private) costs of motor vehicle use, both monetary and nonmonetary, including the value of time.**

The general conclusion that can be drawn from these specific conclusions is that if subsidies were withdrawn, externalities "internalized," and hidden costs brought out into the open and directly charged to motor vehicle users, the perceived costs of motor vehicle use would increase substantially (by 14 to 89 percent, depending on whether nonmonetary costs and other factors are included), and people would drive less.

Another question that this analysis can answer is, are *motor vehicle users paying for the public services they receive?* Motor vehicle users paid $70.3 billion to $72.3 billion for highway in-

[18] That is, motor vehicle users paid for the costs in a manner that is clear and direct; thus the costs are likely to be taken into account in their travel decisions.

frastructure and services in 1990, out of public expenditures of $98.0 billion to $115.9 billion, not counting military costs related to oil use. If military costs are counted, public expenditures were $103.0 billion to $135.9 billion, depending on point of view. Thus, **motor vehicle users paid for 62 to 72 percent of public expenditures for highway infrastructure and services, not counting military expenditures, or 53 to 68 percent if military expenditures are counted.**

If economic efficiency is of primary concern, an attempt must be made to separate those costs that represent marginal costs to society and are paid and recognized by motor vehicle users, and those that do not fit this description.

Only the costs outlined in table 4-2—payments for motor vehicles, fuels, parts, service, and wages of freight drivers—satisfy the conditions for economic efficiency (the items in table 4-3, payments by motor vehicle users for highway infrastructure and services, are not considered to be efficiently priced). These costs amount to $796 billion to $808 billion out of total monetary costs of $988 billion to $1,200 billion, including the cost of free parking and the monopsony cost of importing oil. Thus, **approximately 67 to 81 percent of the total monetary costs of motor vehicle use are efficiently priced, that is, paid for entirely by motor vehicle users, counted in their travel decisions, and priced at marginal costs to society.**

If nonmonetary costs are considered as well, personal nonmonetary costs (table 4-7) may also be viewed as efficiently priced, although there will be arguments about the extent to which travelers properly account for some of these costs—particularly accident costs—in their traveling decisions. If these costs are efficiently priced, motor vehicle users efficiently paid for about $929 billion to $949 billion (or 49 to 65 percent) of total social costs, monetary and nonmonetary, of $1,437 billion to $1,918 billion, excluding the value of travel time. **In other words, approximately 49 to 61 percent of the total monetary and nonmonetary costs of motor vehicle use, excluding the value of time, are efficiently priced.**

An important caveat that must be attached to these conclusions is that they apply to a rather long-term perspective, with the focus on total costs rather than short-term, variable costs. The ratio of "accounted-for" costs to "unaccounted-for" costs would change substantially if only variable costs were being considered. In particular, a large component of the accounted-for costs is the cost of purchasing vehicles, which would not appear in a short-term accounting. And many of the unaccounted-for costs—such as free parking and environmental costs—are variable, and would remain in the travel budget when a short-term perspective is taken. Thus, in taking a short-term perspective, the ratio of accounted-for to total costs should be considerably lower than the ratios computed when both short-term and long-term costs were considered. Does this mean that moving to a system that forced travelers to account for all costs would affect their behavior more than is implied by the relatively small fraction of total unaccounted-for costs discussed above?

The question is, *which perspective-one that looks at total costs, or one that looks only at short-term, variable costs--best reflects how potential travelers will behave?* Certainly, if policy makers were concerned primarily about the impact on travel decisions that would occur immediate] y following a move to a "full cost accounting" system, they would focus on variable costs. However, travelers must eventually make decisions about vehicle purchases, insurance renewals, even the size garage they desire in a new home, and these decisions reflect both short-term variable costs, such as the cost of gasoline, and longer-term costs, such as vehicle purchase prices. These long-term decisions then greatly constrain travelers' future shorter-term decisions about how much to travel and which mode to use. Thus, both short- and long-term costs influence travel behavior.

No attempt has been made here to unravel the relative impacts on travel behavior of variable and long-term costs, although some data exist about certain elements of these impacts. Thus, no quantitative estimate is made of the extent to which a shift to an economic system that forces travelers to confront openly the total (marginal) social costs of their travel would impact both total travel and the distribution of travel modes. Nevertheless, OTA concludes that a shift to such an economic system would have important effects on travel, probably reducing its magnitude by a significant amount and *possibly* shifting the modal distribution. **OTA believes that further research on the subject of social cost estimation and the effects of transport pricing on travel behavior would be a valuable contribution to national transportation policymaking.**

CONGESTION

Analyses of the potential for reducing U.S. transportation energy use—and transportation planning in general-demand a reliable picture of current and future levels of highway congestion and its impacts, for two reasons. First, severe highway congestion may increase energy use by slowing travel speeds to a level at which internal combustion engines are relatively inefficient, and may increase or decrease energy use by affecting travel demand, travel patterns, and residential and business locational decisions. Second, at some level of severity, road congestion would place significant constraints on any transportation strategies that stress continued U.S. reliance on private vehicles for mobility. Some analysts fear that traffic congestion could become the Nation's primary problem in surface transportation by the 1990s,[19] and could cause average travel speeds to slow greatly—and travel times to soar-—soon after the turn of the century. Congestion of this severity clearly would affect the relative priority transportation strategists would give to, say. new transit systems versus improved vehicle efficiency. Other analysts have expressed skepticism that congestion problems are as severe as they have been portrayed, or that the future will be as bleak as predieted. The validity of the available congestion estimates and forecasts must be examined carefully.

Some analysts fear that traffic congestion could become the Nation's primary problem in surface transportation by the end of the 1990s

Proposition: There Is a Major National Congestion Problem

Some recent analyses of highway congestion conclude that growing congestion is an extremely serious problem for the U.S. highway system. The Federal Highway Administration (FHWA) has completed a number of congestion studies whose results point in this direction:

> By all system performance measures of highway congestion and delay, performance is declining. Congestion now affects more areas, more often, for longer periods, and with more impacts on highway users and the economy than at any time in the Nation's history.[20]

For example, FHWA has determined that the percentage of *highway mileage* in which peak-hour

[19] U.S. General Accounting Office, *Traffic Congestion: Trends, Measures, and Effects*, GAO/PEMD-90-1 (Washington, DC: November 1989.

[20] U.S. Congress, *The Status of the Nation's Highways and Bridges: Conditions and Performance*, Report of the Secretary of Transportation (Washington, DC: U.S. Government Printing Office, 1991).

travel occurs in congested conditions[21] rose sharply between 1983 and 1989: on rural interstate, from 3 to nearly 10 percent; and on urban interstates, from 31 to 46 percent.[22] Similarly, the percentage of total *peak-hour travel* occurring in congested conditions rose in the same time frame: on rural interstates, from 8 to nearly 23 percent, and on urban interstates, from 55 to nearly 70 percent.[23] More importantly, most of the peak-hour travel under congested conditions was rated as "highly congested" by FHWA standards.[24]

FHWA examination of severe congestion in a 20-city sample shows similar results. In the sample, FHWA estimates that the percentage of total freeway travel operating under severely congested conditions—level of service F, where traffic is highly unstable and likely to degenerate into stop and go-rose from 5.2 to 6.4 percent during 1985-88.

The Texas Transportation Institute (TTI) also has studied national congestion trends. Table 4-8 presents estimates of changes in values of the roadway congestion index (RCI) from 1982 to 1988. The index is a simple measure of congestion, measuring the daily vehicle-miles of travel per lane-mile of road on freeways and principal arterial roads; an increase of 10 percent in the index means that the growth in vehicle-miles of travel has outstripped roadbuilding (the growth of lane-miles) by 10 percent. RCIs greater than 1.0 are considered to indicate congested conditions, although the average highway speeds generally achieved at RCI = 1.O—a bit more than 40 miles per hour (mph)—would not be considered slow for urban freeways in dense cities.

As shown in table 4-8, in 28 of the 39 cities, the growth in vehicle-miles traveled (vmt) on highways and principal arterial roads outstripped increases in lane-miles by at least 10 percent, and in several cases by well over 20 percent, in just 6 years.

Estimates of the costs of congestion—including time delays, wasted fuel, and increased insurance premiums[25]—indicate that these costs are high. Available studies generally conclude that total costs are in the tens of billions of dollars and are rising rapidly. For example, TTI estimated congestion costs for 39 of the Nation's largest metropolitan areas to be more than $34 billion in 1988.[26]

Some studies have attempted to project future congestion levels by extrapolating trends in highway travel and road building, Their results, in project ions of congestion levels and average highway speeds, appear extremely worrisome. For example:

1. FHWA has projected that by 2005, in the absence of further highway improvements or growth, 23.9 percent of all freeway trave1[27] will be at least mildly congested—that is, traffic will slow from true free-flowing conditions—simply from normal daily peaks in traffic, not

[21] Volume to capacity (V/C) ratios of 0.80 or greater; for urban freeways, a V/C ratio of 0.77 corresponds to an average speed of about 54 miles per hour, and a ratio of 0.80 corresponds to a slightly lower speed. U. S. General Accounting Office, op. cit., footnote 19, table 3.1.

[22] U.S. Congress, op. cit., footnote 20.

[23] Ibid. The travel values are higher because these segments carry more traffic than uncongested segments.

[24] V/C of 0.95 or greater, corresponding to average speeds of about 40 to 45 miles per hour or less according to the U.S. General Accounting Office, op. cit., footnote 19, table 3.1.

[25] Other costs, generally not estimated, include excess vehicle wear and driver stress.

[26] J.W. Hanks, Jr. and T.J. Lomax, *Roadway Congestion in Major Urban Areas 1982 to 1988*, Report No. FHWA/TX-90-1131-3 (College Station, TX: Texas Transportation Institute, July 1990).

[27] Measured in vehicle-miles.

TABLE 4-8: Change in Roadway Congestion Index, 1982-88

Urbanized area	1982	1988	Percent change 1982-88
Phoenix, AZ	1.15	1.00	-13
Detroit, MI	1.13	1.09	-4
Houston, TX	1.17	1.15	-2
Memphis, TN	0.86	0.86	0
Cincinnati, OH	0.86	0.88	2
Pittsburgh, PA	0.78	0.81	4
Louisville, KY	0.84	0.87	4
Corpus Christi, TX	0.67	0.70	4
Philadelphia, PA	1.00	1.07	7
Oklahoma City, OK	0.72	0.78	8
New York, NY	1.01	1.10	9
Baltimore, MD	0.84	0.92	10
Tampa, FL	0.94	1.03	10
Miami, FL	1.05	1.18	12
San Antonio TX	0.77	0.86	12
Milwaukee, WI	0.83	0.94	13
Fort Worth TX	0.76	0.87	14
Salt Lake City, UT	0.63	0.72	14
Albuquerque, NM	0.78	0.90	15
Chicago, IL	1.02	1.18	16
Kansas City, MO	0.62	0.72	16
Denver, CO	0.85	0.99	16
El Paso, TX	0.63	0.74	17
Indianapolis, IN	0.71	0.84	18
St Louts, MO	0.83	0.98	18
Minneapolis-St Paul MN	0.74	0.88	19
Cleveland, OH	0.80	0.97	21
Dallas, TX	0.84	1.02	21
Portland, OR	0.87	1.05	21
Washington DC	1.07	1.32	23
Seattle-Everett WA	0.95	1.17	23
Boston MA	0.90	1.12	24
Atlanta, GA	0.89	1.10	24
Austin, TX	0.77	0.96	25
Los Angeles CA	1.22	1.52	25
Sacramento, CA	0.80	1.03	29
San Francisco-Oakland, CA	1.01	1.33	32
Nashville, TN	0.74	0.99	34
San Diego, CA	0.78	1.13	45
Northeastern average	093	1.06	
Midwestern average	083	0.92	
Southern average	090	1.03	
Southwestern average	082	0.90	
Western average	094	1.21	
Total average	087	0.99	
Maximum value	122	1.52	
Minimum value	062	0.70	

SOURCE J W Hanks Jr and TJ Lamas. Texas Transportation Institute, *Roadway Congestion in Major Urbanized Areas 1982 to* 1988, FHWA/TX-90-1131-3 (College Station TX July 1990) counting accidents or other singular events.[28] In 1984, only 11.4 percent of freeway traffic was congested because of normal traffic peaks. The same analysis projects total delay from both normal peaks and singular events of nearly 7 billion vehicle-hours, from slightly more than 1 billion vehicle-hours in 1984-an increase of 450 percent. Similarly, excess fuel consumption is projected to increase from 1.378 billion to 7.317 billion gallons per year, a 431 -percent increase.[29]

2. Various local studies have projected sharp declines in service because of congestion. For example, Los Angeles freeway speeds are projected to slow to 11 mph from their present 31 mph by 2010.[30] Planners for Southern California projected in 1988 that average freeway speeds would drop by 50 percent and speeds on other roads by 46 percent, to 24 and 19 mph, respectively, within 20 years.[31]

Neither the estimates of changes in actual congestion levels nor the forecasts of future congestion appear at odds with areawide data on highway travel and highway capacity. These data show that travel has been increasing at a far greater rate than capacity; for example, vehicle-miles increased by 168 percent during 1960-87 (3.7 percent per year), whereas highway mileage increased by only 9 percent.[32] And while vehicle-miles are expected to increase more slowly in the future, it remains a virtual certainty that future travel growth will continue to outstrip highway building, at least for the next few decades.

Counterarguments

Despite these trends, some analysts have questioned the high estimates of congestion costs made by FHWA and others. They have focused particularly on travel data that, on the surface, appear to contradict the estimates. One such "contradictory" data set is the available survey data on commuting times; although local commuting times have changed, the national average commuting time has been remarkably stable over the past decade. Two major surveys measuring recent changes in commuting times showed little change during the 1980s: the national census estimates that average commuting times increased by 40 seconds between 1980 and 1990, from 21.7 to 22.4 minutes;[33] the National Personal Transportation Survey (NPTS) estimates that they declined by about 40 seconds during 1983-90.[34] An examination of commuting times in 20 cities showed that between 1980 and 1985, 18 of the 20 cities experienced a decrease in commuting times.[35] Although commuting represents only 32 percent of all

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[28] J. Lindley, "Urban Freeway Congestion: Quantification of the Problem and Effectiveness of Potential Solutions, *ITA Journal*, vol. 57, No. 1, January 1987.

[29] Ibid.

[30] "Transportation and Land Use, Bridging the Gap," *Developments*, the Newsletter of the National Growth Management Leadership Project, spring-summer 1990, p. 2, in J. J. MacKenzie et al., *The Going Rate: What It Really Costs To Drive* (Washington, DC: World Resources Institute, June 1992).

[31] Southern California Association of Governments, *Regional Mobility Plan* (Los Angeles, CA: 1988), cited in P. Gordon et al., "The Commuting Paradox: Evidence From the Top Twenty," *American Planning Association Journal*, autumn 1991.

[32] U.S. General Accounting Office, op. cit., footnote 19.

[33] A.E. Pisarski *New Perspectives in Commuting* (Washington, DC: U.S. Department of Transportation, Federal Highway Administration, July 1992).

[34] P.S. Hu and J. Young, *Summary of Travel Trends; 1990 Nationwide Personal Transportation Survey*, FHWA-PL-92-027 (Washington, DC U.S. Department of Transportation, Federal Highway Administration, March 1992), table 10.

[35] P. Gordon et al., op. Cit., footnote 31, pp. 416-420. The reduction in commuting times represents both a small decrease in average worktrip length and a small increase in speed.

household personal vehicle miles-traveled,[36] it almost certainly represents a substantially larger share of *congested* vehicle-miles traveled. Thus, it is not easy to reconcile the idea of huge increases in congestion and little change in commuting times.

Also, contrary to what might be expected from the thesis that urban congestion—and bumper-to-bumper traffic moving at a crawl—is spreading, essentially all nationwide measures of highway speed (average, median, percentage exceeding 55 mph, etc.) show increases. For example, average speeds[37] on urban interstate highways rose from 55.5 mph in 1981 to 58.6 mph in 1990; similarly, average speeds on other urban freeways and minor arterials rose from 55.0 to 57.6 mph in the same time.[38]

Further, if congestion is such a problem, drivers making unscheduled trips would be expected to avoid peak traffic periods. Although available data do not distinguish clearly between unscheduled and scheduled trips, NPTS data on peak-hour travel reveal that trips *other than* commuting account for 63 percent of all trips in metropolitan areas during the morning and afternoon peaks (6 to 9 a.m. and 4 to 7 p.m.).[39] Although many of these trips (e.g., parents driving children to school) cannot be shifted to other times, it seems likely that others could be taken at off-peak hours. The willingness of drivers to make so many of their nonwork trips during peak hours may imply that many do not consider current congestion levels severe; it also implies the existence of some potential to hold off increased congestion (presumably, at some congestion level, drivers *would* switch to other times).

Evaluation

Do these seeming contradictions mean that either the congestion estimates or the "opposing" data sets are incorrect, or can both be correct? Although the data do not allow a definitive conclusion, it appears likely that the trends of stable commuting time and rising highway speeds could coexist comfortably with rising congestion, at least for a while, There are reasons to doubt, however, that current congestion impacts are as severe as portrayed or that they will necessarily grow as rapidly as forecast. On the other hand, traditional estimates of the economic impacts of congestion tend to ignore some of its important negative consequences.

First. the failure of commuting trips to show significant increases in average time may reflect the effects of one trend being canceled by a few others. That is, although congestion may indeed be growing, which should tend to increase travel times, a variety of factors (e.g., a shift in commuting patterns to suburb-to-suburb routes and a larger percentage of single-rider commuting, thus reducing the average number of stops necessary and trip circuity) would act in the opposing direction to reduce travel times.

Although the data show clearly that total vehicle-miles traveled has grown much faster than total road capacity, there have been important shifts in trip patterns that counteract at least some of the potential congestion impacts of the vehicle-miles traveled versus capacity trends. In particular, there has been a continuing shift of worktrips from central city to suburbs: between 1970 and 1980, for example, central-city to central-city

[36] S.C. Davis and M.D. Morris, *Transportation Energy Data Book*, ed. 12, ORNL-6710 (Oak Ridge, TN: Oak Ridge National Laboratory, March 1992), table 4.9.

[37] These are weighted by traffic flow over a 24-hour period, not by time, so that the reported values are the speeds averaged over all cars on the road during the day. Ken Welty, Federal Highway Administration, personal communication, Feb. 10, 1993.

[38] U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics* (Washington, DC: 1981-1990), tables VS-1, VS-2.

[39] H.W. Richardson and P. Gordon, University of Southern California, "New Data and Old Models in Urban Economics," preliminary draft, December 1992, table 3.

commuting trips declined as a percentage of all commutes by nearly 18 percent, whereas suburb-to-suburb commuting trips increased by 20 percent, and these trends have continued.[40] This appears to be a crucial reason why average commuting times have not escalated. Even if congestion is growing in some areas, many workers have escaped it. Suburban trips are likely to be made under less congested conditions and thus at higher speeds, and they are more likely to be made in autos than on transit, also reflecting lower door-to-door times. In fact, worktrip speeds have increased over time for both central-city and suburban residents, except for those driving off-peak.[41] Evidence is less clear about whether changes in the time of day that trips are made may also have played a role in reducing the impacts of congestion. Although there has been much anecdotal discussion of workers' attempting to avoid the worst congestion by arriving at work significantly earlier than they are expected (or leaving later) or taking advantage of flextime schedules, analysis of American Housing Survey data shows little evidence of peak elongation in the smaller metropolitan areas.[42]

If, *at the national level,* large shifts in travel patterns are compensating for the failure of highway capacity to keep up with growing travel, substantial geographical differences should still show up in the data since there are large differences in growth rates among cities, and large differences among urban areas in their willingness to expand highway capacity. Such differences do appear to exist.[43] For example, during 1980-90, Los Angeles gained 2 minutes in average commuting time, and some of the nearby counties had gains that were much higher; whereas Houston, despite a large growth in commuting traffic, *lost* 1.7 minutes during the period. On a State-by-State basis, New Hampshire showed the largest percentage increase—about 13 percent—while Wyoming showed a 13 percent decline in commuting time.[44]

Another trend that would tend to reduce commuting time is the growth in the percentage of workers driving alone. According to census data, in 1980 single-occupancy vehicles accounted for 64.4 percent of commute trips; in 1990 this mode accounted for 73.2 percent of all such trips,[45] a gain of 22 million single-occupancy vehicles during a period when the total number of workers increased by only 19 million.[46] In the same period, commuting on public transportation declined from 6.4 to 5.3 percent of all commute trips, and carpooling declined from 19.7 to 13.4 percent, with nearly half of the decline coming from carpools of three or more riders.[47] Transit trips and carpool trips tend to be relatively long (because of waiting time and access time for transit, and pickup-dropoff time for carpools; even when husband and wife drive together, one generally drops the other off at a work location, with added distance and dropoff time).

Second, the data on highway speed may also reflect two opposing trends. Increases in average highway speeds could simply result from the combination of speed increases at off-peak hours and (congestion-caused) decreases at peak hours, with the increases thus far outweighing the decreases.

40 P. Gordon and H. Richardson, "Notes From Underground: The Failure of Urban Mass Transit, The *Public Interest*, Issue 94, winter 1989, table 1.

41 P. Gordon et al., op. cit., footnote 31.

42 Ibid.

43 Pisarski, op. cit., footnote 33.

44 Ibid., figure 12.

45 Ibid., table 2.

46 Ibid.

47 Ibid.

As a hypothetical scenario, in 1990,off-peak[48] trips accounted for about 54 percent of total trips in metropolitan areas.[49] If off-peak highway trips are usually uncontested, the actual 2.6 to 3.1 -mph speed increase on urban highways during 1981-90 could have resulted from a 2.5 to 3.O-mph *decrease* in speed during peak hours due to congestion and about a 5.0 to 6. O-mph *increase* during off-peak hours due to more drivers exceeding speed limits.[50] Unfortunately, FHWA does not have time-of-day data on highway speed: further study using State data is necessary to determine the validity of the above hypothetical scenario.

Third, although the estimated costs of congestion appear very high. they may be relatively low *compared with the total volume of travel.* The present amount of congestion seems quite drastic because of current rhetoric and because the aggregate estimates of "congested" roads and monetary damages seem very high. For a variety of reasons. however, the impact on the average driver may not yet be all that great, although it may get much worse.

"Congested flow" in FHWA terminology means only that traffic has slowed from total 1 y unconstrained levels: 54-mph speeds on freeways represent congested conditions under this definition. Even FHWA's "highly congested" traffic flow (volume-to-capacity (V/C) ratio greater than 0.95) implies average speeds of about 40 mph or less,[51] which includes traffic that would be considered quite free-flowing by most residents of large urban areas. Interestingly. FHWA, in its report to Congress, slightly misinterprets its own congestion data:[52] it reports that 70 percent of peak-hour travel on urban interstate is experiencing level E service or worse[53] (E is severely congested). whereas the 70 percent value actually refers to V/C levels of 0.80 or more, which is closer to level C service. or very mildly congested.

To get a better fix on congestion impacts, it makes sense to compare the estimated total delay time caused by congestion with the total time of travel. As noted, FHWA estimates that congestion delay in 1984 was about 1 billion vehicle-hours and will increase to more than 7 billion vehicle-hours by 2005. TTI's estimate of the vehicle hours of delay in 1989 for 50 major urbanized areas (with a combined population of 103 million) is 2.46 billion.[54]

The FHWA estimate is a relatively small number of hours compared with total highway vehicle-hours: in 1983. about 15 billion vehicle-hours were devoted to commuting, and perhaps 40 to 50 billion vehicle-hours to trips of all purposes.[55] If half of the delay hours affected commuting trips,

[48] That is, outside of the 6 to 9 a.m. and 4 to 7 p.m. peaks

[49] Richardson and Gordon, op. cit., footnote 39, table 3.

[50] These hypothetical values assume that nonpeak and peak trips are equally likely to be on highways and that their highway trip distance is the same.

[51] Given the relationship between speed and V/C that was thought to exist at the time the report was written. Recent data suggest that at a V/C of 0.95, highway speeds would average about 55 mph; that is, speeds do not drop off severely until a V/C of 1.0 is reached. See discussion later in this section about recent revisions of the Highway Capacity Manual.

[52] U.S. Congress, op. cit., footnote 20, p. 146.

[53] Ibid.

[54] J.W. Hanks, Jr. and T.J. Lomax, *1989 Roadway Congestion Estimates and Trends*, FHWA/TX-90-1131-4 (College Station, TX: Texas Transportation Institute, July 1992.

[55] We know of no direct estimates of total hours spent for commuting and for highway travel in general, but these can be estimated from the National Personal Transportation Survey (NPTS) and from Oak Ridge data on vehicle-miles traveled. According to the NPTS, 1983 *household* vmt for all purposes was 1.002 trillion miles; and according to the Oak Ridge data book 12, table 3.2, auto and light truck vmt in 1984 was 1.592 trillion miles. Assuming an average travel speed of about 40 mph yields a total travel time for all 1983 trips of about 40 billion vehicle-hours with the higher Oak Ridge figure, which is probably the more appropriate value. The commuting time was estimated by using NPTS data showing 103 million workers in 1983, each traveling about 20 minutes per commute; assuming 250 working days per year and approximately 1.2 workers per vehicle yields about 15 billion vehicle-miles.

then the delay for the average commuting trip in 1983-84 was about one-thirtieth of 20 minutes--40 seconds per trip. However, FHWA's projected 450-percent increase in delay time by 2005 will have far greater impact, because in that period the total number of commuting trips is likely to increase by only about 50 percent over the 1983 value, which implies an average delay of about 3 minutes per trip.

The TTI estimate implies a more substantial impact on the average trip. Even if the sample of 50 urban areas includes a much higher percentage of the Nation's total congestion than is implied by its portion (less than 50 percent) of the total U.S. population, the estimate seems to imply an impact on commuting trips of at least 2 minutes per trip, compared with FHWA's 40 seconds.

It is not easy to interpret these congestion values, particularly because the averages almost certainly hide strong distributional impacts. Even at the higher TTI figure, it is not clear that current levels of congestion represent a substantial inconvenience to the *average* driver at most times. The TTI congestion delay estimate implies that congestion costs the average city dweller about 30 hours per year, or 5 minutes per day. On the other hand, it is entirely possible that the distribution of congestion impacts is strongly skewed, so that a minority of drivers is impacted very heavily. Unfortunate y, available analyses of congestion costs do not attempt to evaluate how the impacts are distributed.

Although the above arguments imply that the trends in highway speeds and commuting times do not really contradict FHWA and TTI estimates of congestion, other evidence implies that the estimates are overstated. FHWA and other organizations that estimate congestion damages do not rely directly on speed data to calculate congestion delays; instead, the organizations *estimate* speed by collecting data on traffic flows and applying known relationships between traffic flows and speed. In one of its estimates, for example, FHWA applies traffic flow-speed relationships derived from 1983 and 1984 traffic counts on Interstates 66 and 395 near Washington, DC.[56] Another, widely used source for traffic flow-speed relationships is a set of graphs of average speed versus volume of passenger cars per lane published by the Transportation Research Board (TRB).[57] New research shows that the old graphs are not accurate anymore; today's drivers are able to maintain higher speeds with high traffic counts than their counterparts in the past. Therefore, applying the old (1985) TRB curves would yield estimated speeds that are too low and estimated delays that are too high. Figure 4-1 compares the 1992 curve for freeways and multilane highways with its counterparts for 1985 and 1965. The curve shows that in 1992, the actual capacity of each freeway lane is at least 2,200 cars per hour, rather than 2,000 cars per hour for the earlier years. Furthermore, there is now essentially no dropoff in speed until traffic flows reach 1,400 cars per hour per lane, and after that the dropoff is relatively mild. The curves for earlier years show an immediate dropoff as traffic increases from zero, and the beginning of a sharp dropoff at about 1,600 cars per hour per lane.

By using the old curve, highways at traffic counts of 2,000 cars per hour per lane would be estimated to be close to gridlock, with average speeds of about 30 mph. Each of the 2,000 cars would be accumulating '*delays" of about 5 minutes for every 10 minutes actually on the highway, By using the new curve, however, average speeds for this situation are estimated to be 55 mph, with essentially no delays. Because the data used by FHWA in its congestion analyses are similarly

[56] U.S. General Accounting Office, op. cit., footnote 19.

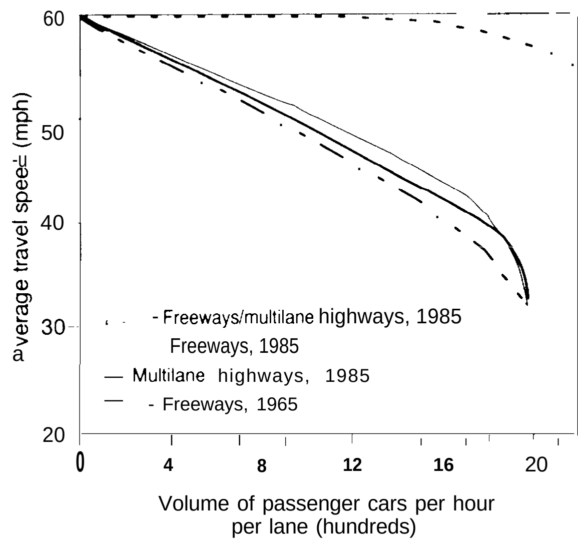
[57] Transportation Research Board, *Highway Capacity Manual*, Special Report 209 (Washington, DC: 1985).

outdated, its congestion damage estimates are overstated.

A reanalysis of urban freeway congestion delays by FHWA[58] using the revised capacity of 2,200 cars per hour per lane and the revised speeds for V/C less than 1.0 indicates that the estimated 1987 vehicle-hours of delay are reduced by 12 percent with the new data. This reduction seems surprisingly small given the severity of the change in figure 4-1. The author of the reanalysis explains that most of the delay occurs at very high V/C levels, particularly during non-reoccurring events, so that the changes have no effect on the greatest portion of the delay.[59] The accuracy of both the original analysis and the reanalysis depends, however, on the accuracy of a key assumption used in both calculations, that average travel speed at V/C levels greater than 1.0 is 20 mph. No data exist to allow a reliable representation of this average speed.

Even if congestion impacts are spread relatively widely and are lower than FHWA has estimated, yielding a somewhat milder view of the current problem, the question of future impacts remains. As noted, congestion is projected to increase rapidly in the future. This is not surprising, given its nature: once traffic reaches a threshold of congestion—about 80 to 90 percent of the design capacity of the road[60]—average speeds drop (and delays increase) rapidly with increasing traffic flows. What the FHWA data seem to show is that traffic flows on a large percentage of U.S. highways have passed the congestion threshold for several hours per day; thus, if traffic continues to increase at historic rates with increases in road capacity lagging behind, congestion will increase very quickly. Presumably, an analysis based on the TTI methodology would yield still higher estimates of future congestion impacts. Although OTA believes that a reanalysis of congestion impacts using the most recent data on speed-traffic flow relationships would yield a reduced estimate of current congestion impacts, this is not to deny that congestion problems exist.

FIGURE 4-1: Alternative Highway Speed-Traffic Volume Relationships



SOURCE 1965 Highway Capacity Manual Highway Research Board (HRB) Washington DC 1985 Highway Capacity Manual," Transportation Research Board *Highway Capacity Manual* Special Report No 209 (Washington DC National Research Council 1985) data from National Cooperative History Research Program Project 3-33 "Capacity and Level of Service for Multilane Highways

The importance of congestion in the future depends on the growth rate of vehicular travel; infrastructure responses (new roads, improved maintenance of roadways, smart highways); behavioral responses of drivers and businesses, either spontaneously or reacting to government incentives: and general trends in urban structure. The actual degree of congestion to be expected in future years should be very sensitive to changes in these vari-

58 J.A. Lindley, Federal Highway Administration, "Supplemental Analysis of Urban Freeway Congestion Using Revised Capacity and Speed-Flow Relationships," unpublished paper, April 1993.

59 J.A. Lindley, Federal Highway Administration, personal communication, 1993.

60 The higher value reflects more recent data on traffic flow-speed relationships.

ables. For example, increasing highway capacity by 20 percent by 2005 would decrease the expected traffic delay by about 27 percent, according to the FHWA model.[61]

No similar analysis is available for possible changes in travel behavior caused by continuing changes in jobs and residential locations, as well as other changes such as varying work hours and shifting of peak-hour nonwork travel out of the peak. The FHWA model does not consider such changes, and data to allow such consideration may not be available. Changes in travel patterns, however, probably could have impacts on congestion at least as strong as the likely increases in highway capacity, especially as congestion becomes severe. Questions that need to be asked, and investigated, include: Will growing congestion cause more workers to change jobs or residences? Will businesses relocate to less congested areas, change their business hours, or perhaps establish remote annexes connected by telecommunications?

Trends in urban land use and travel patterns have tended over the past few decades to mitigate the impacts of rapidly growing travel and slowly growing road capacity, by shifting travel away from congested routes. Unfortunately, it is not clear to what extent congestion played a key role in the important shifts in job and residential locations that have occurred over this time period. In all probability, the shifts in job locations owed as much or more to advances in telecommunications and the general degradation of urban services as they did to congestion. Similarly, movement of workers to the suburbs reflected growing urban crime and degenerating school systems, as well as a desire for single-family housing, at least as much as it reflected an escape from congestion. In other words, although past trends worked well to reduce the impacts of congestion on commuting, *it is unlikely that the primary causal factor behind these trends was the congestion itse[f.* Consequently, it may be risky to assume that businesses and workers will adapt their behavior to growing congestion in the future and thus mitigate it, unless other forces push their decisions in the same direction. Also, the locational shifts of the past may have reduced the growth of congestion in the cities, but they introduced congestion to the suburbs and beyond. If recent trends in job creation continue, the suburbs will gain population and employment. Increases in congestion will then depend on just where this growth occurs—in the already developed portions of the suburbs or in new outer rings of development. Congestion will also depend on whether additional suburban growth concentrates in subcenters or, as some predict, develops in a more uniform character.

Despite the uncertainty, however, it is difficult to believe that the forecasts of extreme drops in travel speeds will prove correct. The forecasting models assume that congestion does not have some self-limiting mechanisms, that is, that traffic will simply keep on increasing as highway speeds fall. It seems more likely that, instead, growing congestion will restrain growth in traffic volumes and shift travel to less congested areas and less congested times, especially when average speeds drop severely. Unfortunately, there are few data on the nature of the effect—the critical speeds beyond which driver behavior might shift strongly, regional differences in driver tolerance of delay, etc.

Aside from concern about the accuracy of current estimates and projection of future congestion delays, estimates of the *dollar costs* of congestion must be treated with care as well. TTI computes costs in three categories-insurance, delay, and fuel. Insurance costs represent the difference between costs in smaller urbanized areas and those in large urban areas.[62] Attributing these differences solely to congestion is unwise, however; higher insurance rates in large urban areas are like1 y to be due to higher rates of auto theft, existence of more intersections and more traffic regardless

[61] U.S. General Accounting Office, op. cit., footnote 19, table 4.3.

[62] Hanks and Lomax, op. cit., footnote 26.

of congestion, more interaction between pedestrians and traffic, and other factors in addition to congestion. Estimates of fuel costs calculate increased fuel use by applying fuel economy adjustment factors obtained from empirical evaluation of automobiles operating at different speeds. Although maintaining high-efficiency levels at low speeds is a problem for auto designers, a large growth in congestion could conceivably spur redesign of vehicle drivetrains to reduce the low-speed fall off in efficiency. This redesign would be facilitated by a shift by the U.S. Environmental Protection Agency in its city-highway adjustment factors, or in its test cycle, to account for changes in driving patterns.

Estimates of delay costs assign an hourly value to lost time (in the TTI study, $8.25 per person-hour) and calculate delay as time lost by driving at speeds below the off-peak average. These estimates implicitly assume that extra time spent in vehicles is wasted. Certainly many would agree with this, but the extreme comfort levels attained in modem vehicles (including high-quality stereo systems and portable phones) may begin to challenge this assumption.

To our knowledge, both TTI and FHWA focus on direct delays attributed to congestion, and do not attempt to quantify the economic impact of congestion-caused changes in travel behavior: the need to schedule extra travel time because of increased *variability* of commuting time due to congestion; and forced shifts in destinations and times, or even foregoing travel because of congestion. These impacts may be quite significant, although clearly they are difficult to measure.[63]

TTI's methodology averages areawide traffic flows with areawide measures of capacity, and may have difficulty correctly gauging actual changes in congestion levels if tripmaking patterns change over time, which they have. FHWA's methodology *appears* to measure individual sections of roadway and average these. Congestion estimates using this methodology would not appear to be easily distorted by changes in travel patterns.

If commuting trips are not getting longer *on average,* but large increases in travel delay are occurring, this could mean that most of the direct impacts of congestion are falling on nonwork trips for shopping, social and recreational purposes, and other family or personal business. Certainly, the time spread of congestion now impinges on trips that once avoided congestion simply by avoiding the traditional "rush hour." Also, the spread of suburbanization and the large movement of women into the workplace may have added enough jobs with short commutes to balance congestion effects on those workers remaining in traditional commuting patterns, so that the data on average commuting time may be hiding strong congestion impacts affecting many workers. Finally, congestion may affect even those workers who have changed jobs and residences and shortened their commuting times; without the added congestion, they would have saved still more time.

To conclude, congestion on U.S. urban and suburban highways is an important and growing problem, but the magnitude of the problem is not well defined. Current congestion levels are not well measured, and available forecasts of future congestion levels appear simplistic. Some analysts believe that FHWA estimates of current congestion levels, and its characterization of the nature of the congestion problem, are grossly overstated. Evidence that appears to contradict the FHWA estimates (constant commuting times, increasing average highway speeds) turns out to be equivocal, however, when examined more carefully. At FHWA-estimated levels, congestion delays are still a small fraction of total travel times during peak hours. Thus, it is not unlikely that congestion at these levels could fail to impact

[63] Recommendations for paying more attention to these impacts appear in A.E. Pisarski, *Summary and Recommendations of the Workshop on National Urban* Congestion Monitoring, FHWA-PL-90-029 (Washington, DC: U.S. Department of Transportation, Federal Highway Administration, September 1990).

measures such as average commuting times, especially when recent changes in commuting patterns are factored in. If congestion does grow as rapidly as forecast, however, the efficiency of the U.S. highway system could be seriously degraded. Given this potential threat, upgrading of congestion measurements and forecasts is a worthwhile goal.

ENERGY SECURITY AND TRANSPORTATION

The high levels of U.S. oil imports and the near-absolute dependence of U.S. transportation on oil—as well as a similar or worse situation for its major allies—represent a threat to U.S. energy and economic security. Yet, neither the price of gasoline nor the prices of other cost components of petroleum-based transportation includes any premium or tax directed at reducing the danger or potential cost to the U.S. economy of a future oil disruption or at establishing a fund to pay for future actions the United States might be forced to take to prevent or reverse such a disruption. This threat to U.S. security is one of several external costs whose absence from the price of travel artificially boosts oil consumption above the level that would be achieved if these prices reflected the full social costs of travel. There are severe disagreements, however, about the magnitude of the costs associated with this security loss.

If domestic oil production continues to fall and U.S. oil demand continues to increase, oil imports will soon surpass 50 percent of consumption. Congress clearly viewed the high levels of oil imports of the 1970s as a threat and responded with extensive legislation establishing programs to promote synfuels development, tax incentives for energy conservation and alternative energy sources, an extensive energy research and development program, and the construction of the Strategic Petroleum Reserve (SPR). In addition, Congress appropriated funds to establish military forces specifically designed to deal with threats far from established U.S. military bases (e.g., in the Middle Eastern oil fields).

Industry supporters of congressional measures to fight increases in U.S. oil imports, especially measures to boost domestic oil production, have portrayed the potential import increases in precisely the same manner—as a serious threat to the security and long-term economic interests of the United States. These individuals, as well as supporters of conservation-oriented import reduction strategies, have pointed to its large expenditures during the Desert Storm campaign in the Persian Gulf as one cost of U.S. oil import dependency.[64]

Will reducing U.S. oil imports cause an improvement in energy security if even the reduced level is a large portion of total supply? And, conversely, will allowing imports to increase adversely affect security? After all, the United States will remain vulnerable to economic and military disruptions associated with Persian Gulf instability whether it is importing 30 percent of its oil or 70 percent, because any price increases attributable to that instability will affect all world oil supplies simultaneously and because U.S. agreements with its allies require sharing the effects of any widespread shortages.

It does matter to U.S. energy security whether import levels are lowered or raised. Lower imports would reduce pressures on worldwide oil supply, at least for a time, lowering the probability of a disruption in supplies and/or a rapid price increase. Also, higher oil prices would likely damage a U.S. economy importing 70 percent of its oil more than an economy importing 30 percent, because more of the added energy expenditures

64 Critics of this viewpoint would point out that attributing to U.S. oil vulnerability all costs of actions such as those Of Desert Storm ignores the other geopolitical considerations at stake, including a desire to protect our European allies and U.S. recognition of the long-term danger to the region of allowing a dictatorial regime to swallow its neighbor and gain access to the enormous wealth of the Kuwaiti oil fields (and the weapons purchases and development this wealth would allow).

would be recycled into the U.S. economy in the latter case. Further, to the extent that lower imports were caused by lower oil consumption-and conservation would yield this result—the effects of a rapid price increase would be reduced simply because the economy would be faced with paying for fewer barrels of higher-priced oil (or oil equivalent). Finally, if a percentage of U.S. highway travel relied on fuels whose prices were somewhat buffered from world oil prices, which is possible under certain circumstances,[65] the economic impact of an oil price shock would be still less.

The two different import levels may also differ in the degree to which the U.S. economy could quickly reduce its oil use to compensate for a shortage. Ironically, an economy with higher imports and oil use, though more vulnerable to damage from an oil shock, may have more options to quickly reduce its oil use; the more oil-efficient economy may already have undertaken many of the available options before a shock occurred.

Extent of the Security Threat

There is little doubt that an oil security threat to the United States still exists. There are four basic elements to this threat—the dependence of the U.S. transportation sector on petroleum: the limited U.S. potential to increase oil production; the preponderance of oil reserves in the Middle East/Persian Gulf; and the basic political instability and considerable hostility to the United States existing there. At least two (transport dependence and limited U.S. production potential) are as true today as they were in the early 1970s at the time of the Arab oil boycott.

In fact, in some ways these elements have grown more severe. For example, during 1973-92. the transportation sector's share of total U.S. petroleum use grew from 52 to 64 percent. This is particularly important because the sector's prospects for fuel switching in an emergency are virtually zero. In addition, the boom-and-bust oil price cycle of the postboycott period, and especial] y the price drop of 1985-86, created a wariness in the oil industry that would substantially delay any major boost in U.S. drilling activity in response to another price surge. With the passage of time, the industry's infrastructure, including skilled labor, that would be needed for a drilling rebound has been eroded. Further, environmental restrictions have placed much offshore oil off limits to drilling.

Despite the continuation of basic security problems outlined above, an examination of differences between the U.S. and world energy situation in the 1970s and the situation today shows some important positive changes:[67]

- the existence of the Strategic Petroleum Reserve and increased levels of strategic storage in Europe and Japan;
- increased diversification of world oil production since the 1970s:
- the end of U.S. price controls, allowing quicker market adjustment to price and supply swings:
- the advent of the spot market and futures market, making oil trade more flexible;
- the increasing interdependence of the world economy, particularly the major investments of the Organization of Petroleum Exporting Countries (OPEC) in the economics of the Western oil-importing nations and, especially, their oil-refining and marketing sectors;
- reduction or elimination of the large cash reserves of Persian Gulf exporters, reducing their ability to absorb the financial losses associated with an embargo;

[65] For example, if feedstocks for producing the fuel had no other uses that might compete with oil, and if the vehicles using this fuel were dedicated rather than flexible fuel.

[66] U.S. Department of Energy, Energy Information Administration, *Annual Energy Review 1992*, DOE/EIA-0384(92) (Washington, DC: June 1993), table 5.11.

[67] For a more detailed discussion of shifts in world oil markets, see U.S. General Accounting Office, *Energy Security: An Overview of Changes in the World Oil Market*, GAO/RCED-88-170 (Washington, DC: August 1988).

- a lessening of the strategic importance of the Gulf of Hormuz due to diversification of transport routes out of the Gulf;
- the growing importance of natural gas and its substitutability for oil in key markets;
- political changes in the Eastern Bloc nations and the resulting lowering of tensions between East and West (although this is counterbalanced somewhat by growing tensions among nations in the former Eastern Bloc);
- new prospects for developing oil resources in the Far East (e.g., Vietnam) and the former Soviet Union;
- demonstration in the North Sea that new technology, cost-cutting design and management, and more sympathetic tax and royalty structures can increase enormously the resource and production potential of areas once thought "mature"; and
- a general lessening in Arab hostility to the United States, associated in part with U.S. sponsorship of Arab-Israeli peace negotiations and its role in liberating Kuwait. Another positive sign in the area is the decline of Mideast-connected international terrorism. A potential counterbalance is the growing tension between the religious and secular communities in the Mideast.

This variety of changes in world oil markets can be summarized as a general shift to more flexible and responsive markets, with closer economic ties between oil producers and users, improved overall supply prospects, and improved capability for effective *short-term* responses to market disruptions.

The overall effect of this complex series of changes and adjustments since the early 1970s has likely been a net improvement in U.S. and world energy security, at least for the short term. A substantial disruption of oil markets is probably less likely now than it was then, and the industrial nations appear better equipped to handle a disruption if one were to occur, especially over the short term. Further, the recent political changes in the Soviet Union and its Eastern Bloc neighbors are redefining basic perceptions about the nature of U.S. national security problems. Nevertheless, it remains true now, as it did then, that the lion's share of the world's oil reserves lies in the Persian Gulf nations, that these nations have most of the world's excess oil production capacity, that they remain politically shaky, and that there exist groups extremely hostile to the United States even in those nations we consider our friends. As long as this is true and as long as a sharp price shock would be disruptive to the U.S. economy (although the magnitude of the disruption is in dispute), policy makers must still count the effects on energy security as an important factor in judging proposed energy policy measures. However, the relegation of energy security from the "number one energy issue" status that it held in the 1970s to the somewhat lower status that it has today, seems to be a reasonable response to both a reduced security risk and an increased concern about environmental issues.

Also, policy makers should recognize that the U.S. balance between domestic and imported energy is enviable compared with most of the developed world. Whereas U.S. oil imports for 1992 were about 41 percent of oil consumption (and less than 20 percent of total energy consumption), the European OECD nations imported about two-thirds of their oil, and Japan all of its oil and most of its energy. However, this difference might be interpreted in the opposite fashion: that it illustrates further the U.S. dilemma because of our close economic and military ties to the OECD nations. Further, the U.S. advantage in its overall reliance on domestic energy sources is partially canceled by its relatively higher level of oil use per unit of gross national product (GNP) and per capita. As discussed in chapter 3, for example, both the Japanese and the Europeans use far less oil per capita than the United States for passenger transport, and far less per unit of GNP for freight transport. This means that oil price increases driven by market disruption would tend to hurt the American economy more than either the European or the Japanese economies.

Impact of Conservation on Security

In examining the impacts of transportation conservation initiatives on U.S. energy security, it is important to recognize that different categories of initiatives will have different impacts. It is worthwhile to examine separately three categories of conservation initiatives:

1. improvement in the long-term technical efficiency of transport;
2. changes in behavior that reduce energy use (e.g., in load factor, driving patterns, and maintenance); and
3. switching from oil-based to alternative fuels.

Improvements in technical efficiency change the capital and management structure of transportation (e.g., by improving the basic fuel economy of vehicles, by smoothing traffic flow with improved signaling, or by using computer-aided scheduling and management to improve load factors in freight hauling). Generally, these improvements occur slowly and require substantial capital investment over time. Thus, the improvements are not available to serve as a short-term response to an oil shock, and their implementation does not "use up" a potential strategy for managing such a shock. Therefore, cost-effective improvements in energy-efficiency technology are unambiguously beneficial to U.S. energy security.

Changes in behavior—such as improving engine maintenance in automobiles, forming carpools, inflating tires properly, using better trip planning—reduce oil use at low cost and will reduce the immediate economic shock of an oil disruption. These measures yield environmental and long-term economic benefits. Ironically. however, their implementation well in advance of a price shock will reduce somewhat the ability of the economy to respond to a disruption. Although deliberately leaving some "slack" in oil consumption is by no means recommended-it almost certainly has fewer benefits than costs--conservation-oriented changes in short-term behavior may have smaller energy security benefits than would improvements in technical efficiency.

The development of alternative transportation fuels can have a positive effect on energy security by diversifying supply sources or getting supplies from domestic or more secure foreign sources, easing pressure on oil supplies through reduced demand for gasoline, and reducing the impact of an oil price shock. The magnitude of the effect will depend on the feedstock used for the fuel, the volume of alternative fuel use, the selection of dedicated vehicles or flexible fuel vehicles, and so forth. The magnitude of any subsidies is important as well. Large subsidies of "secure" energy sources can backfire because the subsidies themselves may harm U.S. economic efficiency and competitiveness. Policy makers must carefully balance the value of establishing alternatives to foreign oil imports against the market distortions of large subsidies.

Although the security benefits of some fuels are indisputable, analysts disagree about others. Fuels such as electricity,[68] hydrogen, and ethanol are likely to be produced domestically and thus unambiguously advantageous to energy security (again, *if* they can be produced cheaply enough), although ethanol current dependence on intensive corn production,[69] which may suffer on occasion from drought, may make it less secure than the others. Natural gas would likely rely on domestic supplies or gas pipelined from Canada or Mexico, although supply requirements above a few trillion cubic feet per year could strain these sources--especially if gas usage for other sectors continues to increase. With secure sources, natural gas use should be beneficial to energy security.

[68] Strictly speaking, electricity is not a fuel, but it is convenient to categorize it as such in this discussion.

[69] Continuing advances in producing ethanol from wood, wood waste, and wastepaper could break this dependence.

However, natural gas competes with both residual oil and middle distillate in commercial and industrial markets. Higher gas prices, which could result from large-scale transportation use, would lead to some shift from gas to oil in these markets, thereby increasing oil imports. Thus, the oil "saved" by shifting to gas in vehicles would not reduce imports on a one-for-one basis.

Methanol could be produced domestically in substantial quantities,[70] although it is also quite possible that a large portion of methanol supplies would be imported from countries with large gas reserves. In the latter case, methanol effect on energy security will depend on which countries enter the market, the type of financial arrangements made between producers and suppliers, the worldwide price relationship between natural gas and oil (i. e., will a large oil price rise automatically raise gas—and methanol—prices?), and other factors. Because two-thirds of the world's gas reserves reside in the Middle East and the Eastern Bloc, some analysts deny that the United States would receive any security benefit from turning to methanol. The Nation *can* derive a security benefit even if much of the methanol were imported, because methanol use will reduce pressures on world oil supplies; also, strategies such as establishing long-term trade pacts with secure methanol sources could enhance the potential benefits.

Positive effects on energy security of alternative fuels use could be reduced or canceled if automakers claim corporate average fuel economy (CAFE) credits for the alternatively fueled vehicles they manufacture and reduce their actual fleet fuel economy below the levels they would have attained had the credits not been available (see chapter 5, section on alternative fuels) .7] The likelihood that CAFE credits will be used in this fashion is in dispute, but the probability that they will be used to depress actual fleet fuel economy will increase steeply if CAFE standards are raised without a shift in the relative indifference to fuel economy currently demonstrated by car purchasers,

There is one energy security issue that cuts across the various categories of conservation measures. A large reduction in U.S. oil demand, whatever the cause, could serve to reduce world oil prices. Lower prices would boost the United States and world economies but would also depress U.S. oil production which would then have to be made up with imported oil. The effect would be to reduce the drop in oil imports that would otherwise be expected, thus reducing the net benefit to energy security. There is considerable uncertainty about the sensitivity y of world oil price to demand, but it is likely that a drop of a few million barrels per day (mmbd) would be needed to sustain a long-term drop in world oil prices.[72]

Energy Security Costs

Some analysts have attempted to measure in dollar terms the energy security costs of using imported oil and thus the energy security *value* of re-

[70] The economics of conventional methanol production depend substantially on the resource cost, interest rates, distance from markets, and availability of support infrastructure. Current low gas costs and interest rates in the United States, coupled with U.S. superiority with regard to availability of infrastructure and closeness to markets, imply that domestically produced methanol can be competitive with methanol produced from inexpensive remote gas and shipped to the United States. The longevity of these favorable conditions is unclear, however. An alternative mode of production—methanol as a coproduct of steel production—might also serve to supply competitive domestic methanol to U.S. markets.

[71] Automakers producing an alternatively fueled vehicle are allowed to record that vehicle's fuel economy according to the amount of o11-based fuel consumed. In other words, a vehicle consuming only a blend of 90-percent methanol and 10-percent gasoline would have a recorded fuel economy approximately 1() times as high as its counterpart vehicle consuming gasoline {rely. By manufacturing large numbers of such vehicles, automakers would artificially raise their fleet fuel economies, thus giving them "headroom" to reduce the fuel economy of the remainder of their fleets.

[72] One Department of Energy model projects a $0.93 per barrel drop in w (mid oil prices in response to a 2.5-mmbd reduction in U.S. demand. Philip Patterson, U.S. Department of Energy, personal communication, 1993.

ducing oil imports. (Note that these costs do not necessarily represent the *total* net security value of reducing imports, because the measures taken may have their own security costs. This is especially true for alternative fuels requiring importation of the fuels themselves or their feedstocks.) The types of costs associated with energy security include the following:

- *Risks of an oil disruption.* Most of the costs to the economy of occasional disruptions to world oil supply—lost productivity, inflation, and so forth—are not included in the price of oil, even though such disruptions have happened three times in the past and almost certainly will occur again. To the extent that significant reductions in oil use and oil imports would lower these costs,[73] their inclusion in oil prices and the incentive to reduce consumption provided by their inclusion corresponds to an actual benefit to the U.S. economy. The Congressional Research Service (CRS) has estimated costs for the disruption risk of $6 billion to $9 billion, or 5 to 7 cents per gallon of motor fuel, after accounting for the protection offered by the SPR, greater private reserves, and the advent of the oil futures market.[74] Other analyses offer alternative estimates of disruption costs ranging from near zero to levels considerably higher than the CRS estimates.[75]
- *Market power associated with oil use reductions.* Theoretically, a substantial reduction in U.S. oil use could create world excess oil production capacity and reduce world oil prices, which would benefit the U.S. economy as well as that of oil importers worldwide. Because individual oil users would not consider such benefits-their actions cannot alone have any effect on world prices—this potential benefit of oil use reduction will be lost unless it is directly incorporated into oil prices or indirectly accounted for by regulatory controls on consumption. Controversy about the magnitude of this benefit of use reduction (cost of consumption) stems primarily from disagreement about the magnitude of reduction necessary to have any effect on price, uncertainty about the potential for OPEC to respond successfully to a drop in oil demand (by decreasing production), and how long the benefit would last. CRS's estimate of this so-called monopsony component of an oil price premium is $21 billion to $24 billion, or 17 to 20 cents per gallon.[76]
- *National security expenditures.* The United States spends large amounts on military expenditures related to oil use, for example, rapid deployment forces that can be targeted to Middle East flashpoints. Desert Storm cost more than $61 billion, although much of this was paid by U.S. allies.[77] Allocation of these costs to actual oil costs is highly uncertain, however. In particular, U.S. military expenditures are linked to complex geopolitical considerations wherein oil security is only one of several elements; and the extent to which U.S. oil use drives military expenditures is dependent on administration and congressional *perceptions* of oil security, which may be different from reality. Further, the U.S. military stake in the Middle East is

[73] By easing oil markets and thus reducing the *risk* of a disruption occurring, and by reducing the volume of capital exported from the U.S. economy to the exporting nations in the event of a disruption.

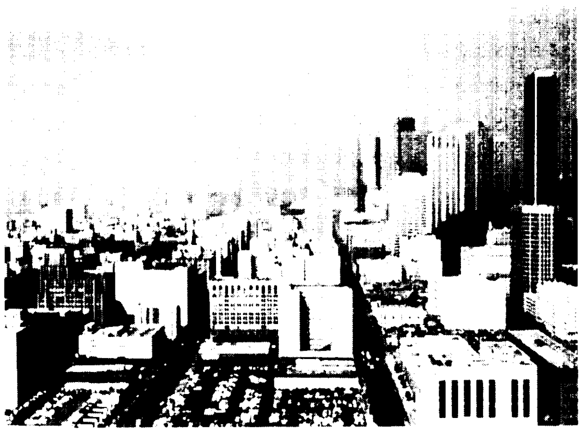
[74] Congressional Research Service, Environment and Natural Resources Policy Division, "The External Costs of Oil Used in Transportation," June 3, 1992.

[75] See for example D.R. Bohi, *Energy Price Shocks and Macroeconomic Performance* (Washington, DC: Resources for the Future, 1989) for a rationale for very low estimated disruption costs. Greene and Leiby (D.L. Greene and P.N. Leiby, *The Social Costs to the U.S. of Monopolization (~I the World Oil Market, / 92-i 99/*, OR NL-6744 (Oak Ridge, TN: Oak Ridge National Laboratory, January 1993) estimate disruption costs (macroeconomic adjustment costs) of $0.8 trillion to $1.3 trillion (1990 dollars) over the 20-year period oil used. Although this value is a 20-year average cost and does not reflect current conditions, it still appears to imply a higher disruption cost than the CRS value.

[76] Ibid.

[77] Ibid.

SCAQMD



Los Angeles has the Nations most severe ozone pollution problem Urban air pollution remains a crucial national problem more then two decades after passage of the Clean Air Act

complicated by U.S. obligations to its allies in the event of an oil disruption; these obligations may limit the reductions in military costs that might otherwise be expected to follow U.S. reductions in oil use. Alternative estimates of annual oil-related expenditures for defense of the Middle East-Persian Gulf region range from less than $0.5 billion annually to $50 billion and higher.[78] Alternative ways of allocating these costs yield a range of 1.5 to 30 cents per gallon.

OZONE POLLUTION AND TRANSPORTATION[79]

Although past transportation energy conservation initiatives have aimed primarily at reducing oil use or at relieving transportation service problems such as congestion, the motivation for many conservation initiatives during the past few years has been the relief of urban air pollution problems, particularly ozone-related problems. Today, more than two decades after the Clean Air Act original passage, about 100 urban areas (depending on weather conditions) still violate the National Ambient Air Quality Standard for ozone.[80]

Since 1970, Federal and State governments have maintained separate but interacting roles to handle ozone control, with the Environmental Protection Agency (EPA) setting nationally uniform ambient air quality standards and New Source Performance Standards,[81] and the States, with EPA's help and oversight, developing and enforcing detailed implementation plans[82] to attain the air quality standards. Based on ozone's known health effects, the standard is currently set at a peak, 1 -hour average ozone concentration of 0.12 part per million (ppm). Any area experiencing concentrations exceeding the standard more than once a year, on average, is declared a nonattainment area. EPA updates the nonattainment list annually, as data become available. The list in 1991 included cities housing about 140 million people.[83]

Why Control Ozone?

The O. 12-ppm national standard for ozone derives from solid evidence of the health effects of short-term exposure above that level. Excessive ozone is harmful to people. Even healthy adults and children can experience coughing, painful breathing, and temporary loss of some lung function after

[78] Ibid.

[79] Except where otherwise referenced, the information in this section is based on U.S. Congress, Office of Technology Assessment, *Catching Our Breath: Next Steps for Reducing Urban Ozone*, OTA-O-412 (Washington, DC: U.S. Government Printing Office, July 1989).

[80] U.S. Environmental Protection Agency, *National Air Quality and Emissions Trends Report, 1991*, 450-R-92-001 (Washington, DC: October 1992).

[81] That is, emission and emission control technology standards for large new individual sources of air pollution (e.g., a new powerplant or refinery).

[82] Which include emission standards for both existing emission sources and new sources not subject to Federal standards, regulations to control development in especially polluted areas, and so forth.

[83] U.S. Environmental Protection Agency, op. cit., footnote 80.

about an hour or two of exercise at peak concentrations found in nonattainment cities.

Experts are unsure whether the current standard adequately protects people who are exposed for long periods or at high exercise levels. Several studies over the past 5 years have shown temporary loss of some lung function after an hour or two of exposure at concentrations between 0.12 and 0.16 ppm, among moderately to heavily exercising children and adults. And despite the current standard's emphasis on a 1 -hour peak, real-life exposures to near-daily maximum levels can last much longer; ozone levels can stay high from midmorning through late afternoon. With exposure during 6 hours of heavy exercise, temporary loss of some lung function can appear with ozone levels as low as 0.08 ppm.

Potentially more troubling and less well-understood are the effects of long-term, chronic exposure to summertime ozone concentrations found in many cities. Regular outdoor work or play during the hot, sunny summer months in the most polluted cities might, some medical experts believe, cause biochemical and structural changes in the lung, paving the way for chronic respiratory disease. To date, however, evidence of a possible connection between irreversible lung damage and repeated exposure to summertime ozone levels remains inconclusive.

Aside from damage to human health, ozone pollution damages the natural and managed environments. In particular, clear evidence shows that ozone damages economically, ecologically, and aesthetically important plants. When exposed to ozone, major annual crops produce reduced yields. Some tree species suffer injury to needles or leaves, and lowered productivity; in severe cases, individual trees can die. Important tree species are seriously affected in large areas of the country. In the most heavily affected forested areas, such as the San Bernardino National Forest in California, ozone has begun altering the natural ecological balance of species.

Whether or not the current standard is adequate, many areas of the country have failed to meet it. About half of all Americans live in areas that exceed the standard at least once a year. In 1991,74 of 98 EPA-designated nonattainment areas were classified either as marginal or moderate, 14 were classified as serious, nine as severe, and one (Los Angeles) as extreme.[84]

Ozone and Its Precursors

Ozone is produced when its precursors, volatile organic compounds (VOCs) and nitrogen oxides (NO_x), react in the presence of sunlight. VOCs, which include hundreds of specific compounds, come from both natural and human-made sources, the latter including automobile and truck exhaust, evaporation of solvents and gasoline, chemical manufacturing, and petroleum refining. In most urban areas, such human-made sources account for the great majority of VOC emissions, but in the summer in some regions, natural vegetation may produce an almost equal quantity. NO_x arises primarily from fossil fuel combustion. Major sources include highway vehicles, and utility and industrial boilers.

Ozone control efforts have traditionally focused on reducing local VOC emissions, partly because the relevant technologies were thought to be cheaper and more readily available, In some areas, however, controlling NO_x is more important than controlling VOCs. However, *under some conditions at some locations,* reducing NO_x can be counterproductive because of the peculiarities of ozone formation chemistry.[85]

Local controls on VOC emissions cannot completely solve the Nation's ozone problem. In many places, even those with good control of local emissions, reducing ozone is complicated by the "transport" of pollutants as ozone or precursors

[84] Ibid.

[85] Although NO_x is an ozone precursor, it also can destroy ozone when NO_x/VOC ratios are high.

originating elsewhere are carried in by the wind. “Plumes” of elevated ozone have been tracked 100 miles or more downwind of some cities: the Greater New York area’s plume, for example, can extend all the way to Boston. More than half of the metropolitan areas that failed to attain the ozone standard between 1983 and 1985 lie within 100 miles downwind of other nonattainment cities. In such cases, VOC (and sometimes NO_x) reductions in the upwind cities could probably improve the air quality of their downwind neighbors. Indeed, reductions in certain areas that are themselves already meeting the standard might also aid certain downwind nonattainment areas.

The significance of transported pollutants varies substantially from region to region and day to day. During severe pollution episodes lasting for several days, for example, industrial or urban NO_x or ozone pollution can contribute to high ozone levels hundreds of miles away. In certain heavily populated parts of the country, pollution transport is a significant and very complex problem. The Northeast Corridor, from Maine to Virginia, contains 21 nonattainment areas in close proximity; California contains eight; the Gulf Coast of Texas and Louisiana, seven; and the Lake Michigan area, five.

Controlling Volatile Organic Compounds

Since 1970, reducing VOC emissions has been the backbone of U.S. ozone control strategy, and the Nation has made substantial progress, at least in slowing further degradation from preexisting conditions. According to EPA estimates, VOC emissions were reduced by 13 percent during 1982-91;[86] without existing controls, they would have grown considerably during this period. Despite this progress, however, large areas of the country have missed each of several 5- and 10-year deadlines set by Congress-the original deadline of 1975, and again in 1982 and 1987.

In 1982, highway vehicles accounted for about 45 percent of all VOC emissions; in 1991, their share had been reduced to about 35 percent[87] through implementation of tighter emission controls, retirement of older vehicles, and institution of limits on gasoline volatility.

If we are willing to use and pay for currently available technology, we can make significant advances over the next 5 to 10 years, achieving about two-thirds of the emissions reductions in nonattainment areas needed to meet air quality standards. This should bring about half of current nonattainment areas into compliance. However, by the year 2000, the entire Nation cannot reach the goal that Congress established in 1970. In the worst areas, even the most costly and stringent of available measures will not lower emission levels sufficiently to meet the standard. Achieving that goal is a long-range project, well beyond the 5- and 10-year horizons of existing law. It will require both new technologies and lifestyle changes in the most affected communities, including changes in transportation, work, and housing patterns.

To meet ozone standards in all cities, new, nontraditional controls, with uncertain costs, must be used. One of these controls involves significantly reducing the use of motor vehicles, especially private cars. Although technologically simple, this is politically difficult. The 1977 amendments to the Clean Air Act required urban areas to implement whatever measures were needed to attain the ozone and carbon monoxide standards, including transportation control measures (TCMs). Experience shows, though, that TCMs require considerable local initiative and political will because they aim to change the everyday habits and private decisions of hundreds of thousands of people. Involuntary TCMs have proven politically infeasible, and voluntary programs difficult to sustain. Success requires long lead times, priority in urban transportation and land use planning, a high degree of public support and participation, and in

[86] U.S. Environmental Protection Agency, op. cit., footnote 80.

[87] Ibid.

some cases such as mass transit development, major capital expenditures. Possible tactics include requiring staggered work hours; encouraging carpools through inducements such as priority parking places, dedicated highway lanes, and reduced tolls; constructing attractive and economical mass transit systems; limiting available parking places; and encouraging employers to locate closer to residential areas, which could cut the distances workers have to travel.

As with the other external costs of transportation energy use, estimates of the costs of ozone-related air quality damage to public health and welfare are controversial because of both scientific disagreements and differences in value judgments. Calculating these costs means constructing a credible inventory of transportation emission sources, estimating resulting pollution concentrations in ambient air, transforming these concentrations into damage estimates, and computing the monetary costs of the estimated damages—and none of these steps is without controversy. For example, even the emission inventory, presumably the most easily measured of the four steps, is subject to considerable error because the available emission tests do not accurately replicate actual driving conditions (e.g., tests performed during inspection and maintenance programs miss the cold start, which is the critical period for emissions and, because they do not use a dynamometer, do not capture the true effects of acceleration).

OTA has investigated the monetary costs of transportation-related ozone damage, focusing primarily on health impacts and damage to commercial crops and forests. The quantifiable health impacts of reductions in ozone concentrations involve primarily the reduction in numerous episodes of respiratory discomfort--coughing, chest pain, shortness of breath—among many of the over 100 million persons living in nonattainment areas. Meeting the ozone standard everywhere would avoid several hundred million of these episodes each year, with some people in the worst areas experiencing dozens fewer incidents of respiratory symptoms annually. About 8 million to 50 million person-days per year of restricted activity may be eliminated; these are days when someone feels ill enough to limit the day activities, if not necessarily to stay in bed or home from work. Most of the benefit would be concentrated in high ozone areas such as southern California and the Northeast corridor cities. The economic value of eliminating these short-term effects might be about $0.5 billion to $4 billion a year, a large fraction of which will be transportation-related benefits,[88] with most benefits concentrated in high-ozone areas such as southern California and the Northeast Corridor. *Although the value of the decreased risk of long-term, chronic effects of ozone exposure cannot be estimated, these potential effects remain a strong concern.*

OTA has also examined the potential effects on agriculture of reduced ozone concentrations. These estimates are complicated by the current inability to reliably predict the impact that VOC and NO_x control measures would have on ozone concentrations in rural areas (partly because current ozone concentrations in areas where crops are grown are not accurately known) and uncertainty about how farmers will respond to improved growing conditions in their planting operations. For a reduction in rural ozone of 50 percent of the difference between current levels and background concentrations, agricultural benefits are estimated to be $1.01 billion to $1.91 billion annually, primarily from improved yields of corn, soybeans, wheat, and cotton. with most benefits occurring in California, the South, and the Northeast.[89] With the likelihood that nontransportation controls would be very limited in rural areas, much of this

[88] If 40 percent of the ozone reduction is caused by reductions in transportation emissions, transportation-related benefits would be about $0.2 billion to $1.6 billion per year. However, the 40 percent value is simply speculation.

[89] Based on two models using different methodologies and assumptions. See U.S. Congress, op. cit., footnote 20.

benefit might be attributed to transportation controls.

The Congressional Research Service estimates transportation-related ozone damage to forests of $0.1 billion per year, incorporating both damage to recreational values and damage to the forest materials resource.[90]

OTHER EXTERNALITIES

Aside from ozone pollution, energy security, and greenhouse warming, other transportation externalities are important and should be considered in evaluating alternative transportation policies or full cost accounting. These include:

- other air pollution damages;
- aesthetic losses from facilities or vehicles;
- noise pollution;
- vibration damage, especially from highways and railroads;
- water pollution, especially from roadway runoff—also, loss of groundwater recharge and absorptive capacity for flood prevention from highway land use;
- accident impacts on nonusers or on society (e.g., lost productivity) that are not compensated by user insurance or other payments;
- ecosystem losses from highways, airports, etc.; and
- effects on energy efficiency, economic vitality, open space, ecosystem protection, and other values caused by the patterns of land use associated with transportation choices.

Although attempts have been made to quantify these costs,[91] they remain uncertain for reasons of inadequate data on the magnitude of the impacts, disagreement about their monetary valuation, and ambiguity about where to draw the boundaries to separate externalities from impacts borne by users. Further, with air pollution excepted, these externalities are not tied as directly to oil use, or energy use, as the initial three (ozone pollution, energy security, and greenhouse warming). Although reducing energy use by reducing travel demand or shifting modes will tend to reduce (or at least change) these externalities, improving technical efficiency (e.g., by improving auto fuel economy) will not; levels of accidents, road capacity requirements, aesthetic losses, and other externalities will be essential y unchanged despite the reduction in oil use.

Other Air Pollutants

Aside from ozone, key transportation-related air pollution problems include emissions of carbon monoxide (CO) and fine particulate matter.

Excessive levels of CO are associated with aggravation of angina pectoris in individuals with heart disease, occasional deaths from suicide and faulty vehicle exhaust systems, and widespread cases of headache and other low-level health effects. About 70 percent of national emissions of CO are vehicle exhaust emissions.[92]

Particulate air pollution—solid particles and liquid droplets—has been associated with a variety of adverse health effects; elevated particulate levels can lead to respiratory symptoms such as cough, shortness of breath, and asthma attacks and have been associated with increased rates of hospitalization, restricted activity due to illness, and chronic respiratory disease. Of greatest concern are fine particulate, those smaller than 10 mi-

90 Congressional Research Service, op. cit., footnote 74.

91 For example, M.E. Hanson, "Automobile Subsidies and Land Use: Estimates and Policy Responses," *Journal of the American Planning Association*, vol. 58, No. 1, 1992, pp. 60-71; B. Ketcham, "Making Transportation a National priority," paper presented at panel discussion on "Transportation as a Matter of Choice," Snowmass, CO, Oct. 6, 1991; J.J. MacKenzie et al., *The Going Rate: What It Really Costs to Drive* (Washington, DC: World Resources Institute, 1992) all discussed in M.E. Hanson, "Results of Literature Survey and Summary of Findings: The Nature and Magnitude of Social Costs of Urban Roadway Use," paper prepared for the U.S. Department of Transportation, Federal Highway Administration, 1992.

92 U.S. Environmental Protection Agency, *National Air Quality and Emissions Trends Report, 1991*, 450-R-92-001 (Washington, DC: October 1992).

crons that can evade the normal defense mechanisms of the human respiratory system, penetrating deep into the lungs. Epidemiologic studies have shown a statistical association between high levels of fine particulate and premature deaths.[93] Key problem areas for highway vehicles include carbon particles from diesel-powered vehicles, particulate formed from hydrocarbon emissions, sulfate particles from diesel and gasoline-powered vehicles, and fine particulate associated with tire wear. Because requirements for diesel fuel and reformulated gasoline include reduced sulfur levels, fine particulate problems associated with sulfate emissions from vehicles should decrease in the future.

Land Use Impacts

As discussed in chapter 5, transportation choices and land use are linked by the varying direct land requirements of alternative transportation modes, the minimum population density requirements of mass transportation modes, and the different types of mobility—and thus the differing levels of practicality for certain locational choices--offered by alternative modes. Although the linkages between land use and transportation are not absolute, urban areas whose transport systems are based primarily on automobiles tend to be far less dense than areas relying primarily on mass transit, with more emphasis on single-family housing than on apartments, less likelihood of walking access to services, and so forth. Automobile-based land uses generally are more energy-intensive than those based on mass transportation, even if direct transportation energy costs are disregarded, because of the higher heating and cooling costs of single-family residences and other factors, Although these costs are not externalities-they are borne directly by "users," if all residents of such developments are at least indirectly users of the dominant transportation system—some or all of the external costs associated with increased nontransport energy use should be charged to the transportation system choice.

Aside from higher energy costs, the type of dispersed land use and economic development associated with automobile-oriented transportation systems has other costs that may be considered, at least in part, transportation externalities. One such cost is disinvestment in downtown areas as retail stores relocate to suburban malls. upwardly mobile families move to the suburbs. and businesses move to office parks; with such trends. social services become more difficult to deliver, job opportunities for inner-city residents shrink. and city neighborhoods decline.[94]

Accidents

Accidental deaths and injuries associated with different transportation modes represent large external costs and subsidies to the transportation system because of the nature of the damages and the way society pays for them, and because a significant percentage (about 17 percent[95]) of the damages occur to persons who are only peripheral users of the modes (e.g., pedestrians and bicyclists). According to a recent FHWA-sponsored study, highway accidents caused $358 billion in damages in 1988.[96] Most of the physical damage occurs to drivers and passengers, but the monetary component of this damage (property damage, medical expenses. ambulance costs. etc.) is paid for only part] y out of auto insurance, as discussed above, and thus there is a substantial subsidy to

[93] D.W. Dockery et al,. "An Association Between Air Pollution and Mortality in Six U.S. Cities," *New England Journal of Medicine*, vol. 329, No. 24, Dec. 9, 1993.

[94] L.S. Bourne, "'Self-Fulfillmg Prophecies? Decentralization, Inner City Decline, and the Quality of Urban Life,'" *American Planning Association Journal*, autumn 1992, pp. 509-513.

[95] National Safety Council, *Accident Facts, 1990 Edition* (Chicago, IL: 1990), cited in MacKenzie et al., op. cit., footnote 91.

[96] Urban Institute, *The Costs of Highway Crashes*, FHWA-RD-91-055 (Washington, DC: U.S. Department of Transportation, Federal Highway Administration, June 1991), cited in MacKenzie et al., op. cit., footnote 91.

the transportation system. The negative effect on society and the economy of lost productivity due to accidents, especially where accident victims have skills that are not easily replaced, may represent a large externality; depending on where analytic boundaries are drawn, so may the component of damages to "peripheral users" that is not paid by auto insurance or directly by the responsible drivers.

Noise and Vibration

Noise and vibration from highway vehicles, railroads, and airplanes strongly affect quality of life, reduce property values, and in the case of vibration, do structural damage. People and property alongside rights of way or under flight paths are the most affected. Data to estimate vibration damage are inadequate. Examination of changes in property values with decibel levels can lead to highway noise damages estimated at several billion dollars per year, primarily due to heavy trucks.[97]

Ecosystem Losses

Both the direct land requirements of transport systems and the requirements of the land uses they support have significant impacts on ecosystems. The value of these losses is controversial, particularly the loss of prime farmland around cities, because there is severe disagreement about the adequacy of U.S. cropland resources for future needs. If long-term annual increases in crop yields continue at historic rates, the effect on U.S. food production capability of cropland losses from roadbuilding and the urban sprawl that our auto-oriented system supports will be small or, from a practical standpoint, nonexistent. However, many in the environmental community believe that increases in crop yields cannot continue, that we are reaching the natural limits of an agricultural system based on high levels of chemical input, and that losing high-quality cropland to urban and suburban development will force agriculture onto ever more marginal land and soon begin to limit production. This is an extremely controversial issue; there is nothing in the statistical record to indicate an imminent slowdown in yield increases, and many in the agricultural community look to genetic engineering to provide another long-term round of yield increases, but data on erosion rates (which have been higher than soil replacement rates for years), pesticide usage and growing immunity problems, and other factors cause great concern.

97 MacKenzie et al., op. cit., footnote 9 l, Decibel levels are correlated with type of roadway, amount and nature of traffic, and air pollution levels, all of which can affect property values (e.g., the safety, aesthetic, pollution, and congestion impacts of a roadway may vary in step with decibel levels and impact property values in the same direction). This type of collinearity makes it quite difficult to separate the effect of a single variable and makes quantitative estimates somewhat suspect.

Policy Options for Transportation Energy Conservation

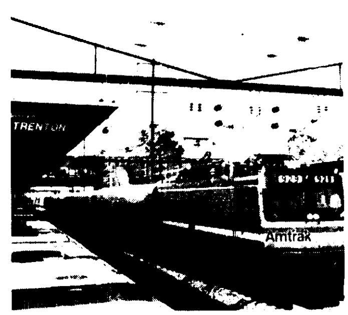
5

Policymakers interested in transportation energy conservation-whether for reducing oil use, lowering emissions of greenhouse gases, or generally reducing energy use and its environmental and economic consequences--are faced with a complex array of conservation activities and a variety of policy options or tools that will promote the activities. The key categories of conservation activities are:

- improving the technical efficiency of existing vehicles, or introducing new, more efficient replacement vehicles;
- increasing vehicle load factors:
- using more efficient travel modes:
- reducing the number and length of trips made; and
- shifting to non-oil-based fuels.

The policy options available to policymakers to pursue the various conservation activities include:

1. *economic incentives--direct* taxes, granting or eliminating tax breaks, subsidies, granting of regulatory exemptions, making pricing more efficient:
2. *public investment---in* research and development (R&D), new infrastructure (including new types of systems and service), maintenance and rehabilitation of old mass transit infrastructure. and expansion of service; also includes withholding investment and investing in urban development, and
3. *regulatory incentives--efficiency* standards, zoning, fuel use requirements, speed limits, inspection and maintenance requirements, and travel restrictions.



In most cases, each of the basic categories of policy options is applicable to each activity, forming a matrix of government actions that can be used to pursue increased efficiency. For exampie, the option of getting travelers to shift to more efficient modes can be pursued with economic incentives in the form of taxes on gasoline and parking, elimination of the treatment of free employee parking as a normal business expense, and higher operating subsidies for transit; public investments in busways and rail transit (also *withholding* of investment from expansion of road capacity); and regulatory incentives in the form of zoning changes designed to increase urban density (increasing the ability of transit systems to achieve high modal shares). Table 5-1 lists each of the

TABLE 5-1: Transportation Conservation Options

Improve the Technical Efficiency of Vehicles

1 Higher fuel economy requirements—CAFE standards (R)
2 Reducing congestion smart highways (E,l), flextime (E, R), better signaling (l), Improved maintenance of roadways (1), time of day charges (E), Improved air traffic controls (1, R), plus options that reduce vehicular traffic
3 Higher fuel taxes (E)
4 Gas guzzler taxes, or feebate schemes (E)
5 Support for increased R&D (El)
6 Inspection and maintenance programs (R)

Increase Load Factor

1 HOV lanes (1)
2 Forgiven tolls (E), free parking for carpools (E)
3 Higher fuel taxes (E)
4 Higher charges on other vmt trip-dependent factors (E) parking (taxes, restrictions, end of tax treatment as business cost). tolls etc

Change to More Efficient Modes

1 Improvements in transit service
  a New technologies—maglev, high speed trains (E,l)
  b Rehabilitation of older systems (1)
  c Expansion of service—more routes, higher frequency (1)
  d Other service improvements (1)—dedicated busways, better security, more bus stop shelters, more comfortable vehicles
2 Higher fuel taxes (E)
3 Reduced transit fares through higher U S transit subsidies (E) [a]
4 Higher charges on other vmt/trip-dependent factors for less efficient modes (E)—tolls, parking
5 Shifting urban form to higher density, more mixed use, greater concentration through zoning changes (R), encouragement of “infill ” development (E, R, I), public Investment in Infrastructure (l), etc

Reduce Number or Length of Trips

1 Shifting urban form to higher density, more mixed use, greater concentration (E,R,I)
2 **Promoting** working at home or at decentralized facilities (El)
3 Higher fuel taxes (E)
4 Higher charges on other vmt/trip-dependent factors (E)

Shift to *Alternative Fuels*

1 Fleet requirements for alternate fuel-capable vehicles and actual use of alternative fuels (R).
2 Low-emission/zero emission vehicle (LEV/ZEV) requirements (R)
3 Various promotions (E) CAFE credits, emission credits, tax credits, etc
4 Higher fuel taxes that do not apply to alternate fuels (E), or subsidies for the alternatives (E)
5 Support for Increased R&D (E,l)
6 Public Investment—government fleet Investments (1)

Freight Opt/ens

1 RD&D of technology improvements (E,l)

[a] U S transit subsidies already among the highest in the developed world may merely promote inefficiencies

KEY CAFE - corporate average fuel economy E - economic incentive; HOV - high-occupancy vehicle, I = public investment, maglev = trams supported by magnetic levitation R - regulatory action RD&D - research, development, and demonstration, vmt = vehicle-miles traveled

SOURCE Office of Technology Assessment 1994

conservation activities and the policy options available to stimulate that activity. Each of the options listed in table 5-1 is tagged with an indicator: *E* for economic incentive, *R* for regulatory incentive, and *I* for public investment.

As discussed throughout this report, policymakers do not have the freedom to pick and choose freely among conservation activities and individual policy actions, even if budgetary limits and potential damage to the private economy were not constraints. The constraint on freedom of choice occurs because there is negative synergy among certain sets of policy actions. For example, policy actions that promote the freer flow of automobile traffic will generally sabotage measures to effect shifts to mass transit, reductions in trip length and frequency, and increased load factors in automobiles.

In choosing transportation energy conservation policy opt ions, therefore, policymakers must consider how implementation of these options will fit into an overall (multioption) transportation strategy, as well as how—individually—the options satisfy a number of performance criteria. Table 5-2 lists relevant criteria for option selection.

The first criterion, examining the extent to which the option requires a major lifestyle shift for transportation system users, is ignored at a policymaker's peril. Some lifestyle shifts are conceptually very attractive—for example, large increases in urban residential density and firm restrictions on development of outer areas can yield strong environmental and energy advantages that go well beyond transportation energy reductions. However, the types of intrusive policy actions required to implement such changes are socially and politically acceptable only if an uncommon consensus can be created among all segments of an urban area's residents and business interests. This is likely to be feasible only in isolated cases or in cases of widespread perceptions of an emergency. Such perceptions may well emerge in the future as more becomes known about global warming and other potential environmental or social problems, but at present there is little likelihood of achieving such a consensus.

The last criterion, which inquires whether the option has relevance to the needs of developing nations, may not apply to most options but recognizes that the largest future growth in energy and

TABLE 5-2: Selection Criteria for Transportation Energy Conservation Options

- Degree of lIfestyle/social changes required
- Cost-effectiveness measured by using market benefits and costs *or* full social benefits and costs
- Effectiveness at resolving individual energy problems
  1 011 use reduction
  2 greenhouse gas reduction and
  3 energy security Improvement
- Effectiveness at resolving other transportation-related problems
  1 air emissions reduction, and
  2 reduced congestion
- Potential risks
  1 technical risks,
  2 uncertainty in consumer reaction, and
  3 management difficulty
- Time scale
- Potential interaction with other goals—does it foreclose or aid future projects?
- Distribution of costs and benefits—which segments of society absorb costs or gain benefits?
- Integration with International needs-–does it yield benefits for other nations, particularly developing nations?

SOURCE Office of Technology Assessment 1994

BOX 5-1: Measuring Costs and Be

Measuring the costs and benefits of adding a new transportation service or changing the nature of an existing one IS complicated by the Interdependence between the supply of and demand for transportation services In general. because much of the U.S. transportation network IS near capacity during parts of the day, adding to the supply of transportation can reduce congestion, improve travel times, and thus Increase demand on the affected segments Highway analysts often comment on the long-term futility of continuously expanding highway capacity, because continued travel growth overtakes the new capacity until it, too, IS congested Similarly, addition of travel capacity on competing modes (e g , competition between high-speed rail and air or highway travel for trips of a few hundred miles) may relieve congestion at airports and on highways, but add to overall travel demand by encouraging more trips

Also, the options for adding new capacity may not be clear although an intensive assessment of new travel capacity may spell out a range of options, in actual planning it is not always clear what will happen if an option under consideration, such as a new railway, IS not built. Will airports, many already close to capacity and experiencing substantial congestion delays, be expanded, or will new airports be built? Will lack of capacity force changes in aircraft design and operations that allow greater capacity without physical expansion? WilI growth in air travel be constrained by lack of capacity, with excess demand either stifled entirely or forced into other modes (such as highways or existing train service)? WilI the lack of physical capacity force early development of advanced telecommunication services that, for a segment of the travel market, can substitute for physical travel?

Each of these alternatives has radically different energy implications, as well as radically different implications for the whole range of societal Impacts Because in many cases it is impossible to predict which option--or which set of options—will be pursued, analysis of the energy implicatlons of adding new systems is made much more uncertain

SOURCE Off Ice of Technology Assessment 1994

oil use and in greenhouse gas emissions will occur in the developing world, not in the industrial nations. Developing nations often cannot afford technological options that are considered cost-effective in the industrialized world, and so apply more weight in their decisionmaking than industrialized nations would to criteria such as low infrastructure requirements, and ease of maintenance.

A critical and difficult aspect of measuring costs and benefits is to measure losses and gains that occur because lifestyle decisions and investments made under the current set of economic and regulatory rules will lose (or gain) value under the new set of rules. For example, restrictions on automobile travel, or large increases in gasoline taxes, will have effects that go far beyond simple increases in travel costs and convenience: they will reshape real estate values and the distribution of prices in the used-car market, as fringe housing loses value and fuel-efficient used cars increase in price.

Another problem encountered in measuring costs and benefits, discussed in box 5-1, is the set of complex interdependencies among alternative transport systems.

This chapter discusses some of the conservation activities and policy options available for the transportation sector. Given the very large number of activities and options available, no attempt is made to be comprehensive; instead, the focus is on a range of potential government actions. The chapter begins with a discussion of how the U.S. transportation future is likely to look if the Federal

Government makes *no* major changes to transportation and urban planning policy.

WHAT IF THE FEDERAL GOVERNMENT INITIATES NO NEW POLICY MEASURES?

If the baseline case in the Energy Information Administration's (EIA's) *Annual Energy Outlook 1993,*[1] Baseline Case is an accurate guide, oil use in the transportation sector will grow from about 11 million barrels per day (mmbd) in 1990 to 12.5 mmbd by 2000 and 13.9 mmbd by 2010-a 20-year growth rate of 1.2 percent per year, for a total growth of 29 percent over the period. The growth of *travel,* however, is substantially higher in this forecast: for 1990-2010, light-duty vehicle-miles traveled (vmt) increases 41 percent, freight truck vmt 45 percent, and air travel (in seat-miles) 128 percent. Thus, even without new efficiency standards, EIA expects moderate rates of efficiency growth to continue: over the 20 years, it projects new car fuel economy to grow from 28.0 to 34.6 miles per gallon (mpg)[2] and light-truck fuel economy to grow from 20.7 to 25.4 mpg, though the total fleet of light-duty vehicles is projected to grow in efficiency only from 18.6 to about 21.3 mpg;[3] and aircraft efficiency is expected to increase 36 percent.

What does this mean in more physical and policy-oriented terms? First, the transportation sector projected addition of near] y 3 mmbd of oil use is a source of substantial concern, particularly since industrial use of petroleum is also expected to increase more than 1 mmbd during the period, and domestic *production* is expected to decline by more than 1 mmbd. This means that oil imports, already at 7 mmbd, or 42 percent of consumption, in 1990, will rise to more than 12 mmbd, or 58 percent of consumption, by 2010. Although the import situation would look considerably better in EIA's high oil price case—10.3 mmbd, or 52 percent of consumption—recent price trends and patterns of reserve additions make this case (assumed oil price of $38 per barrel in 2010, in 1991 dollars) appear to be a low probability one.

The 29-percent increase in energy use also translates into an approximately 29-percent increase in emissions of carbon dioxide (CO_2),[4] in contrast to international goals of maintaining greenhouse gas emissions at or below 1990 levels.

Although EIA's *expected* increases in oil imports and CO_2 emissions are of substantial concern, the Office of Technology Assessment (OTA) believes the EIA projections of energy growth and its consequences to be understated. As discussed in chapter 2, EIA's projections of travel growth appear consistently at the low end, and its projections of efficiency improvements consistently at the high end, of the plausible range. Without new regulations or economic incentives, there is little reason to be optimistic about future increases in new car and light truck fuel economy, nor are changing demographics likely to reduce growth in vehicle-miles traveled (vmt) nearly as much as EIA projects.

Second, the 41-percent increase in light-duty vmt and 45-percent increase in freight truck vmt projected by EIA--or the still higher travel increases that OTA believes are more likely—imply a substantial increase in highway congestion, since road miles will not increase nearly as fast. Available forecasts of congestion, when translated into specific examples, often are alarming:

> A one-way 30-mile commute on U.S. Route 1 from New Brunswick, New Jersey to Trenton could easily turn into a five-hour ordeal by 2005, "

[1] U.S. Department of Energy, Energy Information Administration, *Annual Energy Outlook* 1993, DOE/EIA-0383(93) (Washington, DC January 1993), app. A.

[2] U.S. Environmental Protection Agency test values.

[3] On-road values.

[4] There will be some small variation from 29 percent because the composition of liquid fuels will change due to reformulation of gasoline and moderate amounts of alternative fuels entering the marketplace.

as traffic inches along at an average speed of six miles per hour, slower than a trotting horse.[5]

If Federal Highway Administration (FHWA) forecasts were realized, congestion levels in the year 2010 would create enormous costs in terms of time lost, gasoline wasted, and emissions increased. However, as discussed in chapter 4, the forecasts overstate likely congestion growth. Also, it is quite possible that much of the growth in vmt will occur in areas where congestion problems are limited. Although congestion is expected to grow, this growth will probably not be as severe as feared.

Third, EIA did not model transit explicitly in the forecasts, so energy use estimates are not directly translatable into mass transit's modal share or ridership estimates. However, transit share of total trips is likely to decline during the period, although total ridership may increase. Increased ridership will result primarily from the attempts of hundreds of urban areas to deal with Clean Air Act requirements. A great diversity in transit solutions is expected, with a few planned heavy and light rail systems and system additions, many different types of paratransit[6] operations, and expansions of conventional bus systems. In some areas, such as Portland, Oregon, planned solutions to both air quality and congestion problems will include attempts to shift land use toward greater density and better mixes of uses. It is difficult to predict the outcome of this kind of program, because there is little precedent to forecast the effects of the strategies used---changes in zoning laws, an urban growth boundary, implementation of light rail, etc.—in the face of the U.S. auto-oriented market trends and incentives.

NEW FUEL ECONOMY STANDARDS

Introducing new, more stringent standards for the corporate average fuel economy (CAFE) of each automaker is one option for reducing the fuel consumption of the U.S. light-duty highway fleet. In 1991-92, Members of Congress responded to recent growth in gasoline demand and sagging new car fuel economy by introducing a number of legislative proposals designed to boost the current CAFE standard of 27.5 miles per gallon (mpg) for each corporate domestic and import fleet. One of the first of the 102d Congress, Senator Richard Bryan's bill (S. 279), called for a 20-percent improvement in each company's new car fleet average (over a 1988 baseline) by 1996 and a 40-percent improvement by 2001 (yielding an overall new car fleet average of about 34 and 40 mpg, respectively). Other bills were introduced that offered different standards and approaches.

S. 279 and the other bills generated substantial controversy, with the key issue (aside from the obvious question of whether setting *any* new fuel economy standards is sensible national policy) being disagreement about the level of fuel economy increase that is technically and economically feasible. The debate also brought out significant concerns about potential negative impacts of new standards on vehicle safety and auto industry jobs, as well as substantial disagreement about how much oil would be saved by new standards. Other issues that deserve careful attention are the relative merits of alternative regulatory *structures (e.g.,* level standard, uniform percentage increase, or standards based on vehicle interior volumes) and the appropriate scheduling of any new stan-

[5] Harvey Gantt, American Institute of Architects, testimony at hearings before the House Committee on Interior and Insular Affairs, Subcommittee on Energy and Environment, June 27, 1991, cited in J.J. MacKenzie et al., *The Go@ Rate: What It Really Costs To Drive* (Washington, DC: World Resources Institute, 1992).

[6] Paratransit is public transportation that is more flexible than regular transit operations in route and schedule, and often privately operated.

dards. OTA's findings regarding most of these issues, published in a recent report, are summarized below.[7]

Are Fuel Economy Standards an Efficient and Effective Approach to Fuel Conservation?

Arguments about whether or not standards are a sound approach to conservation in the transportation sector revolve around the effectiveness of the 27.5-mpg standard set in 1975[8] and the relative merits of a regulatory approach versus the use of economic incentives such as gasoline taxes and/or taxes and rebates on vehicles depending on their efficiency.

Arguments have raged for years about the effectiveness of the 1975 standards. The only area of agreement is that the years in which the standards took effect coincided with a large increase in the fuel economy of the U.S. new car fleet, from 17.2 mpg in 1976 to 27.9 mpg in 1986.[9] Although advocates of new regulations seize upon this efficiency increase as an indicator of the success of the standards, opponents point out that real gasoline prices tripled between 1973 and 1980, affecting both industry planning and consumer purchasing decisions about car size and efficiency. Thus, some industry analysts conclude that the CAFE standards increased fuel economy only about 1.0 to 1.5 mpg beyond the level that would have been achieved without them,[10] whereas other analysts conclude that the standards had an impact of 4 to 5 mpg or more.[11] Further, analysts argue about whether or not the standards affected the rate and composition of new car sales, since any slowdown in sales (leaving older and less efficient vehicles on the road) or shift from automobiles to light trucks (vans, pickups. and utility vehicles) would adversely affect the fuel economy of the entire fleet.[12] During the last two decades, light truck sales rose significantly as a percentage of total light-duty sales, and the median age of registered automobiles increased from 4.9 to 6.5 years.[13] The most likely reasons for the rise in median age were the improvements made in rust prevention and auto reliability, and a gradual increase in the value embedded in vehicles (sophisticated sound systems, air conditioning, automatic transmission. etc.). If the trends in light-truck sales and fleet median age were somehow abetted by the CAFE standards, however, the real effectiveness of the standards would be less than it appeared.

To gauge the impact of the CAFE standards, analysts must be able to estimate how automakers would have reacted in the *absence* of standards. Unfortunately, these estimates are suspect because, prior to the 1972 oil shock, oil prices had been low and stable for many years, so no historical model is available. Thus, analysts must rely on other clues about whether or not similar fuel economy gains would have been attained even without standards. Some analysts have focused on the degree to which the standards appear to have constrained automakers; that is, they assume that automakers who easily exceeded the standards probably were not affected by them and would

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[7] U.S. Congress, Office of Technology Assessment, *Improving Automobile Fuel Economy: New Standards, New Approaches*, OTA-E-504 (Washington, DC: U.S. Government Printing Office, October 1991).

[8] That is, demonstrating that the old standard worked (did not work) would serve as evidence that a new standard would be likely (unlikely) to work.

[9] S.C. Davis and M.D. Morris, *Transportation Energy Data Book*, ed. 12, ORNL-6710 (Oak Ridge, TN: Oak Ridge National Laboratory, March 1992), table 3.15.

[10] R.A. Leone and T.W. Parkinson, "Conserving Energy: Is There a Better Way? A Study of Corporate Average Fuel Economy," paper prepared for the Association of International Automobile Manufacturers, May 1990.

[11] Ibid.

[12] Light trucks are less efficient than automobiles, and on the average, old cars are less efficient than new ones.

[13] Davis and Morris, op. cit., footnote 9.

have reached their recorded fuel economy levels with or without standards.[14] OTA's examination of some analyses claiming to demonstrate a minor impact of CAFE standards on fuel economy levels found these analyses to be unconvincing.[15] Probably the most convincing evidence of the effectiveness of CAFE standards is the family of graphs of actual versus required levels of corporate fuel economy.[16] These show that Ford. General Motors, and (to a lesser extent) Chrysler—companies likely to be most affected by the standard because their fleets had relatively low economy—increased their fleet fuel economy in virtual lockstep with the levels required. On the other hand, the levels of Japanese and other manufacturers producing small, high-fuel-economy cars-companies little affected by the standard but affected by rising gasoline prices—meandered (and sometimes fell) during the same period. Although this does not "prove" that the standards played a critical role, it places the burden of proof squarely on the shoulders of doubters.

The role of CAFE standards in the increased sales of light trucks and greater age of the auto fleet is unclear, but no impact on new car sales was obvious, and the success of light trucks seems due primarily to their market attractiveness, not to any artificial advantage conferred by fuel economy requirements.

If the previous CAFE standards "worked" in the sense that they played a major role in driving up industrywide fuel economy levels and had no significant side effects that might have slowed vehicle turnover, policy makers still need to be concerned about the efficiency of standards: Do the gains in reduced fuel use and lower oil imports justify the costs, and are standards preferable to alternative ways of reducing auto fuel use?

Because regulations generally are justified by the claimed existence of market failures (usually the market failure to incorporate social costs into its prices), determination of a favorable cost-benefit ratio for CAFE demands an evaluation of the environmental, energy security, and other social costs of gasoline use. This type of evaluation is discussed in chapter 4. However, policy makers must judge for themselves whether reducing these extramarket costs justifies adding the costs of a CAFE standard.

Opponents of CAFE standards argue that alternatives, especially taxes on gasoline or oil, are a more attractive, efficient means of reducing automobile fuel consumption. Gasoline taxes (discussed later in this chapter) reduce oil use by reducing the demand for travel *in addition to* increasing new car fuel economy. The demand effect applies to the entire fleet, not just new cars, so much of the oil use impact occurs immediately without requiring an extensive period for the fleet to turn over.

Unfortunately, comparative estimates of the costs and benefits of gasoline taxes and fuel economy standards depend on a number of highly uncertain assumptions about the cost of fuel economy increases, manufacturer responses to standards, the gasoline price elasticity of demand for travel, and so forth. One recent comparison concluded that a gasoline tax beginning at 3 cents per gallon in 1996 and rising to 25 cents per gallon by 2006 would save as much gasoline as a CAFE increase to 34 mpg in 1996 and to 40 mpg in 2001, at much lower (43 to 83 percent less) welfare costs than the CAFE standards.[17] However, the as-

[14] See e.g., Leone and Parkinson, op. cit., footnote 10; and D.L. Greene, *CAFE or Price?: An Analysis of the Effects of Fuel Economy Regulations and Gasoline Price on New Car MPG,* 1978-89 (Oak Ridge, TN: Oak Ridge National Laboratory, revised Nov. 30, 1989).

[15] For example, Leone and Parkinson (op. cit., footnote 10) appear to award an "unconstrained" status to some automakers in an unusually generous fashion; and to underestimate the role of technological advances in improving fuel economy.

[16] Greene, op. cit., footnote 14.

[17] Charles River Associates, "Policy Alternatives for Reducing Petroleum Use and Greenhouse Gas Emissions," paper prepared for the Motor Vehicle Manufacturers Association, September 1991.

sumptions used appear to overly favor gasoline taxes over CAFE standards in terms of cost-effectiveness. On the other hand, because it is possible to structure gasoline taxes so that they have few or no net negative impacts on the economy,[18] it should be possible to gain energy savings from a well-designed tax at lower total social costs than from CAFE standards.

The above perspective reflects an "either/or " view of taxes and standards. However, policymakers may not view taxes as a viable option because of political considerations, or they may be willing to consider taxes and standards as complementary policies. Although taxes alone can save much energy by reducing travel demand, they are unlikely to yield very high fuel economy levels at the rates (perhaps up to $1 per gallon) likely to be the outer limit of political feasibility;[19] consumers typically exhibit very high discount rates in their purchasing decisions for energy conserving technologies.

Further, although automakers may complain about the market risk associated with new fuel economy standards, new standards may work to *reduce* some of the market risk of introducing new fuel-efficient technologies. In the current market, consumer devaluation of fuel economy tends either to keep new technologies out of the marketplace or to dictate their use in a form that maximizes performance. For example, the higher specific horsepower of multi valve engines can be used primarily to gain acceleration performance. but this sacrifices a significant component of their fuel economy potential by foregoing the engine downsizing that could be accomplished. Automakers choosing to gain maximum fuel economy from such engines might lose market share to others that stressed performance, a more highly valued commodity in the current marketplace, and in fact multivalves have generally been designed and advertised as performance boosters, A new fuel economy standard, if properly designed to put near equal technological pressure on each automaker, would limit the ability of competing makers to grab market share by focusing on performance, thus limiting the market risk of stressing fuel economy.

What Is the Fuel Economy Potential of the U.S. New Car Fleet?**

Congress has been bombarded with a range of estimates of the "technological potential" of the fleet. Many of the variations among these estimates result not from technical disagreement about the efficiency improvement from specific technologies--although such disagreements clearly exist—but from differences in the following assumptions:

- the time frame of the higher fuel economy levels, that is, the lead time available to the industry for making technical and marketing changes;
- the nature of regulations accomplishing the efficiency change;
- future shifts in the size mix of the fleet;
- changes in acceleration capabilities or other measures of vehicle performance;
- passage of new safety and emission regulations;
- the time required to develop, perfect, certify, and bring to market new technologies;
- judgments about what should be considered an acceptable level of economic disruption to the industry in responding to new fuel economy regulations; and

[18] By "recycling" the revenues into reductions in other taxes, especially taxes that have distorting effects on the economy. See the discussion of gasoline taxes elsewhere in this chapter.

[19] It is worth remembering how difficult it has been to pass gasoline taxes on the order of a few *cents* per gallon.

[20] The evaluation presented here is based on an earlier analysis by Energy and Environmental Analysis, Inc., for the Office of Technology Assessment, for inclusion in its report, *Increasing Automobile Fuel Economy: New Standards, New Approaches*, published in October 1991. Ideally, this analysis should be recomputed using more timely data; in the absence of such an updated analysis, this earlier analysis is presented with comments about revised target dates for new legislative initiatives.

- judgments about the response of consumers to changes in vehicle costs and capabilities (which is, in turn, a function of oil prices and supply expectations).

Assumptions about these factors must be made to calculate "technological potential]," since each factor will affect the ultimate fuel economy achieved by the fleet.

OTA has examined various estimates of technological fuel economy potential, which range from conservative estimates prepared by domestic automakers to optimistic estimates prepared by energy conservation advocates. The technical arguments surrounding the many technologies available to improve the fuel economy of the U.S. auto fleet are not discussed here; the interested reader is urged to examine the 1991 OTA report[21] as well as a report of the National Research Council, especially its appendix B.[22] The range of views about fuel economy potential can, however, be characterized as follows: at the conservative extreme, further increases in fleet fuel economy are characterized as likely to be quite small-—less than 3 mpg within 10 years[23]—because the major gains have already been achieved, consumer tastes are heading toward vehicle characteristics that conflict with greater fuel economy, and government safety and emissions standards will tend to degrade fuel economy. At the optimistic extreme, large increases in fleet fuel economy, to 45 mpg and higher, are portrayed as readily obtainable by existing or soon-to-be-available technology, possibly as early as the year 2000.[24]

OTA's contractor, Energy and Environmental Analysis, Inc. (EEA), prepared a set of estimates of future fleet fuel economy potential for the earlier OTA report. These must be used in context: each individual estimate of the fuel economy potential for a certain "scenario"--a concept of a particular future, with defined characteristics—is associated with a set of critical assumptions that is a powerful determinant of the magnitude of reported fuel economy values. In some regards, EEA estimates may be viewed as somewhat conservative for the 2001 time frame, because they do not consider the possibility that new technologies, not yet available commercially, may begin penetrating the market by that date; they do not allow for improvements in the fuel economy performance of already-installed technologies;[25] nor do they consider the potential for diesel engines to overcome their current negative market perceptions and their problems in meeting emission requirements. On the other hand, the scenarios all assume that, *at worst,* vehicle performance, use of luxury equipment, and size will not increase indefinitely, but instead level off after 1995; other scenarios assume a policy-driven rollback in these characteristics to 1990 or 1987 levels. These assumptions could prove too optimistic. Further, the EEA values assumed passage of fuel economy legislation by the end of calendar year 1991. The passing of this date with no legislative action, the intervening 2 years and the failure of fleet fuel economy to improve during that time, and the high probability that at least an additional year

[21] office of Technology Assessment, op. cit., footnote 7

[22] National Research Council, Committee on Fuel Economy of Automobiles and Light Trucks, *Automotive Fuel Economy: How Far Should We Go?* (Washington, DC: National Academy Press, 1992).

[23] SRI International, "Potential for Improved Fuel Economy in Passenger Cars and Light Trucks," paper prepared for the Motor Vehicle Manufacturers Association, July 1991. This paper concludes that an additional 2.6 mpg (over a 1990 baseline) can be added by 2001, with a 10-year payback for gasoline savings.

[24] E.g., see M. Ross et al., *Options for Reducing Oil Use by Light Vehicles: An Analysis of Technologies and Policy* (Washington, DC: American Council for an Energy-Efficient Economy, December 1991), which concludes that by using only current technology, 42 mpg can be achieved cost-effectively by 2000, with higher values available at some technological risk. Because these and other claims of environmental and conservation organizations were made a few years ago, the "year 2000" target date may no longer be applicable.

[25] That is, where fuel economy technologies have already been incorporated into a number of car models, EEA allows no possibility that when models are redesigned, the technologies will be upgraded to yield better fuel economy performance.

will pass before new standards might be set imply that the times specified in the original analysis should be reset by adding a few years.

Table 5-3 provides OTA estimates for a variety of fuel economy scenarios, ranging from a "product plan" meant to represent a projection of likely fleet fuel economy in a "business-as-usual" scenario (no new fuel economy regulations, no major shifts in market factors), to a "maximum-technology" scenario that postulates what could be achieved if regulations forced maximum use of fuel economy technologies and accelerated model retirement rates, to a longer-term projection postulating the success of several new technologies

[redacted]

		Fuel economy[a] levels achieved (mpg)
1995	*Product plan* Cost-effective technology, continuation of current trends, no new policy initiatives	283 domestlc[b] 31 1 imports 292 fleet
	Regulatory pressure Fuel economy potential with added pressure of new efficiency regulations but without size-class shifts	300 fleet
2001[c]	*Product plan at rising oil prices* No new policy iniatives and no radical changes in market, but higher oil prices ($1 50 per gallon of gasoline in 1991 dollars); size/performance/luxury stable after 1995, tier 2 emissions standards not considered.	32.0 domestic 34.6 imports 32.9 fleet
	Maximum current technology Feasible technology added regardless of cost, size/performance/luxury rolled back to 1987 levels, normal life cycle requirements not allowed to limit technology penetration rates, no advanced technologies.	37.3 domestic 39.9 imports 38.2 fleet
	Regulatory pressure Technology added that is cost-effective at $2 per gallon of gasoline (higher than expected price levels). Ten-year payback, size/performance/luxury rolled back to 1990 levels technology penetration limited by normal life cycle requirements, no advanced technologies.	34.5 domestic 37.4 imports 35.5 fleet
2005	*Regulatory pressure* As above	365 domestic 374 Imports 371 fleet (38 1, mpg with 2-stroke)
2010	*Advanced technologies* Size/performance/luxury rolled back to 1987 levels, no new emissions standards post-2000	
	▪ Addition of technologies that most automotive engineers agree would be commercialized by 2000.	45 fleet
	▪ Addition of technologies without general agreement about benefitsl and commercia prospects.	55 fleet

[a] U S Environmental Protect Ion Agency test values, combined city-highway, potential credits for alternate fuel vehicles not considered

[b] Domestic refers to vehicles made and sold in the United States by the three U S automakers, imports refer to vehicles sold in the United States by the lop five Japanese automakers

[c] Note that these dates reflect the assumption that any **new** standards would be set by the end of 1991

SOURCE U S Congress Off Ice of Technology Assessment *Improving Automobile Fuel Economy OTA-E-504* (Washington, DC U S Government Printing Off Ice October 1991) based on analysis by Energy and Environmental Analysis, Inc such as two-stroke engines. The "regulatory pressure" scenario yields a result that may be viewed by some as a "middle-of-the-road" fuel economy target, although it does assume a rollback in vehicle size and performance to 1990 levels in defiance of current upward trends. OTA does not, however, believe that there is any "best" fuel economy target, since any selected target value involves both a degree of market and technological uncertainty and a balancing of many values.

As illustrated by these scenarios, neither end of the range of claimed fuel economy potential—"little change" to better than 45 mpg by 2000 or soon thereafter—appears credible for the time frame in question. OTA analysis shows that the application of multiple existing technologies can lead to fleet fuel economy gains of several, and up to about 10 mpg by 2001 (or 2004 when the passing of the date by which fuel economy standards were assumed to have been passed is taken into account) if consumers are willing to accept some rollback in vehicle size and performance, and to pay more for improvements in fuel economy than will likely be repaid in fuel savings. Such an acceptance, however, is not a foregone conclusion, given the existing market trends discussed above. A few additional miles per gallon may be available in this time frame from incremental improvements in technology performance and upgrading of existing applications of fuel-efficient technologies. On the other hand, buyer resistance to limits on vehicle acceleration or increased purchases of light trucks could either reduce the potential for increases in fleet fuel economy or partially defeat the purposes of higher auto standards.

The National Research Council (NRC) is somewhat more pessimistic than OTA about achievable levels of fuel economy. NRC projects that a "practically achievable" level of fuel economy for 2006 is 34 to 37 mpg, with the higher value representing a low-technical-confidence, high-cost level.[26] Its practically achievable level for 2001, which may be somewhat comparable to OTA's regulatory pressure scenario (35.5 mpg), is 31 to 33 mpg.[27] In OTA's view, NRC's projections of fuel economy are not consistent with its assessment of the likely technological performance of individual technologies.[28]

Greater fuel economy gains than those discussed above, to 45 mpg or even higher, *may be* available by 2010 when new technologies could make major inroads into the marketplace, although the success of these technologies is by no means guaranteed. The longer schedule is required because of the time needed to develop and adequately test new technologies.

As noted above, changes in consumer preferences for fuel economy, vehicle size, and vehicle performance or, in the extreme, the imposition of limits in the choice of these attributes, offers an alternative to a strictly technological approach to improving new car fleet fuel economy. Moderate changes in purchaser selection of vehicles within size or weight classes toward more efficient models, and shifts in size or weight class to smaller vehicles, can substantially increase fleet fuel economy. For example, in the 1990 U.S. new car fleet, if consumers had purchased only the dozen most fuel-efficient models in each weight class and shifted their purchases towards lighter-weight classes so that average weight was reduced by 6.2 percent, fleet fuel economy would have improved from 27.8 to 33.2 mpg, or 20 percent.[29] About two-thirds of the fuel economy improvement would have been due to consumers selecting the more efficient vehicles in each weight class, with the remainder due to the actual shift in weight class market shares. The "cost" of the improve-

[26] Committee on Fuel Economy of Automobiles and Light Trucks, op. cit., footnote 22.

[27] Ibid.

[28] The individual technologies are assessed in ibid., app. B.

[29] R. M. Heavenrich et al., *Light-Duty Automotive Technology and Fuel Economy Trends Through 1991*, EPA/AA/CTAB/91-02 (Washington, DC U.S. Environmental Protection Agency, May 1991).

ment (in terms of loss of consumer attributes) would have been a 7-percent decrease in the average interior volume of the fleet (from 107 to 99 cubic feet), an 11-percent increase in 0 to 60 miles per hour (mph) acceleration time (12. 1 to 13.4 seconds), and a major shift from automatic to manual transmissions (about 40 percent of the fuel economy benefit would be lost if drivers refused to change transmission types). The "average car"—the car that attains the average fuel economy of the fleet and is representative of its average characteristics—-would have been a Toyota Camry rather than a Dodge Dynasty.[30]

What, then, should be the targets for a new generation of fuel economy standards? If Congress wishes to set a fleet target for 1998 that pushes the industry further than it would otherwise be likely to go, a realistic target would be 30 mpg, if no significant changes occur in current trends in vehicle size and performance. With full use of available alternative fuel credits, a *reported fleet* average[31] of 31 mpg should be feasible. The fleet average could be considerable y higher if consumers change their relative preferences for efficiency, performance, and size; legislators will have to weigh the benefits of attaining this higher level against the risks—particularly potential customer dissatisfaction with smaller, lower-powered cars and the resulting lower vehicle sales. Congress could reduce these risks by coupling higher fuel economy standards with economic incentives-gasoline taxes, or rebates and penalties tied to fuel economy--designed to push the market toward higher efficiency.

For the longer term, the choice becomes more difficult because there are more options and more uncertainties. The maximum-technology value of 38 mpg in 2001 (2004 given delayed passage) assumes a rollback in size and performance to 1987 levels, an increase in vehicle costs that will *not* be offset entirely by fuel savings (unless gasoline prices rise substantially), and early retirement of several model lines. which could be costly to the industry. The compression of vehicle life cycles embodied in the maximum- technology scenario is not unprecedented, however, and legislators may feel that growing oil imports and the need to reduce greenhouse emissions warrant such measures. Further. a high fuel economy standard may accelerate the entry of new technologies, such as the two-stroke engine, into the fleet (although not without market and technical risks). And, as noted. the maximum technology target may be attainable with less performance rollback or at lower cost than projected; the projections do not consider potential improvements in the fuel economy performance of these technologies. or the likely upgrading of pre-1990 applications of fuel economy technologies when the models in which they are installed are redesigned.

For legislators who believe that the market should better reflect the societal costs of oil, but who wish neither to demand that the industry abandon product lines before their initial costs can be recovered nor to risk requiring major changes in vehicle size and performance, a fleet target of 35 mpg should be feasible by 2004. Alternatively, a maximum-technology scenario that assumed a rollback in size and performance only to 1990 levels would yield a fleet average fuel economy of about 37 mpg by 2004. The change in size and performance between 1987 and 1990 cost more than 1 mpg in new car fuel economy. Because of the importance of lead time, these targets assume passage of new fuel economy legislation by calendar year 1994. Substantial delays in passing new rules would lower the fuel economy values attainable in the target year.

For the still longer term (i.e.. 2010 and beyond), as noted above, there is real potential for

[30] Note that the 1990 Camry was a compact, not the larger car it is today.

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

very high fleet fuel economy values, 45 or even 55 mpg,[32] but considerable uncertainty as well because attainment requires introduction of still-untested technologies. For this time period, Congress might consider mechanisms to ensure continued technological pressure while maintaining enough administrative discretion to reduce fuel economy goals if optimistic forecasts of technology potential turn out to be incorrect.

Which Type of Standard Is Best?

Recent proposals for new fuel economy legislation have moved away from the format of current law, which imposes a uniform 27.5-mpg standard on all automakers. With the current format, automakers that produce a variety of vehicle sizes, or primarily large vehicles, are subject to a more demanding technological challenge than those who concentrate on small vehicles. This gives the latter more flexibility to capture markets for larger cars and to introduce features (high-performance engines, 4-wheel drive, etc.) that are both attractive to consumers and fuel-inefficient, which puts full line and "high-end" manufacturers at substantial market disadvantage.

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

New legislative proposals ask that automakers raise their CAFES by a uniform percentage over that attained in a baseline year—1 988 in Senator Bryan's proposal (S. 279). Because these 1988 CAFES reflect in some measure the size makeup of each company's fleet, they will take account of the differences in size among various companies in assigning fuel economy requirements—but only to the extent that these differences do not change from the baseline year to the compliance year. If companies seek to gain share in market segments different from their traditional market (e.g., by marketing large luxury cars), the uniform-percentage approach could prevent them from doing so and thus be viewed as anticompetitive. Furthermore, to the extent that some of the differences for the baseline year were due to differences in fuel economy technology and design, a uniform-percentage increase places the most severe new demands on those companies who have tried hardest to improve their fuel economy. There *have* been differences in fuel economy technology and design among different automakers, and several companies—through deliberate marketing strategy or loss of market shares—have changed their size mix over time; both factors compromise the internal logic of the uniform-percentage approach to CAFE regulation.

An alternative approach is to base company standards on the attributes of each company fleet at the time the standards are to be met. If based on interior volume, for example, a new standard would place the highest numerical fuel economy target on the company making vehicles with the lowest interior volumes. Such a volume average fuel economy (VAFE) standard could be designed to place as equal as possible a technological (or financial) burden on each automaker. This type of standard would put no pressure on automakers to build small (low-interior volume) cars[33]—a minus with some conservationists who believe that

[32] Even higher values could be achieved, but only with major changes in the basic character of cars (e.g., large numbers of diesel-electric hybrid vehicles).

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

most cars are too large, but a plus with others who believe that consumers should have an unrestricted choice of car size and may also believe that large cars are safer. Instead, a VAFE standard demands that automakers focus on technology, design, and performance to improve fuel economy, thereby removing the contentious issue of car size from the policy debate. A perceived disadvantage of a VAFE standard is that any increase in market share of cars in the larger size classes could reduce the overall fleet fuel economy target, a potential outcome that disturbs some policymakers. This disadvantage is not unique to VAFE standards, however; a uniform-percentage increase standard could also have its total fleet target reduced with market changes .[34]

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

Basing fuel economy standards on a wider group of vehicle attributes could provide more of a move to a "pure"' technology standard, that is, a standard that can be met only by improving technology (rather than by reducing size or power). Mercedes-Benz, BMW, and Porsche have proposed a standard based on a group of variables--curb weight, the ratio of curb weight to interior volume, and the ratio of curb weight to torque--that would allow companies in a wide range of market niches to comply with a reasonable standard by improving technology. without being forced to move into other markets to "balance" their production of niche vehicles. The standard is formulated by performing a regression analysis,[35] using U.S. Environmental Protection Agency (EPA) data for the 1990 fleet, that defines current vehicle fuel consumption as a function of the above three variables. A standard requiring 1995 fleet fuel economy to be at least 20 percent higher than the 1990 level would simply reduce the 1990-based fuel consumption function by 20 percent and apply this new function to each automaker's fleet. As with the uniform percentage increase and VAFE standards, this system will not guarantee attainment of an exact fuel economy level (because the market can change), but it will force technology improvement and provide positive incentives for weight and performance reduction.[36]

What Is the Best Schedule for New Standards?

Legislation proposed during the 1991-92 debate focussed on setting new fuel economy standards for 1996 and 2001. If the debate resumes this year, these dates may be changed to 1998 and 2003, (o reflect the loss of 2 years of "lead time" for the automakers. Are these the best years for a set of new standards?

Generally, the design and product development lead time for new models and major components is about 4 to 5 years, indicating that products for the 1998 model year are now being finalized,

[34] For example, if an automaker with a relatively low mile-per-gallon target gained market share, the overall fleet fuel economy target would be reduced.

[35] Regression analysis involves a statistical examination of data that seeks to determine functional relationships among variables the analyst believes to be related, for example, between fuel economy and variables that should affect fuel economy, such as weight and horsepower.

[36] Although this type of standard does adjust the mile-per-gallon target inversely with weight and performance, the technical and economic difficulty of achieving the (lower) target will increase with higher weight and performance. In other words, the form of the standard provides a positive incentive for the automaker to reduce weight and performance.

whereas products for 1997 have moved to a stage at which tooling orders are being placed. The models of domestic automakers will have a life cycle of at least 7 to 8 years prior to redesign, during which their large development costs must be recovered. Japanese models tend to have shorter life cycles, as low as 4 years.[37]

These time horizons imply, first, that 1998 is very early to demand significant improvements in fuel economy beyond those already built into product plans, and second, that 2003, although enough time for major adjustments to be made, is earl y for a standard that might seek fleetwide redesign *unless Congress believes that energy concerns warrant an accelerated redesign schedule that would induce accelerated retirement of several model lines.* Although OTA has reached no conclusion about what an optimal schedule might be, a set of dual dates that would allow an interim fuel economy adjustment followed by a full redesign of all model lines *without forced early retirements* would be 2000 followed by 2006 or 2007. If desired, a 2003 standard could also be included, predicated on redesign of only a portion of company model lines.

Any decision to design a schedule for new fuel economy standards should include a careful examination of changes in new model lead times being pursued by the major automakers. For example, Chrysler's new LH models apparently were brought to market in less time than the 4 to 5 years noted above, and other domestic manufacturers are striving to reduce their lead times as well.

New Fuel Economy Standards and Safety

Arguments about safety have been at the center of the debate about new fuel economy standards. Industry and Administration opposition to new standards has included arguments that more stringent standards, such as those proposed by S. 279, would force consumers into a new fleet of smaller cars that would be significantly less safe than a new fleet with an unchanged size mix—perhaps even less safe than the current fleet.[38] Although some safety advocates argue correctly that small cars need not be unsafe, the bulk of statistical evidence argues that, *given current design,* the car fleet would be less safe if all its vehicles were somewhat smaller than they are today.

In OTA's view, new CAFE standards of the magnitude discussed here would be unlikely to cause *absolute* levels of safety to decrease because automakers should be able to achieve such standards without downsizing and because safety improvements will continue to be introduced to the fleet. There is evidence, however, that reduced *weight--a* likely consequence of new fuel economy standards--could cause some decrease in *relative* fleet safety, although changing safety equipment and design should lessen this decrease. Also, there is no guarantee that automakers will not choose downsizing as a method of meeting new standards (unless standards are specifically designed to avoid this). Further downsizing of the fleet (especially a reduction in exterior dimensions) would likely make the fleet less safe than it would otherwise be. However, much of the rhetoric about safety used by both sides in past debates about new standards has been overstated,[39] and some of the arguments purporting to demonstrate the magnitude of the risk are flawed or misleading.

Car size can be characterized by weight, interior volume, or exterior dimensions. Each has a different relationship to safety. Added weight may help the heavier car in a vehicle-to-vehicle collision, because the laws of momentum dictate that a

[37] Light trucks may have somewhat longer life cycles.

[38] E.g., see Jerry Ralph Curry, administrator, National Highway Traffic Safety Administration, statement at hearings before the House Committee on Energy and Commerce, Subcommittee on Energy and Power, Oct. 1, 1990.

[39] The level of rhetoric has escalated to the point that administration representatives have nicknamed Senator Bryan's fuel economy proposal "The Highway Death Act of 1991." And, some in favor of standards have argued that there is *no* connection between vehicle size and safely.

heavier car will experience less deceleration in a crash, but the weight and safety advantage afforded the first car represents a disadvantage to the second, increasing the forces on it. Although studies of accident records have demonstrated a positive *statistical* relationship between *overall* fleet safety and average weight of vehicles in the fleet, the strong collinearity between weight and various measures of vehicle size, especially exterior dimensions, makes it difficult to separate the effects of weight and size. Many safety experts think size is more important than weight to overall fleet safety, even though weight may be important to consumers making individual purchase decisions. However, some experienced safety analysts do believe that weight plays a role in fleet safety independent of size.[40]

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

Exterior dimensions may be particularly important to a car's crashworthiness, since these will affect available crush space, and narrower vehicle tracks and shorter wheelbases appear to increase rollover frequency (rollover accidents are often associated with fatalities). Accident studies have shown that some of the largest vehicles in the fleet consistently have the lowest fatality rates, even when the data are corrected for driver characteristics (especially age).[41] Further, studies by the National Highway Traffic Safety Administration (NHTSA) indicate that small vehicles experience more rollover accidents, and more traffic fatalities in such accidents, than large vehicles,[42] and the Insurance Institute for Highway Safety claims that downsizing has driven up death rates in several redesigned General Motors models.[43]

Will new fuel economy standards yield a decrease in automobile safety? The risks are less than characterized by some. First, substantial increases in fuel economy can be achieved with little or no downsizing, although automakers might conceivably choose downsizing over other measures to satisfy new fuel economy standards. Vehicle *weight* would likely be reduced, however. If careful attention is paid to vehicle structural integrity, this may not have negative safety consequences, although some statistical evidence points to a distinct role for weight in fleet safety.

Second, even if further downsizing were to cause a decrease in safety relative to that without new standards, this need not mean an *absolute* safety decrease. Since CAFE standards have been in effect, when the median weight of new automobiles decreased by about 1,000 pounds, wheelbase by 10 inches, and track width by 2 to 3 inches, the safety record of the U.S. fleet improved substantially: between 1975 and 1989, death rates for passenger cars *declined* from 2.43 per 10,000 registered cars (2.5 per 100 million miles) to 1.75 per

[40] See e.g., L. Evans and M.C. Frick, General Motors Research Laboratories, "Car Size or Car Mass—Which Has Greater Influence on Fatality Risk?" unpublished document, Aug. 30, 1991.

[41] National Highway Traffic Safety Administration, "The Effect of Car Size on Fatality and injury Risk," unpublished paper, 1990.

[42] C.J. Kahane, National Highway Traffic Safety Administration, "Effect of Car Size on the Frequency and Severity of Rollover Crashes," unpublished paper, May 1990.

[43] Insurance Institute for Highway Safety, "Downsizing Cars Means More Deaths," *Status Report*, vol. 25, No. 8, Sept. 8, 1990.

10,000 registered cars (1.7 per 100 million miles).[44] In other words, *at worst* the reductions in vehicle size and weight reduced somewhat the fleet's overall improvement in safety during this period, and new standards might well do the same. Not surprisingly, this outcome can be interpreted in radically different ways: to proponents of more stringent standards, it indicates that better fuel economy was achieved without compromising safety—in fact with substantially improved safety—and that this can be the case in the future; to opponents, it indicates that nearly 2,000 lives per year, which *could have been saved,* were lost because of forced downsizing of the fleet,[45] and that new standards will similarly reduce our ability to improve safety in the future. Both viewpoints may be correct.

Improvements in vehicle design have not been the sole cause of the noted improvements in the fleet's safety record. Improvements to highway design, a crackdown on drunk driving, reductions in highway speed limits, and other nonvehicle factors played a critical role. Some analysts question whether further improvements in these factors of similar magnitude are available; if they are not, this would call into question the conclusion that absolute levels of highway safety will continue to improve even if there is some decrease in the average size of the fleet.

Third, some of the differences in safety between small and large cars do not seem irrevocable, as stated by some officials, but maybe amenable to correction. The safety technologies now entering the fleet, including air bags and antilock brakes, should work at least as well on small cars as on large ones and should tend to decrease any safety "gap," measured in fatalities per 100 million miles, between the two.[46] Also, some safety features may focus on problems rather specific to small cars. A major cause of increased fatalities in small cars appears to have been their high propensity to roll over.[47] NHTSA is preparing regulations to deal specifically with this problem, and OTA expects design improvements to be available to reduce rollover danger and thus further reduce the safety gap between large and small vehicles.

Fourth, in estimating the likely safety outcome of further downsizing of the fleet, it may be incorrect to assume that all of the safety features incorporated into a downsized fleet would be incorporated even if no downsizing occurred. Under this assumption, new safety features do not really compensate for downsizing, since even more lives would be saved with the same features added to a fleet of larger vehicles. In the past, however, government rulemaking, consumer pressure, and automaker design decisions have not been made in isolation from changes in the actual safety situation. All responded to perceived safety problems, not to some absolute safety standard. In other words, had the problems been less severe, fewer safety measures may have been taken. To the extent that future safety responses are driven by problems emerging from downsizing, the argument that safety would have been still greater

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

[45] National Highway Traffic Safety Administration, op. cit., footnote 41

[46] However, early statistics on air bag effectiveness in preventing occupant fatalities show that for 1987-92, the addition of air bags reduced fatalities per 10,000 registered cars virtually identically in small, midsize, and large cars. Contrary to OTA expectations, the *percentage* decline in fatalities was greater for large cars than for small cars. Thus far, the use of air bags has not decreased the safety gap between large and small cars. Insurance Institute for Highway Safety. *Status Report*, vol. 28, No. 11, Oct. 9. 1993.

[47] Kahane, op. cit., footnote 42.

without such downsizing may become, at least in part, disingenuous.[48]

Opportunities to counteract any adverse impacts of new fuel economy standards maybe foregone by lack of resources. According to the Transportation Research Board, federal funding for highway safety research has been cut 40 percent since 1981—to only $35 million per year-despite the enormous cost of traffic accidents in both dollars and tragedy ($70 billion, 45,000 deaths, 4 million injuries per year).[49] Additions to Safety R&D resources could go a long way toward mitigating any future negative consequences of further fleet downsizing.

In conclusion, potential safety effects of fuel economy regulation will most likely be a concern if increases in fleet fuel economy are required over a period too short to allow substantial vehicle redesign, thereby forcing manufacturers to try to sell a higher percentage of small cars of current design, *or* if requirements exceed the technological capability of the automakers, thus forcing significant downsizing. Significant improvements in fuel economy (on the order of 30 percent) should be possible over the longer term (e.g., by 2004) without compromising safety. Over this time, there are opportunities to improve fuel economy without downsizing, and there are also opportunities to redesign smaller cars so as to avoid some of the safety problems currently associated with them. However, the *potential* for safety problems will still exist if automakers choose to emphasize downsizing over technological options for achieving higher fuel economy, and if they do not focus on solving problems such as the increased rollover propensity of small cars of current design. If auto fatality rates would be lower without new fuel economy standards than with them (even if overall rates decline), then a real tradeoff between new standards and safety *does* exist and must be addressed explicitly during the fuel economy debate.

Employment Impacts

The potential impacts of more stringent standards on both auto industry and national employment have also been a source of controversy in the debate over fuel economy. Focusing on the impact of a 40-mpg standard by 2001, the industry has claimed that new standards would cost hundreds of thousands of auto industry jobs;[50] in rebuttal, analysts in the conservation community have claimed that standards would not claim industry jobs and would increase overall domestic employment by hundreds of thousands of jobs. with many of these being in the auto industry.[51] The basic assumptions and conclusions of two key and opposing positions are described in table 5-4.

Whether new fuel economy standards will be net job creators or destroyers depends on rather uncertain assumptions or conclusions about the capability of automakers to increase fuel economy by technological means; the costs of new fuel economy technologies; and the tradeoff consumers make among added costs, improved fuel economy, and any necessary changes in other vehicle attributes (such as size). These factors will, in turn, affect both total auto sales and the likely share of those sales captured by U.S. manufacturers. For example, the American Automobile

48 It should be noted, somewhat counter to this argument, that automakers tend to introduce new technologies first in the luxury portion of their fleet, and this tendency applies to safety equipment as well, despite the fact that larger luxury models tend to have good safety records and "need" the new equipment less than smaller models. The most recent examples of this tendency are the introductions of airbags and antilock brakes.

49 Transportation Research Board, *Safety Research for a Changing Highway Environment*, Special Report 229 (Washington, DC National Academy Press, 1991).

50 Motor Vehicle Manufacturers Association, "U.S. Employment Effect of Higher Fuel Economy Standards, " unpublished paper, Jan. 30, 1990.

51 H. Geller et al., *Energy Efficiency and Job Creation: The Employment and Income Benefits From Investing in Energy Conservation Technologies* (Washington, DC. American Council for an Energy-Efficient Economy, October 1992).

TABLE 5-4: Assumptions and Results of Two Analyses of the Effects of 40-mpg Fuel Economy Standards on Employment

Motor Vehicle Manufacturers Association

1 Technically achievable fuel economy level:
29 mpg by 1995
33 mpg by 2000

2 Decline in sales of larger car sizes,

Large and luxury cars	87 percent
Midsized cars	72 percent

3 Higher sales of small cars at 80 percent of the labor of larger sizes

4 Overall sales decline of 10 percent by 2001 (increased fuel economy is not cost-effective)

5 Domestic Industry retains current share of small car market segment

6 Half of the Increases in foreign sales of small and midsize cars are produced in transplants

7 Transplant labor productivity is twice the domestic automaker average

Results
- **200,000 jobs lost by 1995, 210,000 by 2001, base case**
- **173,000 jobs lost by 2001 without 10-percent sales decrease**
- **159,000 jobs lost if Big 3 gets 53 percent of small-car market**
- **315,000** jobs lost if sales decline 20 percent

American Council for an Energy-Efficient Economy

1 Technically achievable fuel economy level 34 mpg by 1995, 40 mpg **by** 2000

2 No decline in car sales, no change in domestic-import market share

3 40-mpg increase in fuel economy is cost-effective for 2000

Results By 2010, fuel savings are $53,8 billion per year, fuel economy investment is $17.3 billion per year
- 25,000-job increase nationally by 1995
- 72,000-job increase nationally by 2000
- 244,000-job Increase by 2010
- 47,000-job increase in auto industry by 2010

SOURCE Off Ice of Technology Assessment, 1994.

Manufacturers Association (AAMA)[52] assumes that new fuel economy standards will not be cost-effective.[53] It further assumes that industry jobs will be lost by a combination of lower sales (because of higher auto prices with inadequate compensation in fuel savings); shifts to smaller cars requiring less labor to build (AAMA believes that technology alone cannot achieve 40-mpg standards); losses of domestic manufacturers' market share due to Asian manufacturers' relatively greater strength in the small-car segment of the market; and the greater labor productivity y of transplant factories, which will win part of the Asians' larger market share.

On the other hand, the American Council for an Energy-Efficient Economy (ACEEE) assumes that stringent new CAFE standards are cost-effective; that customers will value the increased fuel economy of new cars well enough to maintain sales levels; and that no shifts to smaller cars are necessary, because new standards can be met by improved technology alone.[54] Under these cir-

[52] Formerly (he Motor Vehicle Manufacturers Association of the United States, or MVMA.

[53] Motor Vehicle Manufacturers Association, 0p. cit., footnote 50.

[54] Geller et al., op. cit., footnote 51.

cumstances, any impacts on jobs are caused by the balance of job losses from lower gasoline sales and job gains from both the added dollars spent on new cars (because of the added unit costs associated with the new fuel economy technologies) and resending by consumers of any net fuel savings (ACEEE estimates that, by 2010, fuel savings will outweigh auto investment costs by $37.5 billion per year[55]). ACEEE also concludes that jobs lost in oil production, refining, and so forth, are more than counterbalanced by jobs created elsewhere in the economy, because the labor intensity of the oil industry is very low compared with the rest of the economy. In other words, even if the money saved in reduced oil expenditures is exactly balanced by the costs of fuel economy technologies. net jobs will increase.

Some elements of each analysis appear firmly grounded, and others do not. For example, achieving a 40-mpg standard by 2001 would be unlikely by using improved technology alone (even assuming that passage of new CAFE standards had taken place when they were first proposed). Automakers would probably have to reduce both average vehicle size and performance, with a likely drop in sales as a result. (Note that, if OTA's fuel economy analysis is correct, automakers could comply with a 35- or 36-mpg standard without reducing car size, although probably with some small reductions in performance.[56]) Thus, ACEEE's "no loss in sales" assumption seems optimistic. On the other hand, AAMA's conclusions about a large sales loss are based on relatively pessimistic assumptions about technology and cost, and appear overstated.[57] ACEEE's premise that losses in oil jobs (from the loss in gasoline sales due to greater efficiency) will be more than counterbalanced by job gains elsewhere in the economy appears to be on firm analytical ground, as discussed above. In fact, this argument applies to an y oil conservation measure, not just automobile-oriented measures. This source of job gain was not considered by AA MA. However, there is substantial controversy about the magnitude of fuel savings—and thus about the extent of the effect on jobs (see discussion below). ACEEE's estimated oil savings are on the high side of the potential range. The oil savings, dollar benefits, and thus new jobs created as a result of new standards appear likely to be lower than the ACEEE estimate.

A new fuel economy standard. if set at a level that does not demand wrenching shifts in the composition of the fleet and does not require the introduction of technologies whose oil savings are greatly outweighed by their costs, might have a positive job impact at the national level, primarily by shifting investment from the low-labor-intensity oil importing segment of the economy[58] to higher-labor-intensity segments: however, new standards may well have some negative impact on *auto industry* jobs if consumers remain relatively indifferent to fuel economy as a positive factor in new car purchase decisions. This type of negative impact might be reduced or eliminated if policymakers were to couple new standards with economic incentives—feebate-rebate programs, or gasoline taxes—that make high fuel economy more desirable to potential auto purchasers.

[55] Ibid.

[56] Office of Technology Assessment, op. cit., footnote 7. Of course, there is no guarantee they will do so; instead, they could adopt only part of the necessary technology, or fail to restrain performance increases, and opt instead to attempt a sales shift to smaller cars. Given the realities of the marketplace, however, this strategy seems unlikely.

[57] As part of a sensitivity analysis, ACEEE did examine the impact on employment of a 2- and 4-percent drop in vehicle sales resulting from adverse consumer reaction to more efficient (but more expensive) vehicles. With a 2-percent drop, net job gains drop from 244,000 to 171,000. With a 4-percent drop, net job gains drop to 98,000. A larger drop in sales could mean a net job loss. Geller et al., op. cit., footnote 51.

[58] Especially because virtually all of the oil displaced, and much of the gasoline, will be imported, with the number of *domestic* jobs lost being quite small and concentrated in fuel handling, distribution, and to some extent, refining.

Fuel Savings From an Aggressive Fuel Economy Standard (S. 279)

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

1. *Fuel economy values without new standards.* Alternative assumptions about the fuel economy of the new car fleet in the absence of new standards will play a critical role in estimating fuel savings associated with new standards. Factors affecting future fleet fuel economy include future oil prices and price expectations, fuel availability, consumer preferences for vehicle size and power, new safety and emission standards, and progress in technology development. The span of credible assumptions about future fuel economy is likely to be quite wide, especially for the late 1990s and beyond.
2. *Use of alternative fuel credits.* Manufacturers can claim up to 1.2 mpg in CAFE credits by producing vehicles capable of using either gasoline or alternative fuels, and can gain additional credits by producing vehicles dedicated to alternative fuels. If the automakers produce large numbers of alternative fuel vehicles and use the credits to help them to comply with new CAFE standards, the actual fuel savings associated with new standards would be reduced.
3. *Magnitude of a "rebound" in driving.* An increase in fuel economy, by reducing per-mile costs, may stimulate more driving and thus reduce the associated fuel savings. The magnitude of such a rebound effect is controversial, with estimates ranging up to 30 percent of potential fuel savings lost to increased driving. In OTA's opinion, estimates on the low side of the range— 10 percent or less—are more realistic, implying greater fuel savings.
4. *Magnitude of vmt growth.* Small differences in the growth rate of vehicle miles traveled can make a significant difference in the fuel savings estimated to occur from a new standard. The credible range of future rates is fairly broad, perhaps from 1.5 percent per year to 3.0 percent per year, which translates into a variance of about 1 mmbd in estimated fuel savings for S. 279 in the year 2010.
5. *Effects of new standards on vehicle sales.* Some opponents of new fuel economy standards have argued that stringent standards will have the effect of slowing vehicle sales (because of higher vehicle prices and reduced customer satisfaction with smaller, slower, less luxurious cars), thereby reducing vehicle turnover and its positive effect on fleet fuel economy. Others consider the likelihood of a sales slowdown that is large enough to affect fleet fuel economy significantly to be very small. Clearly, however, such an effect is theoretically possible, and would be like] y if policy makers were to miscalculate and set a standard beyond automakers' technical capabilities.[59]

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

- American Council for an Energy-Efficient Economy, for the Senate Commerce Committee: 2.5 mmbd by 2005;
- Department of Energy (DOE): 0.5 mmbd in 2001, 1 mmbd by 2010; and
- Congressional Budget Office (CBO): 0.88 mmbd by 2006 and.21 mmbd by 2010 (base case); range of 0.45 to 1.42 mmbd by 2006 and 0.59 to 1.82 mmbd by 2010.

The differences among the above estimates can be readily understood by examining their assumptions. For example, ACEEE assumes that fuel

[59] This assumes that policymakers refuse to reconsider the standard when the industry 'S difficulties become clear.

economy levels will remain unchanged from today in the absence of new standards (i.e., about 28.5 mpg for cars and 21 mpg for light trucks). DOE assumes that without new standards, new vehicle fleet fuel economy will rise to about 33 mpg for cars and 24 mpg for light trucks by 2001, and remain at that level thereafter. CBO has chosen baseline values of 30 mpg (range 28.5 to 33.0 mpg) for 2001. This difference in baseline mpg asresumptions is the most important factor in accounting for differences among estimates.

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

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

In contrast to the DOE estimate, the ACEEE estimate of 2.5 mmbd by 2005 appears overly optimistic because it discounts entirely the potential for a driving "rebound"; ignores the role that CAFE credits for alternative fuel vehicles could play in allowing automakers to boost their official CAFE levels without actually improving efficiency; and accepts pessimistic assumptions about likely fuel economy improvements in the absence of new standards. However, if oil prices remain low for the next decade or so and no major new gasoline taxes are enacted, the assumption of no improvement in fuel economy may turn out to be correct.

Although the range of potential fuel savings from S. 279 is wide, OTA believes that the "most likely" value for savings in the year2010 lies between 1.5 and 2.2 mmbd *as long as compliance with S. 279 does not significantly hurt new car sales.* For a 10-percent rebound effect, a 2-percent vmt growth rate per year. baseline fuel economy of 32.9 mpg in *2001* (frozen for the next decade), and no accounting for alternative fuel vehicles. the fuel savings would be 1.64 mmbd in 2010. Although the 32.9-mpg baseline (no new standards) value is optimistic unless oil prices rise substantially, it is also likely that automakers will use alternative fuel credits to achieve at least part of the fuel economy increase required by new standards. These two factors will tend to cancel one another: an overly optimistic baseline fuel economy will tend to yield an underestimate of fuel savings. and ignoring the likely use of CAFE credits will tend to yield an overestimate.

Regulation of Light-Truck Fuel Economy

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

Currently available technology will not allow automakers to improve light-truck fuel economy to the same extent that they improve passenger automobiles. Sources of fuel economy limitations include:

- load carrying requirements that impose structural and power needs that are more a function of the payload weight than the body weight of the truck—yielding fewer flowthrough benefits from initial weight reduction;

- open cargo beds for pickups and large ground clearance that limit potential for aerodynamic improvements;
- need for low-end torque, limiting benefits from four-valve engines; and
- likelihood of additional safety and emission requirements, with associated fuel economy penalties.

Projecting future light-truck fuel economy and determining the potential for regulation-driven improvements are made difficult by the large differences among types of vehicles—pickups, vans, utility vehicles—all of which are made in varying size and weight classes. Changes in sales mixes among the classes have been a major cause of previous fluctuations in the fuel economy of the fleet; for example, about two-thirds of General Motors' 3.05-mpg light-truck fleet increase between 1980 and 1985 was caused by changes in sales mix, and much of the decline in 1985-90 was caused by mix shifts.[60] During the same periods, there were substantial improvements in fuel economy technology, but these improvements were offset somewhat by increases in performance, weight, and level of options (four-wheel drive, automatic transmissions, air conditioning, etc.). For example, during 1980-90, the fuel economy of GM's standard trucks increased 12 to 14 percent from technology improvements, but decreased 5 to 8 percent from performance, weight, and option increases.[61]

Energy and Environmental Analysis, Inc. has made projections of year 2005 domestic light-truck fuel economy for two scenarios—a product plan scenario that assumes no regulatory pressure on fuel economy, and a maximum-technology scenario that assumes maximum practical adoption of fuel economy technologies and restraints on size and performance levels. In the product plan scenario, domestic manufacturers' light truck fleets average about 23 mpg in 2005; for the maximum technology scenario, the fleets average about 26 mpg. The product plan scenario is optimistic in that it assumes no further size increases past 1998 and holds performance increases to an average of 1 percent per year in horsepower/weight ratios; the maximum-technology scenario holds size and performance constant at 1995 levels, but restricts technology penetration somewhat because of the long product cycles normally associated with light trucks.[62]

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

- *passenger vans--standards* based on interior volume, probably measured somewhat differently from automobiles;
- *utility vehicles--standards* based on passenger interior volume. with miles-per-gallon credit for rough terrain capability; and
- *pickup trucks and cargo vans—standards* based on both volume and tonnage[63] of load carrying capacity (e.g., square or cubic foot-tons).

Given the growing importance of light trucks to overall fuel consumption, more attention needs to

[60] Energy and Environmental Analysis, Inc., "Domestic Manufacturers Light Duty Truck Fuel Economy Potential to 2005," paper prepared for Oak Ridge National Laboratory, July 1993.

[61] Ibid.

[62] Ibid.

[63] However, measures of load carrying capacity would have to be carefully developed and monitored to avoid manipulation.

be paid to the problems associated with regulating these vehicles.

Conclusions

Using new fuel economy standards to promote improved light-duty fleet fuel efficiency is a viable conservation option, but one that involves difficult tradeoffs and demands careful program design to avoid problems encountered by the previous CAFE program. Aside from the decision about whether or not to set new standards, policymakers who favor standards must make careful decisions about the stringency of fuel economy requirements. the schedule for compliance, and the format of any new standards.

Critics of previous CAFE standards have claimed they accomplished little in the way of improving fuel economy and caused severe market distortions. Available evidence implies, however, that the standards did force fuel economy improvements significantly above the levels that would otherwise have been achieved, especially with U.S. automakers, and that much of the market distortion was due to the design of the standards and should be avoidable in the future. OTA's analysis implies that a set of standards that would be technically achievable, would not force early retirements of car lines that would hurt cost recovery, would avoid the most severe market distortions, and would reflect a societal valuation of gasoline savings somewhat above market prices (to account for environmental and other societal costs) might look like the following:

- Required achievement of a fleetwide average fuel economy of about 35 or 36 mpg by 2004 or so for automobiles, and about 25 or 26 mpg by 2005 for light trucks.
- Assignment of individual company fuel economy targets by accounting for differences in the actual makeup of company fleets, by vehicle size or other physical attributes. The assignment formula for autos and light trucks should be different, to reflect differences in use for these vehicles.

Major congressional concerns about new standards include safety and impacts on employment. Some concern about safety is justified, but past debate about likely safety impacts has tended to be highly polarized and characterized by overstated positions. Achievement of the above standards could be accomplished without downsizing vehicles, and this would minimize adverse safety consequences. Also, design and equipment improvements should be available to mitigate problems. Setting unrealistically high standards or designing schedules with too little lead time would pose substantial safety concerns, however.

Employment concerns should also be allayed by setting standards at realistic levels. Policymakers should recognize, however, that it is difficult to forecast employment impacts with accuracy: previous estimates were driven more by their starting assumptions than by data and analytical structure.

FEEBATE PROGRAMS: AN ALTERNATIVE OR COMPLEMENT TO CAFE STANDARDS

As noted earlier, gasoline taxes maybe viewed either as a substitute for new fuel economy standards or as a supplement to them: they could serve to move market forces in the same direction as regulatory pressure, reducing market risk by raising the value of fuel economy in purchaser decisions and thus making the higher vehicle costs required to obtain greater fuel economy seem less onerous. Gasoline taxes clearly are a major policy option for saving transportation fuel and are treated later in this chapter.

"Feebate" plans offer another market substitute for, or supplement to, new fuel economy standards. Feebate plans involve charging fees to purchasers of new cars that obtain low-fuel economy[64] and awarding rebates to purchasers of new

[64] Measured against the average for all cars, cars in that class, or some other value.

cars that obtain high-fuel economy. The plans can be designed to be revenue neutral or revenue generating, but their general purpose is to provide a strong incentive to consumers to purchase efficient vehicles and to manufacturers to produce them.

Price incentives tied to fuel economy have some precedents. The gas guzzler tax in the United States is a primary example. It has been successful in encouraging U.S. automakers to improve the fuel economy of their larger vehicles to avoid the tax (and to avoid having their vehicles branded as "gas guzzlers"), but there is little evidence available to gauge consumer response to the higher prices of those models below the efficiency cutoff (because only a few luxury vehicles have been forced to pay the tax). Austria allows cars averaging less than 3 liters per 100 kilometers (km) (more than 78 mpg) of fuel consumption to escape any excise tax, and applies a sliding-scale tax of up to 14 percent on less efficient vehicles.[65] Other related programs exist in Denmark, Germany, and Sweden, and Ontario (Canada) has a four-tier gas guzzler tax.[66] The State of Maryland has proposed a feebate program, but the program has been blocked by the U.S. Department of Transportation. And a number of such programs have been considered at both the State (e. g., California, Arizona, Connecticut) and the Federal levels.[67]

Feebates can be structured in a variety of ways. They can be scaled on fuel economy or fuel consumption,[68] or a measure of one or the other normalized to a measure of size (interior volume, wheelbase, wheelbase times track width, and so forth).[69] The purpose of normalizing is to focus the incentive on choosing vehicles with good technology and design rather than on small vehicles, which may present safety problems. Light trucks can be treated separately or combined with the auto fleet.

A critical issue associated with feebates is the possibility that U.S. domestic manufacturers would fare poorly compared with their Japanese counterparts, because the Japanese fleets have higher CAFES than the U.S. fleets. However, most of the Japanese advantage is due to the smaller average size of the vehicles they sell. Analyses of hypothetical feebate programs by the American Council for an Energy-Efficient Economy show that a feebate program that separated light trucks from autos and normalized according to size measures-either interior volume or "footprint" (wheel base times track width)—-largely eliminated the disadvantages to domestic automakers.[70]

Estimates of the effectiveness of feebate programs are uncertain because of doubts about the likely response of manufacturers to the incentives for increasing fuel economy that such programs provide. Although calculations of potential consumer response can be made, this response is complicated by the existence of different configurations of each vehicle model (e.g., different engine and transmission choices, levels of power equipment), the interaction between (unknown) manufacturer actions and consumer actions, and

[65] J.M. DeCicco et al., *Feebates for Fuel Economy: Market Incentives for Encouraging Production and Sales of Efficient Vehicles* (Washington, DC: American Council for an Energy-Efficient Economy, May 1993).

[66] Ibid.

[67] Ibid.

[68] That is, for a program scaled to fuel economy, if the target was 30 mpg, a 40-mpg vehicle would receive half the feebate of a 50-mpg vehicle; if the program was scaled to fuel consumption, the 40-mpg vehicle would receive about 62 percent of the feebate rewarded to the 50-mpg vehicle, because the 10 mpg between 40 and 50 mpg saves less fuel than the 10 mpg between 30 and 40 mpg.

[69] An alternative to normalizing is to subdivide the fleet into groups (e.g., according to EPA size classes), and to have separate feebates for each group. A limitation of using groups is that it provides a very strong incentive for vehicles at the upper range of a group to grow into the next group (e.g., in a size class group, to increase interior volume to the point where it reaches the next class), which presumably would have a lower average fuel economy.

[70] DeCicco et al., op. cit., footnote 65.

the large number of factors that affect vehicle purchase decisions. ACEEE quotes a rough estimate for the consumer response of 1 -mpg fleet improvement for a $300/mpg feebate, ignoring multiple vehicle configurations and assuming a one-time only response.[71] Such a response would save 0.3 million barrels of oil per day in 10 to 12 years;[72] coupled with good manufacturer response, the likely total response would be substantially larger.

A recent study by Lawrence Berkeley Laboratory (LBL) accounts for both consumer and manufacturer response to feebates.[73] LBL estimates manufacturer response by using EEA's model, which contains estimates for both the costs and the effect on fuel economy of a large number of automotive technologies, and by assuming that manufacturers will introduce any technologies costing less than the fuel saved plus the increase in feebate that they will capture (by improving the fuel economy of the vehicle),

LBL estimated the impacts of six different feebate schemes on fleet fuel economy, fuel use, CO_2 emissions, and consumer surplus. 74 Key (draft) conclusions are:

1. A relatively moderate feebate (e.g., one that awarded a $500 differential between a 20- and a 25-mpg car) can achieve substantial fuel economy improvements (e.g., a 15 percent improvement in new car fuel economy by 2010 over levels expected without feebates).
2. Virtually all of the fuel economy improvement comes from manufacturers' adding more fuel economy technologies to their vehicles. Because vechicles of about the same size and performance tend to have similar fuel economies to begin with, and because the fuel economy upgradings they would receive in response to a feebate system should not be dissimilar, such vehicles will tend to have similar fuel economies and feebates after a feebate system is instituted; the major differences in fees and rebates will arise between vehicles with very different size and performance characteristics, and consumers are rarely willing to switch to very different vehicles in response to rewards of a few hundred dollars.
3. For feebates that group all autos (or all light trucks and autos) together, domestic manufacturers on average will pay a fee on their vehicles, and foreign manufacturers will receive a rebate. The net fees and rebates will decline over time.
4. Feebates that account for vehicle size[75] can reduce the disparity between domestic and foreign manufacturers, but at a substantial cost in the improvement of total fleet fuel economy.
5. There is a rapidly diminishing response to increases in the size of feebates, because manufacturers "use up" most available technology at relatively moderate feebate rates. Although higher rates will increase consumer response, this response is small and will remain that way.
6. The precise form of the fuel economy performance indicator used in a feebate program (i.e., either miles per gallon, gallons per mile, or some nonlinear function of one or the other) does not make a great deal of difference in the results.

It is difficult to know how reliable these conclusions are. The key uncertainty involves the assumption that manufacturers will add technologies on the basis of their cost-effectiveness. In fact, the presence in the marketplace of technologies that are not cost-effective, such as four-speed automatic transmissions, indicates that manufac-

[71] Ibid.

[72] Ibid.

[73] W.B. Davis et al., *Feebates: Estimated Impacts on Vehicle Fuel Economy, Fuel Consumption, CO_2 Emissions, and Consumer Surplus*, LBL-34408 (Berkeley, CA Lawrence Berkeley Laboratory, August 1993), draft.

[74] Ibid.

[75] That is, small vehicles would have to achieve a higher fuel economy than large vehicles to receive the same rebate.

turers' decisions about technology introduction involve more complex decision making processes. Another important source of uncertainty is the tradeoff between performance and fuel economy. The technologies can be used to achieve either higher fuel economy, improved acceleration performance, or both, with more of one usually meaning less of the other. The likely choices of manufacturers, in their design tradeoffs, and of consumers, in their purchase decisions, are not well understood. Other potential problems with the calculations include treatment of the auto manufacturers as one large entity rather than as multiple companies with a variety of design and marketing strategies; and the inability of the model to account for manufacturers' desire to optimize their investment decisions *over time,* rather than to immediately capture as many of the available feebate dollars as they can regardless of the potential near-term availability of less expensive technologies.[76] Finally, part of the very high benefits and low costs may be due to the model's assumption that two-stroke engines, a very inexpensive way to gain large fuel economy benefits, will be fully successful in a short time.

In conclusion, feebates appear to be a potential-1 y attractive option to improve fleet fuel economy while maintaining market flexibility. According to LBL, most of the improvement in fuel economy is likely to come from manufacturers' attempts to maintain or gain market share by reducing the net costs of their vehicles (by adding technologies whose costs are less than the gains in rebates plus fuel savings). If the consumer response is as small as LBL concludes, this implies that a small feebate program (e.g., the program proposed by Maryland), will have little impact because it will likely have little or no effect on manufacturers' design decisions. Only a national or multistate program is likely to affect manufacturers; thus only this large a program is likely to have a significant impact on fleet fuel economy.

The uncertainty associated with manufacturer response implies that policy makers should be prepared for the possibility that feebates, by themselves, might not improve fleet fuel economy nearly as much as hoped. LBL suggests that feebates might be used to complement CAFE standards, to add certainty that the desired fuel economy improvements will be achieved.[77] Since virtually all of feebates fuel economy improvements are expected to come from manufacturer response, feebates would do little to help achieve the standards. Their purpose would be to ensure continued incentives to boost fuel economy *above* mandated levels; if new, relatively inexpensive fuel economy technologies became available in the future, feebates would give the manufacturers an added incentive to incorporate these technologies *in addition to,* rather than instead of, the technologies already in use.

MOVING TO THE SUPEREFFICIENT AUTOMOBILE

Conventional improvements to automobile fuel efficiency-particularly at the optimistic end of the spectrum (e.g., a 40- to 45-mpg new car fleet)--have the potential to stabilize oil use and

[76] All of these uncertainties also apply to analyses of the costs and benefits of fuel economy regulations, discussed previously. However, the analysis of feebates attempts to understand how manufacturers will behave in a free market situation. In the absence of regulatory constrains, manufacturer behavior different from what the model predicts might sharply reduce or increase the fuel savings benefits being sought with feebates. The previous analysis, on the other hard sought to understand what the manufacturers co/{/d do in response to a regulation. Presumably, if they could behave differently to save themselves money or reduce risk while complying with the regulation, this would reduce only the costs of the regulation while maintaining: the fuel savings benefits of compliance. In other words, uncertainty is much less of a concern with the analysis of a fuel economy regulation, at least m terms of projecting the impact on fuel savings. On the other hand, cost and performance uncertainties become a very great concern in computing CAFE standards' *economic impact on producers,* because standards based on overoptim istic assumptions could create large negative impacts; with feebates, the effect would be simply to reduce the magnitude of the manufacturer response.

[77] Davis et al., op. cit., footnote 73.

carbon dioxide emissions, at least for a decade or two. To "outrun" rising travel demand and achieve absolute reductions in oil use, however, will require *either* a successful effort to suppress travel through economic incentives. radical shifts in urban form (which would take many decades to have significant impacts), and other means, or else a much larger change in automobile design than required to reach 40 mpg. Whatever the technical and economic benefits and costs of each approach, a major change in design should most easily gain public acceptance if the new designs do not significant] y degrade the basic amenities offered by current designs—space, performance, safety, reliability, convenience in refueling—and can be made available at competitive prices. Reducing the overall cost of key technologies--batteries or fuel cells, lightweight materials, and so forth--will be a critical challenge to any effort to "reinvent" the automobile.

For purposes of this discussion, a "major change" in automobile design would entail a major shift in materials and drivetrain technology built around either the internal combustion engine (ICE), fueled by reformulated gasoline or by one of a variety of alternative, nonpetroleum fuels, or an electric or electric hybrid drivetrain.[78]

The option of moving quickly to superefficient automobiles raises a number of generic issues that deserve careful evaluation. These include:

- the appropriate role of government in researching, designing, and commercializing superefficient vehicles, given the government's ability to focus on longer-term goals, the expertise of the national laboratories, the need to avoid stifling innovation. and so forth;
- the importance of financial and personnel resource constraints on the auto industry, given requirements for continued evolutionary updates[79] and satisfaction of new safety and emission standards:
- the potential for important shifts in market power away from the traditional vehicle manufacturers, especially if the new vehicles are electric, and the large changes in employment patterns and other national economic factors that would follow:
- the vulnerability of radically new vehicle designs to product liability challenges; and
- the potential need for substantial new investment in infrastructure (e.g., new electric capacity, charging stations).

On September 29. 1993, the White House announced the signing of an agreement between the Federal Government and the three domestic automakers designed to create a Federal-industry partnership to develop a new generation of vehicles up to three times more fuel efficient than current vehicles. Box 5-2 describes the proposed effort.

Designs Based on the Internal Combustion Engine

The basic features that would have to be included in a major redesign of an ICE vehicle are reasonably well known:

- a shift in body materials, probably to carbon-fiber or other composite materials;
- a total dedication to streamlining, bringing the vehicle drag coefficient[80] down to 0.2 or lower, compared with the current commercial state of the art of about 0.3;
- high-pressure, low-rolling resistance tires, perhaps similar to those in General Motors" Impact electric vehicle:
- an advanced engine, probably either a superefficient four-stroke design with four or more valves per cylinder, adjustable valve lift and

[78]See A.B. Lovins et al., Rocky Mountain Institute, "Supercars: The Coming Light-Vehicle Revolution," unpublished paper, Mar. 31, 1993. This paper contends that advanced vehicles with an electric hybrid configuration can achieve fuel economies well in excess of 100 mpg.

[79]It is unlikely that the auto industry would discontinue its current evolutionary approach to model updating while developing the alternative "revolutionary" vehicles, given the substantial risk that the revolutionary approach will not succeed.

[80]Defined as aerodynamic drag divided by (vehicle frontal area) x (velocity squared).

BOX 5-2: The Clinton Administration's Clean Car Initiative

On September 29, 1993, the Clinton Administration, together with the chief executive officers of Ford, General Motors, and Chrysler, announced the formation of a research and development (R&D) partnership to develop a new generation of vehicles that would be up to three times as fuel efficient as today's models. Broadly, this Clean Car Initiative is intended to restore U.S. leadership in automotive technologies, reduce the environmental impact of automobiles, and reduce U.S. dependence on imported oil The specific goal is to develop a manufacturable prototype within 10 years that achieves a threefold increase in fuel efficiency while maintaining the affordability, safety standards, performance, and comfort available in today's cars

Achieving this goal is expected to require technological innovations in both the vehicle power plant and the vehicle structure. These innovations might include replacing the internal combustion engine with fuel cells or a gas turbine-electric hybrid power plant, and making the car body with advanced polymer composites instead of steel. Accordingly, the R&D partnership will also develop supporting technologies, such as advanced manufacturing techniques and lightweight, high-strength materials.

The Clean Car Initiative is intended not just to pioneer technical frontiers, but also to serve as a model for a more cooperative relationship between government and industry in the future On the government side, many agencies will contribute, including the Departments of Energy, Defense, Commerce, and Transportation, the Environmental Protection Agency, the National Aeronautics and Space Administration, and the National Science Foundation They will be coordinated by Mary Good, Undersecretary of Commerce for Technology. On the industry side, the effort will be coordinated by USCAR, a partnership of Ford, General Motors, and Chrysler that also includes other ongoing automotive research consortia (such as the Advanced Battery Consortium, the Automotive Composites Consortium, and the Vehicle Recycling Partnership)

The research agenda of the Clean Car Initiative will be set jointly by a team of officials from both government agencies and industry No new money is expected to be earmarked for this effort, rather, the goals are to be achieved through reprogramming existing funds so as to mesh ongoing research efforts more closely Projects will be funded jointly by government and industry, with the proportion of industry funding greater for those projects having near-term commercial applications, and the proportion of government funding greater for riskier projects with longer term payoffs. The Administration sees the initiative as an opportunity to realize a "peace dividend, " with defense researchers and weapons laboratories contributing their expertise to expand the envelope of available technologies. Indeed, the Administration compares the level of effort required to that of the Apollo and Manhattan Projects.

SOURCE Office of Technology Assessment, 1994

timing, and other low-friction measures; a two-stroke engine; or an advanced diesel;

- extensive use of aluminum and other light-weight materials in suspension and other components (e.g., brake rotors and calipers, sway bars, wheels);
- major redesigns of seats, bumpers, and other components to reduce weight; and
- advanced transmissions, probably a five or six-speed automatic.

Another possibility might be an automatic engine turnoff at stops coupled with a flywheel for accessory power.

The ultimate capabilities of such a vehicle are somewhat controversial. Although some advocates of advanced designs use 100 mpg as a target and hold up existing prototype vehicles[81] as demonstrations of this potential, most of these prototypes are small two- or four-passenger vehicles

[81] For example, Renault's VESTA2, which claims a fuel economy of 78 mpg city and 107 mpg highway, or Toyota's AXV, with 89 mpg city and 110 mpg highway. See D.L. Bleviss, *The New Oil Crisis and Fuel Economy Technologies* (Westport, CT: Quorum Books, 1988).

with limited performance and few if any power accessories. Maintaining the performance and other basic vehicle attributes now common to the U.S. market presents a substantial challenge to attempts to attain very high levels of fuel economy. Similarly, existing and new safety and emission standards may create additional constraints on the achievable efficiency levels.

General Motors' new Ultralite prototype demonstrates both some of the potential and some of the limitations of a major redesign. The vehicle weighs just 1,400 pounds despite being comparable in interior volume to a Chevrolet Corsica, which weighs over 3,000 pounds; is powered by a 1.5-liter, three-cylinder, two-stroke engine that weighs only 173 pounds yet generates 111 horsepower at 5,000 revolutions per minute (rpm); has a drag coefficient of only O.192: and rolls on high--pressure, low-rolling resistance tires that need no spare because they are self-sealing. Although its fuel economy at 50 mph is 100 mpg, the Ultralite's EPA fuel economy is only 56 mpg, or about 48 mpg when adjusted for on-road conditions.[82] This value, although superb, still falls far short of the levels often touted as readily available to the farsighted vehicle designer. Perhaps backing off vehicle performance (the Ultralite can reach from O to 60 mph in 7.8 seconds, which is sports-car performance and far better than the fleet average) and improving on the conventional four-speed automatic transmission (from Saturn) will help, but reaching 70-mpg levels and higher clearly will require even more radical redesigns.

Electric Vehicles

Electric vehicles, or EVs, use either batteries. fuel cells, or a combustion engine-generator combination to provide electricity to power electric drive motors. An advanced EV would use small, efficient, variable speed alternating-current (AC) motors mounted at the wheels, rather than the larger. heavier direct-current (DC) motors used on most current EV designs: recent advances in electronics have greatly reduced the size and weight of equipment to convert DC power (provided by fuel cells or batteries) to AC power for the motors. This setup provides very high drivetrain efficiencies, since AC motors can readily attain efficiencies well above 90 percent, no transmission is required, and the engine need not run when the vehicle is stopped. Further, regenerative braking—using the motors as generators to provide braking force and storing the electricity thus generated in the batteries—further enhances system efficiency by capturing a portion of the otherwise-wasted braking energy. The key roadblock to EVs is the difficulty of storing enough energy on-board; the energy density of battery storage is a small fraction of that of gasoline;[83] and hydrogen (for fuel cells) is also lacking in energy density.

Cost analyses of advanced EVs are quite speculative, and projections by advocates that EVs can have life-cycle costs fairly competitive with gasoline-powered vehicles clearly must be viewed with some skepticism. Optimistic estimates depend on a number of factors:

- *Vehicle lifetimes.* Although advocates assert that electric drivetrains will outlast ICE-based drivetrains severalfold, this must be proven in actual automotive service, and other components of the vehicle may determine scrappage times anyway. Many analysts assume EVs will last longer than ICE vehicles. Although this may be likely, the uncertainty associated with any estimates of the difference in lifetimes is high. Similarly, most analysts assume that the electric drive train will require significantly less maintenance than the ICE vehicle drivetrain;

[82] General Motors Corp. brochure, n.d.

[83] Gasoline stores over 300 (80) times the energy of the same weight (volume) of conventional lead-acid battery, assuming 40 watt-hour/kg for the battery (J.M. Ogden and R.H. Williams, *Solar Hydrogen: Moving Beyond Fossil Fuels* (Washington, DC: World Resources Institute, October 1989), table 14. Gasoline's energy density advantage is reduced by a factor of perhaps 4 or 5 when the higher efficiency of an electric drivetrain over a gasoline-based drivetrain is accounted for.

this appears likely, as well, but the magnitude of savings is essentially a guess.

- *Overall vehicle design and performance.* Designs for EVs may well stress efficiency more than competing ICE vehicles, and may downplay high performance, because the EVs will have to maximize range to be competitive. Cost comparisons will depend critically on whether the competing vehicles are assumed to achieve similar levels of design efficiency and performance, or whether the EVs are assumed to be more efficient in design and poorer performers. Similarly, demanding longer ranges for EVs will raise costs, so the range assumption will be important in the cost comparison.
- *Technology cost.* An advanced EV will have critical technologies that are not currently commercial and thus cannot be costed firmly. The battery system will generally be the critical cost element, although hybrids will have a complex power control system and other elements that, in some configurations, may exceed the battery in cost.

Fuel-Cell Vehicles

A fuel-cell-powered vehicle is essentially an electric car, with the fuel cell[84] and storage tank (for hydrogen or for a hydrogen-carrying substance such as methanol) substituting for the battery. If the fuel is not hydrogen but a "hydrogen carrier" (methanol or natural gas), an onboard reformer is required to release hydrogen from the carrier fuel. Because any excess electricity from the fuel cell, as well as electricity obtained from regenerative braking, can be shunted to battery storage, the vehicle can use a high-power-density battery (or other storage device such as an ultracapacitor or flywheel[85]) to provide the necessary power boost for rapid acceleration; the fuel cell then does not have to be sized for the vehicle's maximum power needs.

All advanced EVs have important opportunities for reduction in energy use and greenhouse gas emissions. A fuel-cell-powered electric vehicle (FCEV) is especially intriguing because fuel cells are extremely efficient energy converters and would be coupled to an EV efficient drivetrain; in addition, they generate no harmful emissions (although the total system will generate emissions if the vehicle fuel is a hydrogen carrier such as methanol and must be converted into hydrogen on board). And they can be refueled quickly, so that range constraints are far less of a problem once sufficient refueling infrastructure is put into place. This is important because, like battery storage, hydrogen is not an energy-dense fuel: its energy density is about one-third that of natural gas, which at 3,000 pounds per square inch (psi) has only about one-quarter the energy density of gasoline.

Three types of fuel cells may be suitable for light-duty vehicles. Proton-exchange membrane (PEM) fuel cells, also known as solid-polymer-electrolyte (SPE) cells, generally are considered closest to commercialization of the three candidates, although policy makers should be skeptical of any claims that practical fuel cells for vehicles are only a few years away from fleet entry. The recent patenting of a method to achieve an 80-fold reduction in the amount of platinum needed in the cell—to levels not a great deal higher than those used in three-way catalytic converters-has greatly enhanced the commercial possibilities of PEM

[84] A fuel Cc]] converts the chemical energy in its hydrogen fuel into electricity in a manner similar to that of a battery. Hydrogen is fed into the cell at the negative anode and gives up its electrons to the anode, becoming hydrogen ions in the process; the electrons then flow through a circuit to the cathode, where they combine with atmospheric oxygen to form oxygen ions. The hydrogen ions then move through the electrolyte, which will allow them to pass but will block hydrogen or oxygen in gaseous form, to the anode where they combine With the oxygen to form water.

[85] An ultracapacitor is an energy storage device that stores electricity directly, rather than transforming it into chemical energy and reconverting it to electricity when demanded, as a battery does. A flywheel stores electricity as mechanical energy in the form of a rotating mass.

fuel cells.[86] Alkaline fuel cells should have low material cost and high performance, but CO_2 will poison the electrolyte so that a CO_2-free air supply is required; this type of fuel cell will depend for success in light-duty vehicles on a breakthrough in CO_2 removal or identification of a CO_2-tolerant alkaline electrolyte.[87] Solid-oxide fuel cells also should have high performance, but are far from commercialization.[88]

Aside from differences in engineering design details and choice of fuel cell, an FCEV system has a range of major design options. In addition to the choice of hydrogen or hydrogen carrier as a fuel, multiple storage technologies can be used (hydrogen can be carried as a highly compressed gas; a low-temperature, or cryogenic, liquid; a metal hydride; or in water, to be released in reaction with sponge iron[89]) and multiple ways to produce the hydrogen or hydrogen carrier (e.g., hydrogen can be produced from natural gas, by gasifying biomass or coal, or by electrolysis of water with any source of electricity). Some of the choices will be made because of the different stages of development of the technologies (e.g., initial production of hydrogen would likely be from natural gas, with water electrolysis from solar electricity following if costs of photovoltaic cells are reduced sufficiently). Others might be made because of variances in impacts among the choices (e.g., although biomass hydrogen costs may be considerably lower than solar power-based costs, hydrogen production from solar electricity would use about one-fiftieth the land area required by a system obtaining hydrogen from biomass gasification because of the inefficiency of photosynthesis and of the gasification process[90]).

Technological (and cost) uncertainty, high with any advanced EV, should be highest with an FCEV. Sources of uncertainty include the fuel cell itself, the reformer (if necessary), and the fuel storage system (storage at very high pressure—e.g., 8,000 psi—is desirable, and this requires carbon-wrapped aluminum canisters, which have been very expensive but apparently are coming down in price,[91] and powerful compressors that may have high initial and operating costs), as well as high-tech materials and other efficiency technologies needed to maximize system efficiency and thus ensure adequate range. Also, hydrogen supply costs are highly uncertain, especial] y if nonhydrocarbon sources are used.

Battery Electric Vehicles and Electric Hybrids

The alternative to a fuel-cell-powered vehicle is one powered either by a high-energy-density battery or by a hybrid system combining two power sources, with at least one powering an electric motor. The range of potential power sources includes batteries, flywheels, ultracapacitors, heat engines, and others,

Hybrid systems generally are advanced as a means to obtain most of the gains of an EV with greater range. They come in a variety of configurations. One would use a small, constant-speed ICE as a generator to power high-efficiency electric motors at the wheels, with a high-power-density battery or ultracapacitor used to provide a cur-

[86] U.S. Congress, Office of Technology Assessment, *Defense Conversion: Redirecting R&D*, OTA-ITE-552 (Washington, DC: U.S. Government Printing Office, May 1993).

[87] M. DeLuchi, Institute of Transportation Studies, University of California-Davis, "Hydrogen Fuel-Cell Vehicles," unpublished paper, Sept. 1, 1992.

[88] Ibid.

[89] In this system, steam reacts with sponge iron to create rust and release hydrogen; after the iron is completely oxidized, the fuel storage canister is removed, and in a special facility, the rust is regenerated to iron through reduction. This system has been newly patented by J. Werth, H-Power, Inc.

[90] DeLuchi, op. cit., footnote 87.

[91] Ibid.

rent boost to the motors for acceleration or hill climbing. The ICE in this case would be sized for average power needs, can be quite small, and can be very efficient and clean because it runs at one design speed.[92] Alternative systems could rely exclusively on batteries for most trips, with the engine-generator for extended range only, or they could use both electric motors and a small ICE to drive the wheels, perhaps with the electric motors providing higher power only when necessary.

For the simpler, all-battery alternative, the crucial element for successful commercialization is development of a battery that combines high energy density for range, high power density to allow competitive acceleration performance, long lifetime under relatively adverse conditions, and moderate cost. A variety of battery types are under development, including lithium-aluminum-iron disulfide, a variety of lithium-based batteries including lithium polymer, nickel-metal hydride, and others. Also, a number of variants of lead-acid batteries are being developed that seek higher energy density and longer life through design alterations and use of new materials. Although a variety of claims about performance and cost have been made for all battery types, virtually all of the advanced batteries are far from commercialization, with numerous design decisions that affect performance yet to be made and crucial problems yet to be solved. In other words, it is too early to know whether the batteries currently under development will perform (and cost) as claimed under mass production and use conditions.

Optimistic estimates for conventional and hybrid EVs depend on the factors noted above. Further, analyses of all of these vehicle types may assume superefficient characteristics throughout the vehicle, with relatively low power and fuel storage requirements because of the extreme light weight of the vehicles, the very high efficiency of the power train, the recovery of most of the braking energy through regenerative braking systems (for the electric systems), the advanced aerodynamics, and extremely low-friction tires. These characteristics do create some difficult questions for designers, however. For example, safety may become a critical issue for these vehicles, especially if they aim for weights around 1,000 pounds, which the Ultralite demonstrates is possible. Although the new materials used may be extremely strong, and the vehicles presumably would incorporate extensive safety equipment and design, the basic problem of protecting passengers in such a light structure is a difficult one—especially if the vehicle shares the road with much heavier vehicles. Another concern is the *robustness* of the vehicle's performance, It is not clear that optimistic design concepts for extremely light, aerodynamic vehicles have taken fully into account the variety of tasks for which automobiles are sometimes used. For example, with a 1,000-pound vehicle, four heavy passengers plus luggage will more than double the total vehicle weight; hauling cargo on the roof of such a vehicle could make a huge difference in its total aerodynamic drag; and so forth. Although challenges of this nature may well be met, either through design or through changes in the way consumers use automobiles, they add more uncertainty to fuel economy projections.

Finally, key uncertainties remain about crucial design and manufacturing details. In particular, the production of vehicle bodies with strong, lightweight composite materials is still accomplished largely by hand, at great cost. Unless manufacturing processes can be heavily automated, costs will remain prohibitive. And component efficiencies, especially for regenerative braking, remain unclear, although they are critical to overall efficiency and cost.

[92] Lovins et al., op. cit., footnote 78, discusses this configuration. At idle or other times when power needs are low, the excess electricity generated by the ICE recharges the battery or ultracapacitor; at times when power requirements are high, the battery adds power to the electric motors.

Which Technology Will Win?

A combination of varying State and Federal requirements, the existence of various niche markets. and likely preferences for their "own"' fuel by electric and natural gas utilities guarantees that a variety of power-train types will be represented in the U.S. fleet during the process of moving to a super-efficient auto. It is far from clear which types of vehicles will endure and gain significant market shares over the long term. However, it is worth noting that the development of many of the efficiency technologies that apply to all power-trains (lightweight materials, low-friction tires, advanced aerodynamic designs, etc.) will yield a gasoline-fueled auto of considerable attractiveness, with a built infrastructure and built-in public acceptance, probably capable of attaining emission reductions that might reduce some of the critical environmental arguments against it.

ALTERNATIVE FUELS AND CONSERVATION

The use of alternative, nonpetroleum-based fuels in vehicles, though generally viewed as a fuel substitution measure, also offers opportunities to reduce overall energy use and greenhouse emissions; in other words, alternative fuels can play a role in energy conservation. The shift from gasoline and diesel fuel has effects that reverberate throughout the entire fuel cycle. Feedstock materials for alternative fuels are different from those in the oil-based system, with different energy use required to find, collect, and transport the materials, different processes to transform them into fuel, (sometimes) different means of distributing the fuel, and different fuel efficiencies and possibly even different engine and storage technologies on (he vehicle. These differences in energy use, coupled with the alternative fuels differences in carbon content and general chemical makeup, yield fuel cycle emissions of both carbon dioxide and non-CO_2 greenhouse gases (carbon monoxide (CO), nonmethane organic compounds (NMOC), nitrogen oxides (NO_x), nitrous oxide (N_2O), methane (CH_4), and possibly chlorofluorocarbons) that maybe significantly different from the greenhouse emissions produced by using petroleum fuels (see box 5-3).

Background

During the 1970s, programs aimed at developing and commercializing alternative transportation fuels were a centerpiece of U.S. efforts at combatting perceived problems of national security; the aim was to reduce U.S. oil use and import dependency. Today, the primary impetus for alternative fuels programs has shifted toward reducing urban air quality problems, especially in State programs such as California's. At the national level, however, national security still plays a strong complementary role in driving legislative initiatives for increasing alternative fuel use.

Both Federal and State governments have taken a number of policy steps to introduce alternatives to petroleum-based fuels into the transportation sector. The alternative fuels of primary interest for the light-duty fleet of automobiles and light trucks are the alcohols methanol and ethanol, either "neat" (alone) or as blends with gasoline; compressed or liquefied natural gas (CNG or LNG); liquefied petroleum gas (LPG) and propane; hydrogen; and electricity. The fuels and their basic characteristics are described in table 5-5.

Several important policy measures for promoting alternative fuels development have already been undertaken. These are:

1. CAFE credits[93] available to automakers who produce alternatively fueled vehicles, allowing them to treat the vehicles as very high mileage cars that can be averaged into their fleets, allowing fuel economy standards to be met more easily. These credits are unlikely to provide

[93] Under the Alternative Motor Fuel Use Act of 1988.

BOX 5-3: Why Does Alternative Fuel Use Affect Greenhouse Emissions?

Efficiency

Because many of the fuel-cycle stages of alternative fuels differ significantly from their gasoline fuel-cycle counterparts, the overall energy efficiency of alternative fuel vehicles can differ substantially from that of gasoline or diesel vehicles Important sources of differential energy use Include

1 *Feedstock recovery.* Alternative fuel feedstocks include wood and other biomass materials (including intensively grown row crops), natural gas, coal, and all feedstocks used to generate electric power. The energy use for obtaining feedstocks such as coal and row crops will be significantly higher than for oil; natural gas production may have energy consumption similar to that for oil, except for pumping energy. (In most cases, natural gas flows freely from the wellhead and requires no pumping; an exception is the pumping energy required to remove water from coalbed methane wells.)
2 *Fuel processing.* Processing energy for alternative fuels made from coal and biomass may be much larger than that for gasoline, and larger still than that for natural gas. However, natural gas as well as hydrogen may incur large energy penalties for compression and, possibly, liquefaction.
3 *Transportation.* Locally made fuels, such as biomass-based methanol or domestic natural gas, may incur less transportation energy costs than gasoline made with imported oil or imported directly from abroad.
4 *Fuel characteristics.* Differences in the basic characteristics of the fuels can greatly affect energy usage at the vehicle, even if the fuels are used in internal combustion engines similar to gasoline engines. For example, higher octane ratings (methanol's octane is 101.5, natural gas's is 120 to 130, versus about 87 to 93 for typical gasolines) allow higher compression ratios, raising efficiency. Other fuel characteristics such as flame speed and flammability limits affect the ability to use lean burn, a significant energy saver. And fuel energy density and character (pressurized gas, liquid, etc.) affects fuel storage volume and weight, significant factors in vehicle energy efficiency. Further, some fuels allow or require the use of completely different propulsion systems (e.g., electric motors) and drive trains, with unique energy efficiency characteristics.
5 *Vehicle longevity.* Some fuels may have a significant impact on vehicle longevity (because of effects on engine wear, materials requirements, complexity of emissions equipment, and so forth), affecting overall fuel-cycle efficiency by increasing or reducing the share of energy use attributed to vehicle manufacturing. Many analysts expect electric vehicles to have significantly greater lifetimes than gasoline-powered vehicles (although this proposition should be considered speculative until experience is gained with mass-produced vehicles). Natural gas vehicles may also have a longevity advantage over gasoline-powered vehicles.

Renewability

Fuels made from renewable resources have a significant greenhouse emissions advantage over those based on nonrenewable resources, because the regrowth of feedstocks recaptures the carbon dioxide (CO_2) released by combustion of the fuel.

Fuel Carbon Content

Gasoline and diesel fuels and their alternative fuels, as well as all energy sources used at different stages of the fuel cycle, each have unique carbon contents, and thus produce different amounts of carbon dioxide emissions *per unit of energy content* upon combustion. Consequently, even if gasoline and natural gas-fired vehicles have identical energy efficiencies, the carbon dioxide emissions from each will be different because gasoline has a higher carbon content per unit of energy than the natural gas.

(continued)

BOX 5-3: Why Does Alternative Fuel Use Affect Greenhouse Emissions? (cont'd).

When fuels are burned, most but not all of the carbon present in the fuel—95 to 99 percent—is immediately oxidized to CO_2.[1] The rest is either emitted as carbon monoxide (CO), methane (CH_4), nonmethane hydrocarbons, and carbon particulates, or remains in the combustion chamber or on the exhaust system or flue as carbon deposits. As discussed below, even though much of the non-CO_2 emissions will eventually oxidize in the atmosphere to CO_2, these emissions should be treated separately.[2]

In burning fuels directly, oil ranks between natural gas and coal in CO_2 emissions—burning 1,000 Btu's of coal produces about 20 percent more CO_2 than does burning oil, whereas burning the same amount (in energy units) of natural gas releases only about 70 percent of the amount released in oil combustion. As noted above, however, process energy is critical. Although oil refining is energy intensive, transforming natural gas into a liquid fuel like methanol can be more so—about 30 percent or so of the input energy is lost. And producing a liquid fuel from coal will likely be even more energy intensive than methanol, with the potential to lose half the input energy. The continued development of less energy-intensive processing methods can change these relationships in the future.

Non-CO_2 Gases

As noted earlier, CO_2 is not the only gas currently in the earth's atmosphere that exhibits greenhouse characteristics,[3] and is not the only such gas whose atmospheric concentration is accumulating and thus increasing its greenhouse effect. CO_2 is thought likely to cause about half of the expected greenhouse warming; the other gases will contribute the rest. Important non-CO_2 greenhouse gases include CO, CH_4, nitrogen oxides, nitrogen dioxide, and nonmethane organic compounds. The relative importance of these gases to the total greenhouse effect depends upon the time horizon being examined, because all of these gases undergo slow chemical transformation in the atmosphere—in particular, CH_4 has a short lifetime in the atmosphere but is a powerful greenhouse gas, so its relative effect is extremely sensitive to the time frame under consideration.

[1] M A DeLuchi, Emissions of Greenhouse Gases From the Use of Transportation Fuels and Electricity,' paper prepared for Argonne National Laboratory, June 26, 1991

[2] Ibid

[3] A gas may be a direct greenhouse gas (by exhibiting relative transparency to incoming light but reflectivity to outgoing infrared radiation) or an indirect greenhouse gas (by acting to change the concentration of direct greenhouse gases)

SOURCE Off Ice of Technology Assessment, 1994

much incentive to most automakers unless fuel economy standards are raised.

2. The Clean Air Act Amendments of 1990 (CAAA) establish three clean fuels programs: section 249 establishes a pilot-test program in California (described below); section 246 establishes a centrally fueled fleet (10 or more vehicles) program in air quality nonattainment areas; and section 227 requires gradually increasing sales of urban buses that use clean fuels. The California Air Resources Board (CARB) believes that reformulated gasolines will satisfy CAAA's clean fuels requirements, which would limit the extent to which the act will actually promote alternative fuels .[94] However, the act's Phase 11 emission standards, set

[94] D.E. Gushee, Congressional Research Service, "Alternative Transportation Fuels: Are They Reducing Oil Imports?" CRS Issue Brief, updated Mar. 8, 1993.

[redacted]

Gasoline

A motor vehicle fuel that IS a complex blend of hydrocarbons and additives, produced primarily from the products of petroleum and natural gas Typical octane (R+M/2) level is 89.

Methanol

Commonly known as wood alcohol, CH_3OH, a light volatile flammable alcohol commonly made from natural gas Energy content about half that of gasoline (implies range for the same fuel volume is about half that for gasoline, unless higher efficiency is obtained) Octane level of 101 5, allowing use in a high compression engine Much lower vapor pressure than gasoline (low evaporative emissions, but poor starting at low temperatures),

Natural gas

A gas formed naturally from buried organic material, composed of a mixture of hydrocarbons, with methane (CH_4) being the dominant component, Octane level of 120 to 130. Energy content at 3,000 psi about one-quarter that of gasoline

Liquid petroleum gas, LPG

A fuel consisting mostly of propane, derived from the liquid components of natural gas stripped out before the gas enters the pipeline, and the lightest hydrocarbons produced during petroleum refining

Ethanol

Grain alcohol, C_2H_5OH, generally produced by fermenting starch and sugar crops Energy content about two thirds of gasoline Octane level of 101 5 Much lower vapor pressure than gasoline.

Hydrogen

H_2, the lightest gas Very low energy content even as a cryogenic liquid, less than that of compressed natural gas Combustion will produce no pollution except NO_x. Can be used in a fuel cell, as well as in an internal combustion engine

Electricity

Would be used to run electric motors, with batteries as a storage medium Available batteries do not attain high energy density, creating range problems Fuel cells are an alternative to batteries, Fuel cells run on hydrogen, obtained either directly from hydrogen gas or from hydrogen "carriers" (methanol, natural gas) from which the hydrogen can be stripped

Reformulated gasoline

Gasoline that has been reblended specifically to reduce exhaust and evaporative emissions and/or to reduce the photochemical reactivity of these emissions (to avoid smog formation). Lower vapor pressure than standard gasoline (which reduces evaporative emissions), obtained by reducing quantities of the more volatile hydrocarbon components of gasoline Addition of oxygenates to reduce carbon monoxide levels,

SOURCE U S Congress, Office of Technology Assessment, *Replacing Gasoline. Alternative Fuels for Light-Duty Vehicles*, OTA-E-364 (Washington, DC U S Government Printing Off Ice, September 1990)

to begin in Model Year 2001, are very stringent (.075 gpm of non-methane organic gases with 5 yr/50,000 miles certification for vehicles under 3,750 pounds[95]), so estimates that relatively low levels of alternative fuels will be promoted by the act should be considered preliminary.

3. The State of California's pilot-test program under the CAAA, called the Low Emission Vehicle Program (LEVP), requires minimum sales of vehicles in different emissions categories, ranging down to zero emissions. New York and Massachusetts have decided to adopt the California LEVP. As with the CAAA clean fuels requirements, CARB believes that reformulated gasoline, perhaps in conjunction with modified emission control systems, will satisfy most and perhaps all of the emission categories

[95] U S Environmental Protection Agency, *C/can Air Act Amendments of/990: Detailed Summary of Titles* (Washington, DC: November 1990).

except the zero emission vehicle (ZEV) requirement,[96] which probably can be satisfied only with an electric vehicle or a fuel cell vehicle using onboard hydrogen as its fuel. The next most stringent category, for Ultra Low Emission Vehicles, may generate alternative fuel use even if reformulated gasoline can satisfy its requirements, because of cost considerations. (As above, these assessments of reformulated gasoline's ability to meet stringent emissions standards should be considered preliminary.)

4. The Energy Policy Act of 1992 establishes a national goal of 30-percent penetration of nonpetroleum fuels for light-duty vehicles by 2010, with definite requirements for alternatively fueled vehicles in Federal fleets and centrally fueled fleets operated by alternative fuel distributors, and provisions for adding requirements for centrally fueled fleets run by State and local governments and by the private sector. The Act also provides tax incentives for vehicle purchasers and for service station operators.

The Energy Information Administration has estimated that, as a result of all these initiatives. alternatively fueled light-duty vehicles will consume from 1.9 to 2.4 percent of total light-duty fuel use by 2010, with the major contribution coming from the Energy Policy Act fleet provisions.[97] This estimate assumes vehicle sales of about a million per year by 2010, with a total stock in that year of about 8.1 million vehicles, or 3.4 percent of the fleet.

There remain important outstanding policy issues regarding alternative fuel use, despite the important measures already in place. In particular, neither Federal nor State fuel tax regimes take appropriate account of alternative fuels, yielding widely different tax rates for different fuels, and in some cases taxing alternative fuels at substantial y higher rates per *unit of energy* than gasoline.[98] Further, though EIA's projected market penetration of alternative fuels is substantial, it falls short of the high expectations expressed in the Energy Security Act and, as well, depends on some relatively optimistic assumptions about marketplace acceptance of electric vehicles. Consequently, there may well be continued policy suggestions for increased support of alternative fuels, especially if early penetration is disappointing. Evaluation of policy proposals for these issues requires an understanding of alternative fuels environmental characteristics, economic competitiveness, and market acceptance.

Emissions and Air Quality Impacts

Improving urban air quality was the driving force behind much of the push to move alternative fuels into the U.S. motor vehicle fleet--especially California's groundbreaking efforts. Proponents of alternative fuels believe that their physical and chemical makeup gives these fuels a substantial advantage over gasoline in controlling emissions. Electricity and hydrogen offer the most obvious benefits: electric vehicles have no harmful emissions associated with combustion or fueling;[99] and hydrogen-fueled vehicles will have no emissions if the power source is a fuel cell, and only nitrogen oxides if the power source is an ICE. In their pure form, the other alternative fuels—natural gas. methanol, ethanol, and LPG—are chemically simpler than gasoline, which should allow easier engine optimization for low emissions.

[96] U.S. Department of Energy, Energy Information Administration, *Assumptions for the Annual Energy Outlook 1993*, DOE/EIA-0527(93) (Washington, DC: January 1993).

[97] Ibid.

[98] D.E. Gushee and S. Lazzari, Congressional Research Service, "Disparate Impacts of Federal and State Highway Taxes on Alternative Motor Fuels," Mar. 12, 1993.

[99] However, generating the electricity may create substantial emissions, though these may be far removed from the urban airsheds where air quality improvements are desired, and powerplants produce few hydrocarbon emissions, which are primary precursors of ozone.

Also, they have various attributes that appear superior to gasoline. For example, methanol:

- has a lower photochemical reactivity than gasoline. As a consequence, emissions of unburned methanol, the primary constituent of methanol vehicle exhaust and fuel evaporative emissions, have less ozone-forming potential than an equal weight of organic emissions from gasoline-fueled vehicles;
- has higher octane and wider flammability limits than gasoline. This allows a methanol engine to be operated at higher (leaner) air-fuel ratios than similar gasoline engines, promoting higher fuel efficiency and lower carbon monoxide and exhaust organic emissions;
- has lower volatility than gasoline, which should reduce evaporative emissions; and
- lacks the toxics (e. g., benzene) found in gas line, relieving some issues of carcinogenic emissions.

On the other hand, methanol emissions contain a significantly higher level of formaldehyde than do gasoline emissions, a cause for concern especially in enclosed spaces such as parking garages. Natural gas, ethanol, and LPG share similar advantages over gasoline, with each having unique characteristics. For example, natural gas has no evaporative emissions, and direct contact with ethanol is less toxic to humans than contact with either gasoline or methanol.

However, the relative emissions performance of the various alternative fuels and gasoline cannot be assessed adequately by simply comparing the physical and chemical characteristics of the fuels, or by relying on limited successful emissions testing of alternatively fueled vehicles. First, gasoline, and the gasoline vehicle, are moving targets. Under pressure from both State and Federal regulation, gasoline is being improved and new emission control technologies are nearing commercialization. As noted above, CARB believes that the combination of reformulated gasoline with new emission controls, especially the electrically heated catalytic converter, 'm will satisfy extremely strict California emission requirements,[101] and, apparently, place gasoline virtually on a par with alternative fuels. On the other hand, advocates of alternative fuels argue that emission controls depending primarily on complicated technological equipment may frequently fail with actual use. Available evidence indicates that about 10 to 20 percent of current automobiles are "gross polluters" even thought most of them are equipped with sophisticated emission controls. 02 However, this concern affects alternative fuels also; methanol vehicles, for example, will require sophisticated catalytic control to reduce formaldehyde emissions.

Second, it is not practical to use most alternative fuels in their pure form, so that some of their physical and chemical advantages will be compromised. Methanol and ethanol will most likely need to be mixed with 15-percent gasoline to promote cold starting, since the alcohols' lack of volatility inhibits fuel vaporization in cold weather. Natural gas is largely methane, but 5 to 15 percent is a variable combination of ethane, propane, and nitrogen, thus complicating emission control.[103] Similarly, LPG is largely propane, but it contains other constituents in varying amounts. This lack of purity and uniformity complicates any attempt to optimize engine design. Also, the likelihood that the alcohol fuels will be used in flexible fuel vehicles, with varying combinations of alcohol and gasoline, further complicates emission control.

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[100] Or a similar device, e.g., a close-coupled converter (located nearer to the engine to promote rapid heating).

101 U.S. Department of Energy, op. cit., footnote 96.

[102] D. E. Gushee, "Alternative Fuels for Automobiles: Are They Cleaner Than Gasoline?" Congressional Research Service Report for Congress 92-235 S, Feb. 27, 1992. This paper is an excellent source of information about emission and air quality implications of alternative fuel use.

[103] Ibid.

Third, tests of individual vehicles often are difficult to extrapolate to conclusions about mass-produced fleets because of variability among different vehicle models, important changes in emissions as catalysts age, and uncertainties about how vehicles will be maintained in actual use.

Fourth, the formulation of emission standards will play a major role in the actual environmental effects of alternative fuels because vehicle designers try to meet standards, not minimize emissions. Alternative fuels appear to have clear advantages over gasoline when held to the same mass emissions requirements, because their exhaust emissions are less photochemically reactive. Federal standards are based on mass emissions, preserving this advantage.[104] California, however, is moving towards emissions standards that correct for the reactivity of emissions, e.g., gasoline-fueled vehicles would have to achieve lower (mass) emissions than methanol-fueled vehicles because the gasoline exhausts produce more ozone per unit mass. Under such a regulatory system, alternative fuels might enjoy no environmental advantage over gasoline, at least so far as exhaust emissions and criteria pollutants (carbon monoxide, nitrogen oxides. hydrocarbons) are concerned.[105]

Fifth, exhaust emissions are only part of the picture. Evaporative emissions are important, and becoming increasingly so as exhaust emissions are subject to more stringent controls. Except for alcohol-gasoline mixtures, the alternative fuels have lower and less reactive evaporative emissions than gasoline.

Energy Security Impacts

Switching to alternative fuels has complex effects on energy security. Development of alternative fueled systems—vehicles, supply sources, and distribution networks-is viewed by supporters as both a means to reduce dependence on oil, lowering the economic and national security impact of a disruption and/or price rise, and leverage against oil suppliers, threatening them with loss of markets if they raise prices too high or disrupt supply. The use of alternative fuels does offer the *potential* to significantly enhance U.S. energy security, but the effect depends greatly on the fuel chosen, the scale of the program, and the specific circumstances of the supply and vehicle system used. The security effects are complex and sometimes ambiguous, because some characteristics of an alternative fuels program maybe beneficial and some deleterious to energy security.

First, of course, an alternative fuels program cannot enhance energy security unless it reduces U.S. oil use. This potential benefit of alternative fuels use may be compromised by the fuel economy (CAFE) credits made available to auto manufacturers who sell alternatively fueled vehicles. In essence, these credits will allow these manufacturers to produce a less-efficient fleet than they otherwise would have produced, or else allow them to avoid paying fines because they couldn't achieve the mandated fuel economy standards. If automakers choose to produce less-efficient vehicles, alternative fuels use will save little oil and may have no positive impact on energy security.

Assuming that CAFE credits do not negate potential oil savings, the security benefit of an alternative fuels program will likely be clearest if the fuels can be domestically supplied. Fuels such as electricity, hydrogen, and ethanol are likely to be domestically produced and thus unambiguously advantageous to energy security *unless* their costs are so high as to damage the national economy.[106] Ethanol's dependence on intensive agriculture, which may suffer on occasion from drought, may make it less secure than the others; successful de-

[104] Ibid.

[105] Note that this is not a criticism of the California proposal, which puts all fuels on an equal basis as far as allowable air quality impacts are concerned.

[106] Assuming that the fuels are used because of regulatory requirements or generous economic incentives.

velopment of economic ethanol production processes using lignocellulosic material (wood and wood wastes, waste paper) as a feedstock would significantly reduce this potential problem. Methanol *might* be domestically supplied based either on coproduction of pig iron and methanol in steel mills or on use of domestic gas resources. The potential of the former is somewhat theoretical; the latter requires a continuation of low domestic gas prices and low interest rates, with future low prices hardly assured given increasing demands on domestic gas resources (especially from power production). And natural gas would likely be supplied either domestically or with pipeline imports from Canada and Mexico, because the alternative--overseas shipment in liquefied form--would tend to be more expensive.

If alternative fuels are imported, this does not necessarily negate energy security benefits. An imported fuel's effect on energy security will depend on its physical characteristics, the characteristics of the suppliers, the type of financial arrangements made between producers and suppliers, the worldwide price relationship between the fuel and oil (that is, will a large oil price rise automatically raise the fuel prices?), and other factors.

For example, two-thirds of the world's natural gas reserve reside in the Middle East and former Eastern Bloc, leading some analysts to deny that the United States would receive any security benefit from turning to methanol (which is produced from natural gas). However, methanol use will reduce pressures on world oil supplies, and natural gas resources are more diversified than oil resources; also, the U.S. might be able to establish long-term trade pacts with secure methanol sources, which could enhance security benefits. Finally, the United States' changing relationships with the nations of the former Soviet Union and its satellites may lead to a more optimistic assessment of the energy security effects of methanol trade with these nations.

Other factors affecting energy security include scale of the program and selection of dedicated (that is, designed to use one fuel only) or multifuel vehicles. The size of the program affects the magnitude of impact on oil markets, the credibility of the program as a deterrent to intentional disruption of oil supplies, the magnitude of the financial risks, the supply source (moderate-scale natural gas and propane programs could be fueled domestically, large-scale programs probably would require imports), production costs, and so forth. The choice of multi-fueled vehicles might allow the United States to play off suppliers of oil against suppliers of alternative fuels (assuming they are different), but only if the supply and delivery infrastructure is available to allow the vehicles to be fueled exclusively with the alternative fuel if this became necessary. Concentration on dedicated vehicles. on the other hand, offers no ability to play off oil and alternative fuel suppliers, but *requires* full infrastructure development and offers important emission and performance benefits as well.

In conclusion, development of alternative fuels appears likely to offer energy security benefits if the use of CAFE credits does not eliminate oil savings, but the magnitude of these benefits could vary widely depending on the precise development scenario that unfolds, including the fuel choice, method and location of production, scale of production, and vehicle choice. There are remaining uncertainties about the direction of some of the security effects, and some of the factors that affect security are not really controllable by policymakers but will unfold over time as the fuels program develops. Consequently, estimates of the security impacts for potential alternative fuels programs should be considered tentative, especially for programs that may require importation of feedstocks or finished fuels.

Sources of Uncertainty About the Greenhouse and Energy Use Impact of Alternative Fuels

With few exceptions, there is little practical experience with large-scale use of alternative fuels in the United States, and the details and the impacts of the fuel-cycle changes necessary to support such use are uncertain.

An important source of uncertainty is the relative immaturity of much of the necessary technology to power vehicles and, in many cases, to obtain the fuel. The rapid technological change that will characterize such development implies that estimates of vehicle efficiency, emission of non-CO_2 gases, and efficiency of feedstock conversion processes are all quite uncertain. Further, many of the decisions regarding efficiency of engines and processes involve complex economic, environmental, and vehicle attribute tradeoffs that are essentially unpredictable—for example, how will engine designers trade off engine power, efficiency, and engine-out emissions in designing dedicated alcohol engines?

The energy balance of the upstream part of the fuel cycle—finding and obtaining the feedstock, processing it into fuel, and transporting the fuel to market--depends heavily on the type and location of the feedstock. In turn, this depends on the scale of worldwide development, political and trade decisions, and so forth, all unforeseeable. For example, there are multiple sources of natural gas that could prove suitable for methanol production. Most are outside of the United States, though relatively low U.S. natural gas prices and the United States' low cost of capital currently make domestic methanol production look attractive.[107] The various sites have different infrastructure and labor availability. different tax codes, and different gas prices; these translate into different tradeoffs between, for example. capital intensive high-efficiency methanol production processes and less expensive but less efficient plants. Each location requires longer or shorter travel distances to move the methanol to market, incurring higher or lower transport energy costs. As the scale of worldwide development increases, methanol will "move up the supply curve, " using more expensive feedstock natural gas sources and, perhaps, eventually move to coal as a feedstock, with negative greenhouse implications. And to complicate this issue further, methanol may be produced as a coproduct with pig-iron as an alternative to more traditional steelmaking operations involving coke ovens and blast furnaces. This form of production apparently would produce less CO_2 than a separate conventional steel mill and methanol plant.[108]

There also are a variety of straightforward technical unknowns in evaluating the fuel cycle. For example, given the importance of methane as a greenhouse gas, there is a critical uncertainty about the amount of natural gas leakage in the gas production and distribution system, As another example, both N_20 and NO_x are powerful greenhouse gases that arise, in part, from the denitrification and vitrification of fertilizers. The relative greenhouse impact of the ethanol and other biomass fuel cycles depends in large part on the rate of emission of these gases, but this is generally unknown.

Finally, there remain important uncertainties about the relative magnitude of the greenhouse forcing roles played by the non-CO_2 gases, Understanding of the role that each gas plays in global climate is still evolving.

Recent Estimates of Greenhouse Impacts of Alternative Fuel Cycles

Despite the substantial uncertainties, clear differences in likely greenhouse impacts exist among several of the alternative fuels. One of the most thorough and best-documented analyses of the fuel-cycle greenhouse emissions from alternative

[107] D.E. Gushee, Congressional Research Service, Memorandum to the House Committee on Energy and Commerce, Subcommittee on Energy and Power, "Methanol Supply Demand Balance to 2000. " June 5, 1992.

[108] Ibid.

fuel "scenarios" is the work of Mark DeLuchi of the University of California at Davis. Table 5-6 shows DeLuchi's estimates of the fuel-cycle emissions from the use of several alternative fuels in internal combustion engine-powered light-duty vehicles, relative to the emissions from a baseline gasoline-powered automobile in the year 2000. The ranges of the estimates reflect the uncertainty discussed above.

Policy Issues

As discussed above, both Federal and State governments have initiated a number of important policy initiatives to move alternative fuels into the U.S. motor vehicle fleet, and current expectations are optimistic that significant amounts of these fuels—a few percent of total consumption-–will be consumed by 2010. Some important policy issues remain unresolved, however.

First, as noted, fuel taxation policy does not appear to take rational account of alternative fuels' unique characteristics. For example, electricity currently is charged no Federal highway tax and natural gas is charged very little, whereas LNG and methanol pay significantly higher taxes than gasoline on a dollars per unit of energy basis.[109] Although it may make sense to tax different fuels at different rates based on differential environmental or energy security impacts, current rates seem to bear no relation to energy policy or environmental goals. Two options that would take account of the properties of the fuels might be:

1. Tax each alternative fuel at the same rate in dollars per Btu delivered to the vehicle, possibly with electricity rates being adjusted to account for energy lost at the powerplant. The rate could be equal to or lower than current gasoline taxes, to reflect the government's desire to allow the market to decide or to favor alternative fuels over gasoline.
2. Tax each alternative fuel at different rates that reflect evaluations of each fuel "nonmarket" characteristics, e.g., energy security implications and environmental characteristics.

A problem with the second approach is the substantial uncertainty that underlies the likely societal impacts of the fuels, discussed above.

A second issue is closely related to the first. Federal policy currently is demanding that certain fleets-its own and those of fuel suppliers—buy alternative fuel vehicles and use these fuels. The rationale behind these requirements is to promote energy security and air quality. However, although the different fuels have very different impacts on these values, the requirements ignore these differences; fleet owners will choose fuel/vehicle combinations based only on market incentives. It is possible--even probable—that the fuel/vehicle combinations most often chosen will have significantly less favorable impacts on energy security and air quality than other choices.[110]

Congress was aware of this issue at the time of passage of the Energy Security Act and chose not to try to further influence fleet owners' market decisions. If Congress's views change, perhaps after the emergence of sales patterns for alternative fuel vehicles and the fuels, it could influence sales by using differential fuel taxes, as above, and/or by "weighting'* sales according to estimated nonmarket impacts.

[109] Gushee and Lazzari, op. cit., footnote 98.

[110] The most popular combinations are likely to be those that involve minor adaptations from current gasoline vehicles (and thus are least costly in capital investment and most easily resold into normal markets)—primarily flex fuel vehicles. These will likely yield only modest air quality benefits (and possibly no benefits over reformulated gasoline), and their ability to use gasoline may translate into a relatively low consumption of alternative fuels.

TABLE 5-6: Fuel-Cycle CO_2-Equivalent Emissions of Greenhouse Gases

Feedstock/fuel/vehicle[a]	Fuel-cycle CO_2-equivalent emissions (grams/mile)[b]	Change with respect to reformulated gasoline[c] (in percent)
Internal-combustion-engine vehicle (ICEV)		
Coal/methanol/ICEV[d]	741	58
Coal/compressed hydrogen/ICEV[e]	713	52
Natural gas/methanol/ICEV[f]	439	-6
Natural gas/compressed natural gas/ICEV[g]	346	-26
Natural gas/compressed hydrogen/ICEV[h]	351	-25
Wood/compressed hydrogen/ICEV[i]	117	-75
Wood/methanol/ICEV[j]	80	-83
Wood/ethanol/ICEV[k]	-43	-109
Corn/ethanol/ICEV[l]	499	6
Solar electrolysis/compressed hydrogen/ICEV[m]	84	-82
Petroleum/reformulated gasoline/ICEV[n]	469	n a

[a] This analysis assumes that all vehicles would use advanced engines and drivetrains, would be optimized to run on the particular fuel shown and would meet the in-use emissions standards mandated by the 1990 amendments to the U S Clean Air Act

[b] This is the sum of ermss-ions of carbon dioxide (CO_2), methane (CH_4) nitrous oxide (N_2O), carbon monoxide (CO) nitrogen dioxide (NO_2) and nonmethane organic compounds (NMOCs) from the entire fuel-production and use cycle (excluding the manufacture of vehicles and equipment) per mile of travel All the results shown are from unpublished runs of an updated version of the greenhouse-gas emissions model developed by M A DeLuchi Emissions of gases other than CO_2 have been converted to an equivalent amount of CO_2, by multiplying mass emissions of each gas by the following "global warming potentials CH_4, 21 N_2O 270 CO 2 NO_2 4 NMOCs 5 The resultant CO_2 equivalents of these gases have been added to actual CO2 emissions to produce an aggregate measure of greenhouse-gas emissions

[c] The percentage changes shown are with respect to the baseline gasol[ne-vehicle gram-per-mile emissions shown at the bottom of this table

[d] The conversion of coal to methanol is assumed to be 61 8 percent efficient

[e] Hydrogen is made in centralized coal -gasification plants at 630 percent conversion efficiency, then compressed for pipeline transport using electricity generated at the biomass plant At the station hydrogen is compressed to 8400 psi for delivery to vehicles by a compressor using the national mix of power sources in the United States in the year 2000 projected by the Energy Information Administration

[f] The conversion of natural gas (NG) to methanol is assumed to be 675 percent efficient

[g] NG is compressed (CNG) to 3,000 psi for delivery to vehicles with high-pressure tanks

[h] Hydrogen is made at the refueling site from natural gas delivered by pipeline and then compressed to 8400 psi for delivery to vehicles The compressor uses electricity generated from the projected national mix of power sources in the United States in the year 2000 Reforming of NG to hydrogen is assumed to be 848 percent efficient

[i] Hydrogen is made in centralized biomass-gaslflcatlon plants at 68 6 percent efficiency, then compressed for pipeline transport using bioelectricity generated at the biomass plant At the station hydrogen is compressed to 8400 psi for delivery to vehicles by a compressor using the projected national mix of power sources in the United States in the year 2000

The conversion of wood to methanol is assumed to be 628 percent efficient

[k] An advanced conversion process is assumed in which one unit of biomass energy produces O 52 units of ethanol energy and O 068 units of electrical energy for sale Thus for every energy unit of ethanol produced, 1 9 units of biomass are required as input and O 12 units of electricity are coproduced The emissions displaced by the sale of this excess electricity are counted as a credit against actual emissions from the wood-to-ethanol fuel-cycle (The emissions credit from the sale of the excess electricity exceeds actual emissions from the rest of the fuel-cycle hence the reduction m emissions with respect to reformulated gasoline is greater than 100 percent)

[l] A relatively high productivity of **440** liters ethanol per metric tonne of corn is assumed Coal is the process fuel at the corn-to-ethanol plant and an emissions credit is taken for the production of byproducts at the plant

[m] Hydrogen is produced from water Using solar power, delivered by pipeline to the service station and then compressed to 8,400 psi for delivery to high-pressure tanks on board vehicles The hydrogen compressor at the refueling station runs off electricity generated from the projected national mix of power sources in the United States in the year 2000

[n] These are projected emissions of greenhouse **gases** from a light-duty vehicle Operating on reformulated 9a soline in the year 2000

SOURCE M A DeLuchi University of California at Daws 1993

PUBLIC TRANSPORTATION

Expanding mass transit's role in urban tripmaking has long been a key part of plans aimed at reducing transportation energy use as well as solving a number of urban problems, especially poor air quality, traffic congestion, and lack of mobility for disadvantaged groups. As discussed in chapter 2, mass transit has been fighting a generally losing battle against automobile travel throughout the United States, but its proponents believe that the proper combination of policy changes and new investment could reverse its fortunes. Proposals for transit revitalization include investment in new services (especially light rail), provision of exclusive busways, general investments in better service and improved equipment for existing systems, lower fares, and a variety of measures aimed at discouraging automobile travel (e.g., banning free parking, reduced amounts of parking, higher fuel taxes, auto-free zones). Some proponents advocate the simultaneous expansion of mass transit service and the promotion of transit-compatible land use—filling in underdeveloped areas in city centers and close-in suburbs, increasing residential densities, and promoting mixed-use development. The two strategies would then support each other. The use of urban planning as a transportation energy conservation measure is discussed in the next section.

This section focuses on the question of whether mass transit can play a major role in reducing energy use in the United States. The reader should note that this is *not* the same as asking whether transit service can be improved and thereby gain some modal share (proportion of total travel) or stop the continuing decline in modal share. It is self-evident that there are a variety of measures that can improve service, including improved maintenance, investment in new equipment, restructuring of routes, and institution of new services (including flexible paratransit services). Instead, the focus here is on the feasibility of making major shifts away from auto usage into mass transit, and the energy saving consequences of doing so.


AMERICAN PUBLIC TRANSIT ASSOCIATION

New York City transit bus, Expansion of bus and other transit services is viewed by many as a crucial part of any national strategy to save energy in transportation.

Views of Transit Proponents and Critics

Although polarization is common to policy discussions about all aspects of transportation improvement, it is most pronounced in arguments about the role of public transport in the U.S. transportation future. Opponents of expanded investment in public transportation see it as basically an expensive and ineffective failure, neither energy efficient nor capable of luring enough drivers out of their cars to make a significant dent in congestion or air pollution. Proponents of public transportation, on the other hand, often see it as the only practical solution to an inexorable rise in urban congestion, pollution, and destruction of urban amenities associated with a continuation of auto dominance in personal transportation, and they consider it to be both energy-efficient and cost-effective when *total* societal costs are considered. In slightly more detail, the opposing positions are described below.

Transit Proponents

A key to the pro-transit position is the idea that the automobile has attained its current overwhelming modal share in the United States only because its true costs are hidden from view. By one estimate, "commuters going to work in major central business districts in the United States in their own motor vehicles directly pay for only about 25 percent of the total cost of their transport. The other 75 percent is typic tiny borne by their employers (e.g., in providing "free" parking), by other users (in increased congestion or reduced safety), by fellow workers or residents (e.g., in air or noise pollution), and by governments (passed on to the taxpayers of one generation or another in ways that usually bear no relationship to auto use)."[111] Further, there are other incentives for automobile travel in addition to the hidden costs discussed above, such as the automobile-oriented land use spurred by income tax deductions for mortgage interest payments and zoning laws that force low-density development.[112]

Transit proponents point to transit's symbiotic relationship with land use[113] to argue that an increase in transit services can lead to very large reductions in energy use and pollution. They argue that even on a passenger-mile basis, transit systems are more efficient and less polluting than current automobiles with their low load factors, but that this effect is dwarfed by the ability of transit coupled with denser land use patterns to drastically reduce tripmaking. Thus, some transit proponents evaluate the energy and pollution effects of transit-oriented strategies by assuming a transit "leverage''--each passenger-mile on transit represents a reduction of four to 10 automobile miles,[114] if expansion of transit services is coupled with ''densification" of the area served.

A point of reference often used as a model for the United States is Western Europe. As discussed in Chapter 3, not only do Western Europeans, with their dense, transit-oriented cities, take five times more transit trips per capita than their American counterparts, they also travel about half the total miles--creating an enormous savings in energy use and pollution production.[115]

Transit proponents also argue that the ever-increasing U.S. reliance on the automobile has left large segments of the population-the elderly, the poor, youth, the disabled—with greatly diminished mobility at the same time that the spread of auto-oriented sprawl and subsequent loss of close-by cultural, recreational, and work opportunities have made mobility all the more important. In European cities, these opportunities are often within easy walking or bicycling distance, and when longer distances must be traversed, the denser pattern of residences and destinations is highly compatible with transit service--in contrast to transit inability to efficiently serve sprawling U.S. cities.

Final i}. proponents argue that expansion of mass transit usage and reduction of auto use will yield substantial environmental benefits: reductions in auto-generated air pollution; reduction in ecosystem loss from roadbuilding and urban sprawl; fewer fatalities and injuries from transportation-related accidents; and a reduction in the loss of productivity and the pain and suffering that thes cause. An extension of the above argument about transportation's relationship to land use is that an expansion of transit service and usage is a critical element in revitalizing urban centers. Proponents believe that these potential benefits of

[111] E.W. Johnson, "Taming the Car and Its User: Should We Do Both?" *Aspen Quarterly*, autumn 1992, based on a presentation by J. Meyer, Harvard University.

[112] J. Pucher, "Urban Travel Behavior as the Outcome of Public Policy: The Example of Modal-Split in Western Europe and North America," *American Planning Association Journal*, autumn 1988.

[113] That is, the idea that transit service encourages higher density land uses, which in turn encourages greater transit patronage.

[114] Alliance to Save Energy et al., *America's Energy Choices: Technical Appendixes* (Cambridge, MA: Union of Concerned Scientists, 1992), app. C.

[115] L. Schipper et al., "Energy Use in Passenger Transport in OECD Countries: Changes Between 1970 and 1987," *Transportation: The International Journal*, April 1992.

transit far outweigh investment costs, especially when reductions in required auto investments are taken into account.

Critics of Transit Expansion

The core of most arguments that large investments in transit in the United States are not appropriate and will not yield significant changes in auto dominance or reductions in energy use is that mass transit fits neither the development patterns of U.S. cities nor the preferences of U.S. travelers, and its pattern of failure in the United States demonstrates this lack of fit. For example, opponents of large investments in new transit systems point out that despite an investment of more than $100 billion over the past 25 years, urban mass transit systems have lost modal share (i.e., percentage of total trips) and have not succeeded in convincing significant numbers of drivers to abandon their automobiles. In fact, despite continuing growth in total passenger travel, the number of trips taken on public transit has been basically stagnant over the past decade and is lower than it was 30 years ago[116] when mass transit received no Federal subsidies.[117] Per capita transit usage has dropped in all of the metropolitan areas that initiated or expanded rail systems in the 1980s--even Washington, DC, where a showcase rail system was built at a cost of $8 billion.[118]

According to those opposed to large investments in new transit systems, even the experience in Europe (where per capita transit usage is much higher than in the United States) supports the thesis that public transportation is unlikely to succeed here even if we adopt many of the policies advocated by the environmental community—high taxes on gasoline, high parking costs, strict land use controls, and implementation of major new rail transit construction. Over the past few decades, despite the reality that Europe already has the very policies that supposedly will transform U.S. transportation, European trends have turned sharply in the U.S. direction: per capita automobile ownership has risen three times faster than in the United States; vmt per capita has grown more than twice as fast; and the modal share of transit has steadily dropped.[120]

Critics also argue with the thesis that transit systems, especially rapid rail systems, have the power to shape urban areas in ways that not only provide positive feedback to the systems themselves but also reduce total travel. They point to evaluations in the literature of transit-urban form interactions that have not found a strong linkage between new transit services and subsequent shifts in urban growth patterns.[121]

Another aspect of the critics' case against transit is the claim that it has very poor cost-effectiveness and overall efficiency, perhaps because it is heavily subsidized. For example, public transit operating costs have risen even faster than health care costs: from 1970 to 1985, operating costs per vehicle mile rose 393 percent, or twice the rate of inflation.[122] Further, 9 of 10 recent urban rail projects evaluated by the Department of Transportation exceeded their capital cost estimates; transit

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116 U.S. Department of Transportation, Federal Transit Administration, *Public Transportation in the United States: Performance and Condition* (Washington, DC: June 1992), fig. 1.1.

117 J. Love and W. Cox, *False Dreams and Broken Promises: The Waste/i4/ Federal Investment in Urban Mass Transit*, Policy Analysis No. 162 (Washington, DC: Cato Institute, Oct. 17, 1991).

118 Ibid.

119 C. Lave, "Cars and Demographics," *Access*, published by University of California at Berkeley, fall 1992.

120 Ibid. During 1965-87 "nit per capita grew 154 percent in Europe, compared to 69 Percent In the United States; and in 1987, 'he auto modal share had already grown to 82 percent.

121 For example see G. Giuliano, School of Urban and Regional planning, University of Southern California, "Literature Synthesis: Transportation and Urban Form," report to the Federal Highway Administration, October 1989.

122 Love and Cox, op. cit., footnote 117.

labor productivity has declined substantially over time (e.g., hours of bus service per constant dollar fell by 43 percent during 1964-85); and average annual service hours worked per employee decreased from 1,205 to 929 during the same period.[123]

Finally, and perhaps most disturbingly, some critics of expanded transit investment claim that many urban systems do not even satisfy some of the basic goals of mass transit—saving energy, reducing air pollution, or serving the urban poor and disadvantaged—at any price. They claim that whatever the *potential* energy efficiency of transit may be, the low load factors and the time spent at idle and backhaul by the average public transit bus, and the enormous amounts of energy embodied in the roadbeds, tunnels, and railcars of urban rail systems, make public transportation less energy-efficient than automobiles.[124] Similarly, given the *reduction* in transit's already very low modal share over time, it is difficult to assign significant contributions to air quality or reductions in congestion to any new transit systems. Finally, the critics point to the low usage of transit by the poor (in 1983, less than 7 percent of trips by low-income people were transit trips) and to studies of transit subsidies that show a bias in Federal operating subsidies toward the *affluent* as evidence that transit does not even serve its basic socioeconomic goal.[125]

The discussion that follows attempts to clarify these arguments and draw some conclusions about transit's potential for expansion in the United States. However, drawing firm conclusions about this potential is exceedingly difficult, because lessons that might be drawn from its past performance are compromised by the harsh environment for mass transit under which past investments were made. One conclusion should be clear, however: although there is much room for improvement in fitting appropriate transit designs into their particular physical and demographic circumstances and for improving operational methods, any *large-scale* increase in mass transit's share of passenger travel—and thus, any significant new energy savings-cannot occur simply by adding new services, no matter how efficient these may be. If there is to be any possibility of such an increase in transit modal share and new energy savings, sharp changes will have to be made in the policy and physical environment, both of which are now hostile to mass transit. There will have to be changes in urban design toward greater urban density and a better mix of commercial and residential land uses, and economic or physical restrictions will have to be placed on the automobile system. As discussed later, such changes would have sharp effects on lifestyle and would be exceedingly controversial; instituting them will require major changes in the current societal consensus about transportation and urban life.

Transit Performance in the United States

Although there may be important individual exceptions, by most standards the performance of mass transit in American cities during the past few decades has not been encouraging for those who would like to see it play a major role in a national energy conservation strategy. Virtually all measures of performance-energy intensity, ridership and modal share, cost efficiency, and so forth—have either declined outright or lag significantly behind other modes. However, some stabilization of performance has been obtained since the mid- 1980s.

It is certainly true that mass transit plays a crucial transportation role in many American cities, particularly in moving workers to and from the

[123]Ibid.

[124]Ibid.

[125]Ibid. The affluent are benefited by a shift in emphasis toward suburb-to-downtown commuter services.

workplace. Table 5-7 lists 16 U.S. metropolitan areas whose transit modal share for commuters in 1980 was equal to or greater than 10 percent.[126] Because high percentages of commuting trips in most of these metropolitan areas are from suburb to suburb, where mass transit usage is very low, transit's share in these cities for commuting trips beginning or ending in the central city will be considerably higher than the areawide average (of at least 10 percent), and higher still for commuting trips directed at the central business district (CBD). For example, in 1980 about 15 percent of workers in the Washington, DC metropolitan area—but 38 percent of workers living in the District itself—used transit.[127] Given existing levels of congestion, there is some basis for fears that if transit service in the more transit-dependent cities is allowed to deteriorate, the CBDs of these cities will become unsupportable.

TABLE 5-7: Metropolitan Areas With Over 10 Percent of Workers Using Public Transportation

Metropolitan/metropolitan statistical area	Percent of workers using public transportation, 1980
New York, NY	49.3%
Jersey City, NJ	258
San Francisco, CA	221
Chicago, IL	204
Washington, DC-MD-VA	148
Philadelphia, PA-NJ	140
Boston-Lawrence-Salem -Lowell Brockton, MA	126
Nassau-Suffolk, NY	125
Pittsburgh, PA	117
Oakland, CA	111
Newark, NJ	109
Iowa City, IA	107
Cleveland OH	106
New Orleans, LA	104
Baltimore, MD	102
Honolulu, HI	100

SOURCE American Public Transit Association, *Transit Fact Book* (Washington, DC September 1990), table 20, p 52 from U S Bureau of Census *State and Metropolitan Area Data Book.* 1986

The key indicators of transit performance are those that show changes in patronage. Although subsidy levels increased 14-fold in the 1970s, there was little change in total ridership. The number of workers who commute by transit actually *declined* between 1980 and 1990 by about 100,000, or from 6.4 to 5.3 percent of all workers.[128] According to the Nationwide Personal Transportation Survey, total mass transit person-(rips have been relatively stagnant over the past two decades, starting at about 4.9 billion in 1969, reaching a high of about 5.5 billion in 1983, and dropping to 4.9 billion again in 1990.[129]

The relative lack of change in total transit ridership during the past 20 years hides some interesting changes in the nature of that ridership. An important change is the beginning of a shift in focus away from traditional service of central-city residents and toward suburbanites commuting to the central city. In 1970, 3.7 million workers commuted from central-c it y homes to central-city jobs by transit—21 percent of all such commuters.[130] By 1980, although the number of central-city to

[126] Although the 1990 census has been completed, data on commuting have not yet been released.

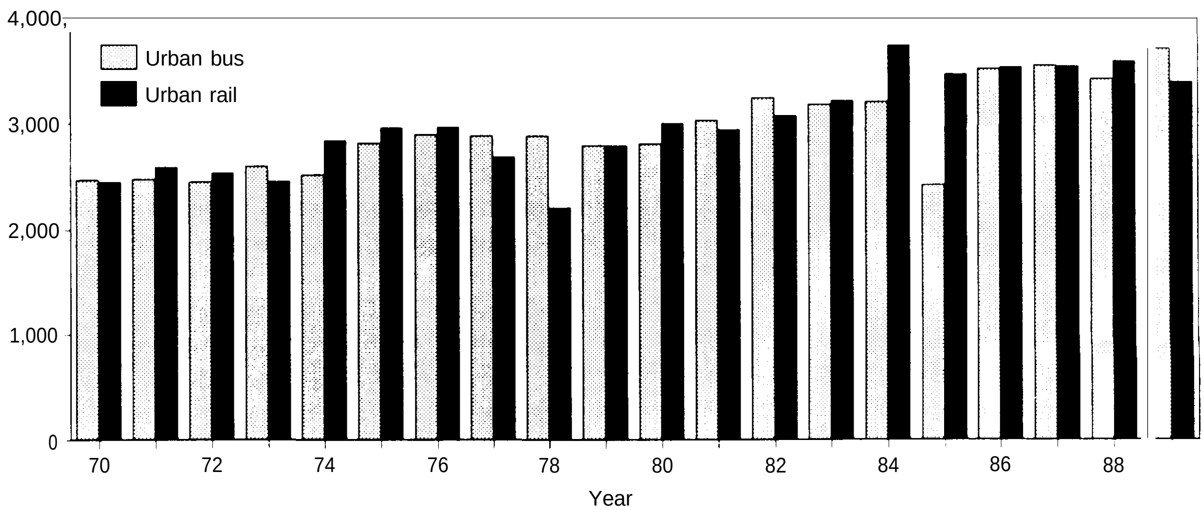
[127] American Public Transit Association, *1990 Transit Fact Book* (Washington, DC September 1990), table 21.

[128] A.E. Pisarski, *Travel Behavior Issues in the 90's* (Washington, DC: U.S. Department of Transportation, Federal Highway Adnlinis{ra-[ion, July 1992).

[129] P.S. Hu and J. Young, *Summary of Travel Trends: 1990 Nationwide Personal Transportation Survey*, FH WA -PL-92-027 (Washington, DC: U.S. Department of Transportation, Federal Highway Administration, March 1992), table 16. Data from the American Public Transit Association for all trip purposes, however, indicate a gradual *increase* in *unlinked* transit trips (a complete trip may include a few unl inked trip segments) from about 1975 to the present, from 7.3 billion trips to 9. I billion (American Public Transit Association, op. cit., footnote 127, table 17), or an increase of about 1.6 percent annually Unfortunately, interpreting this increase is difficult, because a large percentage of the added trips were on heavy rail systems, and many of these trips generate home-to-station and work-to-station bus trips that are not independent trips but inflate the selected statistic. Thus, many of the new trips are probably statistical artifacts, that is, transit users went from one long bus trip (one unlinked transit trip) to a short bus trip to the rail station and a long rail trip (two unlinked transit [rips).

[130] U.S. Department of Transportation, Federal Transit Administration, *Public Transportation in the United States: Performance and Condition* (Washington, DC June 1992), fig. 1.10.

FIGURE 5-1: Energy Intensity of Urban Bus and Rail Transit



SOURCE S C Davis and M D Morris, *Transportation Data Book*, ed 12, **ORNL-671 O** (Oak Ridge, TN Oak Ridge National Laboratory March 1992) table 213

central-city commuters had increased by 29 percent, the number of these using transit had declined to 3.28 million—16 percent of all such commuters. During the same period, workers commuting from suburban homes to the central city by mass transit rose from 777,000 to 1.185 million.[131]

A key attribute of transit promoted heavily by its supporters is supposed to be its high energy efficiency. Comparing the energy intensity of alternative modes is complex and often mishandled. However, a simple measure of performance—changes in energy intensity of a mode over time—shows that both bus and rail transit have increased in energy intensity (see figure 5-1). From 1970 to 1989, bus transit increased from 2,472 British thermal units (Btu) per passenger mile (p-m) to 3,711 Btu/p-m,[132] a 70-percent increase in intensity, primarily because lower load factors and growing urban congestion overwhelmed increases in the technical efficiency of the vehicles. Similarly, urban rail transit energy intensity increased from 2,453 to 3,397 Btu/p-m during the same period, at least in part because a number of new systems were added that are faster and tend to operate at lower load factors than the earlier systems, **most** of which are in very dense older cities on the Eastern seaboard. Recently. rail transit energy intensity appears to have stabilized: the reported 1989 value of 3,397 Btu/p-m is the lowest intensity since 1983.[133]

Direct comparisons of transit and auto energy use are complicated by the need to account for several factors aside from the average energy use of the vehicles:

1. energy use in accessing transit (e.g., bus access to rail, or auto access to rail or bus);
2. differences in "trip circuity''—the relative directness of auto versus transit trips (because of

[131] Ibid.

[132] Davis and Morris, op. **cit.,** footnote 9, table 2.13.

[133] Ibid.

limited numbers of routes, transit trips tend to be longer than auto trips with the same origin and destination);
3. appropriate vehicle load factors (e.g., because transit riders share similar socioeconomic characteristics with carpoolers, using average (low) auto load factors in transit-auto comparisons will likely be incorrect; on the other hand, some auto trips involve the driver acting primarily as chauffeur rather than active traveler, implying that basing load factors solely on occupancy may understate auto energy intensity);
4. differences in the energy embodied in system infrastructure and fuel production and delivery;
5. properly characterizing travel conditions (e.g., city or highway driving, degree of congestion; most urban transit competes with auto city driving, much of it under congested conditions); and
6. distinguishing between national averages and individual situations. Transit averages are strongly influenced by New York and a few other dense urban centers, which have very high load factors and slower, less energy-intensive rail systems. New systems will tend to have lower load factors and, for heavy rail systems, heavier, faster, more energy-intensive cars.

Thus, although simplistic measures of energy intensity show the urban modes—auto, bus, rail—to be converging,[134] individual situations require very careful and sophisticated analysis to gauge the relative energy intensity of travel alternatives.

As noted above, many measures of transit productivity have fallen substantially during the past few decades, but they have stabilized somewhat since the mid-1980s. Perhaps the most critical measures are labor productivity and cost, since wages and fringe benefits make up more than 70 percent of transit operating cost.[135] Since the inception of Federal transit subsidies in 1961, labor productivity has fallen sharply: from 1960 to 1985, transit employment rose by 67 percent, while vehicle revenue miles of service increased by less than 40 percent; vehicle-miles of service per employee fell from 14,000 to less than 11,000.[136] Recent performance has been better: between 1985 and 1989, vehicle revenue miles of service increased about 17 percent, while employment rose only 6 percent.[137]

Per-hour labor costs have risen rapidly, with public transit operators routinely earning far more than both unionized and nonunion private bus service operators.[138] primarily as a result of this labor inflation, the inflation-adjusted operating cost of transit service (dollars per vehicle-mile) rose by 80 percent between 1965 to 1983, with increases in all regions and in both bus and rail transit.[139] Again, recent results have been better: during 1984-90, the inflation-adjusted cost per revenue mile rose only 1 percent.[140]

Although part of the deterioration in transit economic efficiency is likely due to the lack of incentive for efficiency provided by heavy Federal, State, and local subsidies, part may be due to a deliberate policy of providing service to suburban

134 According to S.C. Davis and S.G. Strang, *Transportation Energy Data Book*, ed. 13, ORNL-6743 (Oak Ridge, TN: Oak Ridge National Laboratory, March 1993), table 2.13, 1990 energy intensities per passenger-mile of auto, urban bus, and urban rail were, respectively, 3,739, 3,735, and 3,453 Btu.

135 M. Wachs "U.S. Transit Subsidy Policy: In Need of Reform," *Science*, vol. 244, June 30, 1989, pp. 1545-1549.

136 Ibid.

137 American Public Transit Association, op. cit., footnote 127.

138 Wachs, op. cit., footnote 135, cites the total earnings of bus drivers with the Southern California Rapid Transit District at $49,777 in 1986 compared with total earnings of $34,426 at a unionized private operator nearby, and drivers at the Washington Metropolitan Area Transit Authority earning $44,014 compared to $19,418 for a Washington area nonunionized private operator.

139 Ibid.

140 Federal Transit Administration, op. cit., footnote 130.

workers traveling downtown or from suburb to suburb. As noted above, transit ridership for suburban to central-city commutes increased by 50 percent from 1970 to 1980. These trips often require nonrevenue backhauls and they are highly peaked; the backhauls will lower recorded worker productivity (since this counts revenue hours only), and the need to work two peaks means that unless drivers are part time or working split shifts without overtime, the result will be either substantial "dead-time" for drivers or high overtime charges. When these conditions are combined with express service—fairly common with suburban-to-downtown commutes-the cost-effectiveness of the service is particularly problematic. For example, Federal Transit Administration case studies for eight cities[141] of comparative transit costs for five types of service[142] found that Express/Limited service was the most expensive (in dollars per vehicle-hour or revenue vehicle-hour) in all eight cities.[143] In two cases (Miami, St. Louis), the cost of this service was twice (hat of other transit services.[144]

The move to serve suburbia with transit systems yields more negative impacts on over-all transit performance than just declining labor productivity and higher costs. The lower density of development has meant fewer passengers per vehicle-mile. and the highly peaked nature of the trips (mostly commutes to work) yields long periods when minimum service must be maintained but transit users are few. Further, development has shifted away from transit traditional service areas, especially within central cities, at the same time that rising auto ownership levels have drawn customers away from transit. For example, work-(rips that start and finish within central cities—the trips that are easiest to serve with transit--declined as a proportion of all worktrips from 46 to 30 percent in 1960-80.[145] Trips that are very expensive to serve with transit rose dramatically: for example, the number of commuters who both live and work in the suburbs rose from 11 million in 1960 to 25 million in 1980, from 28 to 38 percent of the workforce.[146]

The service by transit of suburban commuters also presents the paradox of the general public heavily subsidizing the transportation of relatively high-income individuals. Further, a large proportion of these commuters drive to the stations and park, thus adding to pollution loads. Also, the availability of rapid rail service into the central city may actually have the perverse effect of increasing the attractiveness of suburban development, accelerating the centrifugal forces that are weakening the central city. A response to this latter concern, however, may be that these systems merely recognize the reality of suburban residential development; they follow it rather than acting as a stimulus. Also, the systems may encourage denser development than would otherwise occur.

The combination of higher labor operating costs and fewer riders per vehicle-mile has driven up operating costs per passenger and per passenger-mile. Costs per passenger rose by 50 percent (inflation adjusted) from 1975 to 1990, and costs per passenger-mile rose by 30 percent from 1980 to 1990.[147] Operating costs averaged 41 cents per passenger-mile in 1990.[148] And unlike other performance indicators, these costs have *not* stabilized recently: real operating costs per passenger

[141] For Miami, FL; Minneapolis, MN; Los Angeles, CA; Washington, DC; St. Louis, MO; San Diego, CA; Albany, NY; and San Antonio, TX.

[142] Local/Radial, Suburban, Crosstown, Feeder, and Express/Limited.

[143] Federal Transit Administration, op. cit., footnote 130, fig. 2.7.

[144] Ibid.

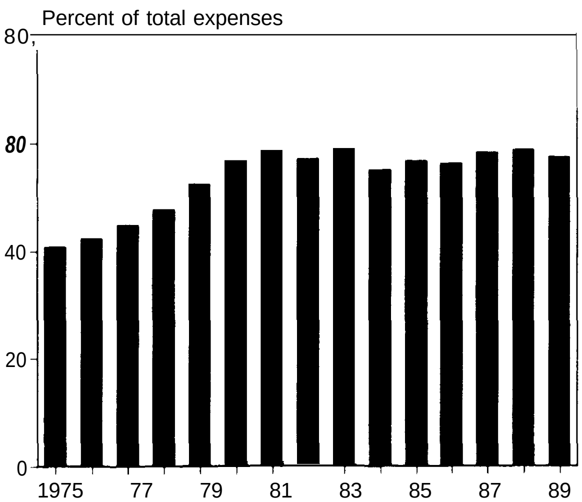
[145] Wachs, op. cit., footnote 135.

[146] Ibid.

[147] Federal Transit Administration, op. cit., footnote 130, fig. 2.3.

[148] Ibid.

FIGURE 5-2: Transit Operating Subsidies



SOURCE American Public Transit Association, *Transit Fact Book* (Washington, DC September 1990), table 8A. p 26

rose 25 percent between 1984 and 1990, and costs per passenger-mile rose 17 percent during the same period.[149] These trends result from substantial increases in transit service without a proportional increase in passengers.[150] Because transit revenues have not kept up with costs (operators have been afraid that raising fares will yield sharp declines in ridership), transit subsidies have had to rise from 41 percent of total operating costs in 1975 to 57 percent in 1989, as shown in figure 5-2.[151]

A large portion of the billions of dollars made available to U.S. transit systems (more than $100 billion over 25 years) went to build a number of new rail systems—rapid rail in Washington, DC, Atlanta, Baltimore, and Miami, and light rail in Buffalo, Pittsburgh, Portland, and Sacramento. A recent study by the Transportation Systems Center of the Department of Transportation evaluated the total (capital plus operating) cost of each of these systems.[152] These are shown in table 5-8. The rapid rail costs vary from $5,93 (1 988) per passenger trip in Atlantato$16.77 in Miami; the light-rail costs vary from $5.19 in Portland to $10.57 in Buffalo. In all of these systems, operating costs represented a relative] y small fraction of total costs. If a 10-percent discount rate to pay off capital is assumed, operating costs in Washington, DC, were slightly less than 20 percent of total operating and capital costs. Among the rapid rail systems, operating costs ranged from 13 percent (Atlanta) to 21 percent (Miami) of total costs; and among the light rail, operating costs ranged from 11 percent (Pittsburgh) to 26 percent (Sacramento). As noted below, local transit agencies' focus on operating expenses in making service and fare decisions, because capital costs often are subsidized by Federal and State governments and thus are "free" to the agencies, means that decisions that save money at the local level, by reducing *operating* subsidies per rider, can lead to substantial increases in the *total* subsidy (capital plus operating) per rider.

Evaluating Costs and Benefits

The picture of U.S. transit service that emerges is a discouraging one if viewed in the context of current travel conditions and measured economic costs. However, what if emerging and future traffic problems, existing subsidies to the automobile, and environmental or other costs and benefits are included in the overall cost-benefit evaluation?

First, some proponents of mass transit argue that rapidly growing urban highway congestion will soon cause massive gridlock in many U.S. cities, with very high costs to society as well as to

[149] Ibid.

[150] Ibid.

[151] American Public Transit Association, op. cit., footnote 127, table 8A.

[152] D H Pickrell *Urban Rail Transit Projects: Forecast Versus Actual Ridership and Costs*, DOT-T-91-04 (Cambridge, MA: Transportation Systems Center, October 1990).

TABLE 5-8: Cost Per Passenger of Recent Rail Transit Projects[a]

Rapid rail				Light rail			
Washington	*Atlanta*	*Baltimore*	*Miami*	*Buffalo*	*Pittsburgh*	*Portland*	*Sacramento*
Operating cost per passenger (1988 dollars)							
172	075	1 83	360	1 44	090	091	1 73
Total cost per passenger (1988 dollars)							
8.75	593	1292	1677	1057	794	519	653

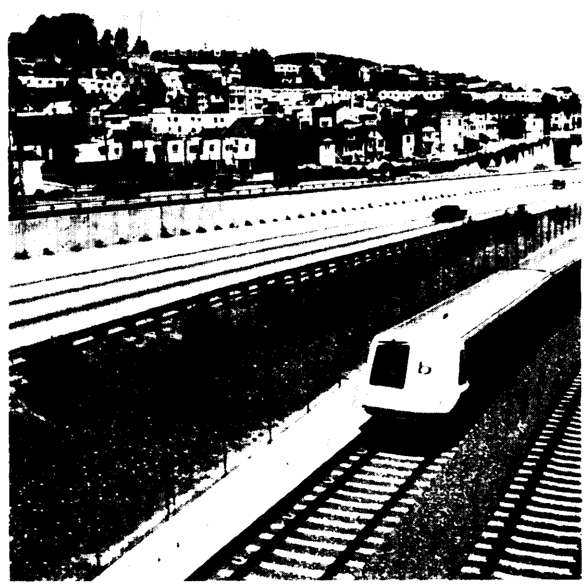
[a] Not Including feeder bus costs
[b] Assumes a 40-year lifetime and a discount rate of 10 percent per year

SOURCE: D H. Pickrell, *Urban Rail Transit Projects: Forecast Versus Actual Ridership and Costs*, DOT-T-91-04 (Cambridge, MA: Transportation Systems Center October 1990) table 5-1

travelers. From this viewpoint, expanding transit ridership and reducing automobile usage would be a critical component of an anticongestion strategy and would generate substantial societal benefits. Also, growing congestion should encourage ridership on those transit systems that will be relatively unaffected by highway congestion (e.g., guideway systems and buses in exclusive lanes).

The validity of this argument depends on the likely magnitude of future congestion problems, the extent to which they would encourage transit ridership, and the degree of relief that increased transit ridership would provide to congestion. As discussed in chapter 4, the magnitude of future congestion problems is not easy to predict, because both travelers and traffic planners will respond to emerging problems in a variety of ways, with many of the responses (particular] y of travelers) being essentially unpredictable. Given the current travel time superiority of automobiles over mass transit, a substantial increase in transit ridership is unlikely unless a large increase occurs in congestion delay costs for autos (or a large shift in the relative monetary costs of the two modes, e.g., a substantial increase in parking costs). Recent forecasts by the Federal Highway Administration do foresee such an increase, but as noted in chapter 4, these forecasts are based on the assumption of no policy adjustments or travel reactions to growing congestion, and their reliability is questionable. Whether additional transit service will reduce congestion (or significantly reduce congestion growth) is clearly a function of the magnitude of any increase in transit ridership; most new investments in mass transit have not been able to siphon off more than a small percentage of trips, but the potential exists for a larger impact in well-chosen corridors.

Second, to the extent that the current price of auto travel does not account for its true societal cost, automobile use may be overutilized in comparison to other options (e. g., mass tran-



FEDERAL HIGHWAY ADMINISTRATION

The Bay Area Rapid Transit (BART) system serving San Francisco and its suburbs allows its riders to avoid heavily congested highways during rush hour commutes, while siphoning potential drivers off these highways.

sit).[153] As shown in chapter 4, even without accounting for societal costs such as air pollution, auto costs *are* substantially underpriced because of subsidies (payment of portions of road construction costs through general funds) and inefficient pricing (e.g., failure to charge directly for parking). The degree of underpricing appears to be less, however, than the underpricing of transit services due to direct government subsidies (U.S. transit operations are heavily subsidized; fares covered only 43 percent of operating costs in 1990,[154] with all other costs paid by local, State, and Federal governments). In other words, if a case is to be made that further subsidies to mass transit are warranted (or that further costs should be added to automobile travel) to correct an imbalance in pricing, the case will have to be based on external i ties not covered in the analysis in chapter 4.

Magnification of Transit Benefits

Generally, planners assume that 10 trips on a new mass transit system will eliminate fewer than 10 auto trips, because some of the transit trips are new trips induced by building the new system and others have been captured from different transit systems (e.g., a new rail system capturing passengers from buses). Assuming that transit eliminates relatively few auto trips implies that a major portion of transit benefits (reduction of congestion, air quality improvement, etc.) will be estimated to be quite low.

Some transit proponents claim that the assumption of low auto trip reductions, critical to the cost-benefit calculations used to evaluate new transit proposals, is seriously flawed. For example, the Natural Resources Defense Council (NRDC) and the Sierra Club claim that each new transit trip can reduce four or more auto trips, because "the availability and usage of transit services also changes the location of trip origins and destinations in a way that reduces the need to travel by car, and reduces the distance of travel required by the majority of people who will continue to drive their cars,"[155] that is, instituting new transit service will change land use in ways that reduce the need to travel.

Key to claims that transit has a "magnifying effect" in reducing automobile travel is a series of analyses of different areas that show a strong relationship among the level of transit usage in an area, its land use density, and its level of auto travel. For example, the NRDC-Sierra Club analysis compares five areas in California that have similar income levels but very different levels of mass transit service and land use density.[156] These areas have marked differences in (per capita and per household) auto usage, with the highest level of transit use corresponding to the lowest level of auto use. Assuming that transit is the critical causal variable yields the relationship that 1 mile of transit replaces from 4 (Walnut Creek versus Danville-San Ramon) to 8 (San Francisco versus Danville-San Ramon) miles of auto travel.[157] The NRDC-Sierra Club analysis does make an assumption of causality: "For California conditions, we found that inducing one passenger mile of ridership on transit reduced community-wide VMT by 4-13 miles, " and "in a little over 10 years, BART [Bay Area Rapid Transit], and

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[153] Other options are to forego travel altogether or to consolidate trips.

[154] Federal Transit Administration, op. cit., footnote 130.

[155] D.B. Goldstein et al., "Efficient Cars in Efficient Cities," NRCD Sierra Club testimony for conservation report hearing on transportation issues before the State of California Energy Resources Conservation and Development Commission, Apr. 23, 1990, revised Apr. 2, 1991, p. 8.

[156] Ibid., app. A.

[157] Ibid., app. A.

mixed-use densification around its stations, has given Walnut Creek a huge mobility advantage over Danville-San Ramon. "[158]

The data in the NRDC-Sierra Club analysis and similar analyses, however, do *not* show that mass transit alters land use over time, or that the introduction of transit service reduces auto travel by more than one trip for every transit trip added. For the most part, the analyses contain few historical data and do not show changes in land use over time. In discussing the above two communities, for example, the NRDC-Sierra Club analysis does not even show whether or not the differences in Walnut Creek and Danville-San Ramon that appeared in the 1988 estimates, and supposedly were caused by BART, existed 10 years earlier when BART was built. Consequently. the analysis does not even show that there *were* any changes in mobility over time that might have been caused by BART.

Further, the analysis pays only modest atten(ion to demographic differences among communities, focusing primarily on average income, despite the important role that demographics play in travel behavior. Factors such as age, household size, lifestyle choice, and so forth are important determinants of travel behavior. To the extent that denser urban areas with transit tend to attract people who would ordinarily travel less than average, the role that density and transit service *by themselves* play in reducing travel is weakened. That is, it is not just the density, transit service, and greater availability nearby of recreational, cultural, and employment opportunities that goes along with these areas, that contributes to lower travel per capita; it is also the characteristics of the people who tend to live in such areas, because many of these people would tend to travel less than average no matter where they lived.

Finally, statistical analyses cannot show cause and effect. Demonstration of a statistical relationship between transit and residential density does not, for example. imply that mass transit leads to increases in residential density, although it is clear that efficient transit makes high-density development more feasible. In fact, there is a strong possibility that much of the density-transit relationship may reflect density's influence on transit markets rather than transit influence on density; although man y factors affect transit effectiveness and economic viability, including management skills, levels of subsidy, labor relationships, and so forth, density is a key determinant of its customer base and practicality. Thus, proponents of a transit magnifier effect interpret comparisons between U.S. cities that have declined in density as their transit systems declined, and those that have maintained viable city centers with good transit, as showing that maintenance of good transit service has succeeded in keeping downtowns viable; skeptics would instead argue that in U.S. cities, many factors have contributed to downtown declines, but that one offshoot of the decline has inevitably been a concurrent drop in transit, as worsening urban economic fortunes lessened the cities' ability to subsidize transit at the same time the transit systems' customer base was decreasing. Understanding that increases in transit services may not automatically lead to land use changes, many transit proponents propose that added transit service be coupled with land use policies that yield higher densities and mixed uses. The interrelationship among transit, land use, and travel is discussed in the next section.

In conclusion, the relationships among land use, transit services, and travel behavior found in the NRDC-Sierra Club analysis and elsewhere are sufficient to call into question the assumption that an added transit trip will replace less than one auto trip, but they do not justify replacing this assumption with that of a large "magnifier" effect for transit (i.e., each transit trip replaces several auto trips). This area requires further, sophisticated analysis that examines changes in land use, travel behavior, and transportation system performance *over **time*** and takes careful account of differences

[158] Ibid., p, 6 and app. A

in a variety of traveler characteristics, such as age, gender, income, and household size. Some important research into travel behavior has been conducted by Kitamura[159] and Schipper,[160] but much more needs to be done.

What Is Possible?

What could policymakers accomplish if they were willing to push for a future in which mass transit played a much greater role in the U.S. transportation system? The large gap between the reality of actual transit performance in the United States and the vision held out by strong transit proponents in the environmental community demands a hard-headed weighing of both the potential of pro-transit policies and the obstacles to progress in improving transit service and increasing ridership.

Clearly, it is fair to argue that despite high transit subsidies, the transportation environment in the United States has been skewed against high levels of transit usage. As noted above and in chapter 2, the competing public and private transportation systems evolved during a period when the private system—the automobile--enjoyed strong subsidies in the form of: low-cost or free parking; development patterns shaped by mortgage subsidies and zoning for low density that strongly favored auto over transit; freedom from payment of a variety of external costs (air pollu-(ion damages, high noise levels, ecosystem losses, and so forth): and payments of many costs (police services, portions of road construction and maintenance etc.) by government. It can be argued, of course, that U.S. mass transit also enjoys high levels of subsidy—an average 57 percent of operating costs plus much or all capital costs. Further, this could create a "level playing field" for transit in the sense that the transit subsidy, although different in form from the auto subsidy, may account for a similar or even higher percentage of the total cost to society of mass transit use. However, whatever the balance of subsidies ***now,*** the U.S. transportation system and most U.S. cities were shaped during a time when the Federal Government did *not* subsidize transit (although local governments did), and the form that the system and the cities acquired as a result—low-density development, large quantities of parking, very high levels of road density, dispersal of jobs throughout urban and suburban areas, lack of centralization—heavily favors the automobile over transit.

This argument implies that given a different set of incentives, one that established a balanced playing field from the beginning, the United States might have ended with urban environments and transportation systems quite different from those we have now. This thesis would be attacked vigorously by many analysts on the grounds that the primary forces behind the automobile's conquest of the U.S. transportation system were, quite simply, its vastly superior mobility and the growing income levels that allowed Americans to afford an auto-oriented system. However, from the standpoint of current policy choices, *the validity of either thesis is not relevant.* Rather than being interested in what might have been, policymakers addressing U.S. transportation problems must ask what is possible and desirable *given the physical system that we have--at least as a starting point.* In other words, **policy makers must take as a starting point the United States' actual auto-oriented physical infrastructure, societal attitudes, demographic balance, and interest groups, and ask what is possible from this starting point.**

The U.S. urban environment is not one that is easily served by mass transit, and over time, it is moving in a direction that will make it still less amenable to successful transit service. And the natural advantages in convenience, privacy, and travel time of automobiles over transit are enhanced considerably by an entrenched network of

[159] See e.g., R. Kitamura, "Life-Style and Travel Demand," *A Look Ahead-Year 2020,* Transportation Research Board Special Report 220 (Washington, DC National Academy Press, 1988).

[160] See, e.g., "Linking Life-Styles and Energy Use: A Matter of Time," *Annual Review of Energy,* vol. 14, 1989, pp. 273-320.

U.S. laws and customs that reduce the cost of auto use. Thus, if policy makers hope to make mass transit a major factor in a national energy conservation initiative, they must be willing to attempt to reverse the current course of urban development (i.e., continuing suburbanization) and try to create denser, mixed-use urban environments; they must also drastically shift government expenditures and other economic incentives away from auto use. Further, they must find a way to improve the general management of mass transit systems in this country, because the recent history of transit service has been one of rapid cost escalation and declining efficiency.

Will the Political Impetus Exist?

The willingness to attempt such a course of action is likely to depend on the degree to which a national consensus can be reached that very strong actions are justified to achieve a reduction in transportation energy use. The most likely driving forces behind such a consensus are:

1. the extent to which objections to other transportation and land use-related problems—growing travel congestion, the environmental impacts of continuing suburbanization—add to the consensus for change;
2. national security issues (since the energy in virtually all U.S. transportation use, except rail transit, is oil energy) and greenhouse warming; and
3. the extent to which the public comes to recognize the linkage between urban form and transportation needs and abilities.

It is difficult to make the case that the current policy environment is "ripe" for any attempt to change the course of U.S. urban development or of auto use. For example, although both Congress and the general public are concerned about energy security and greenhouse warming, over the past several years neither has shown much interest in taking substantive measures to deal with either issue. Of course, advancing scientific knowledge about greenhouse warming and unpredictable world events could easily thrust these issues to the forefront of public consciousness and significantly increase the probability that strong initiatives will be taken.

As discussed in chapter 4, OTA believes that current forecasts of growing congestion are overstated; although the importance of congestion as a transportation problem is undisputed, there are doubts as to whether the problem will become sufficiently acute *within the next decade or so* to create the necessary impetus for drastic changes in basic transportation and land use policy. Instead, it seems more likely that pressure will be exerted for a host of more moderate measures—including congestion pricing for key routes, high-occupancy vehicle (HOV) lanes, ridesharing initiatives, and possibly an end to free parking—that may, in concert with continued suburban and exurban development patterns, limit the growth of congestion. These measures are discussed later.

Reaching a consensus that continuing suburbanization is unacceptable and that auto use must be restricted may be extremely difficult, although there are examples—Portland, Oregon, for one—where such a consensus appears to have begun.[161] The issue here is not the actual magnitude of the adverse impacts of unchecked suburban growth and increased auto use—these are large and well-documented—but their perception versus the perception of suburban benefits-that is, the relative privacy, safety, and quiet of living in a suburban environment. For example, many planners believe that suburban development is an important

161 However even in Portland, land use restraints have not yet prevented new low-density development from being built—though these restraints probably have affected the location of this development. The strength of the consensus will begin to be tested when residents discover that they cannot live in such developments or when restrictions on low-density building begin to drive up the prices of existing low-density developments.

cause of inner-city decline. Whatever the truth of this, however, it is not the perception of most urban residents. The current negative state of most large-city downtowns leads many urban area residents to shun the inner city as "dirty, polluted, overcrowded, decaying, and downright dangerous,"[162] and they tend to view these conditions as a *cause* of suburban flight, not an effect. The actual truth of this or other such views is not relevant to the political truth: there is little sign that voters are so unhappy with any perceived negative impacts on downtown areas, or with the energy inefficiency, capacity to absorb prime farmland, and other problems of suburban development, that they are ready to take drastic action against such development.

In other words, whatever the truth of arguments that society would benefit if large amounts of auto travel were replaced with mass transit, there is no discernible outline of a political coalition that could accomplish the changes in land use, fuel costs, capital investment, and other factors that would lead to such a replacement. Instead, areas with transportation and air pollution problems are more likely to adopt incremental improvements in transit services and relatively moderate changes in incentives for using private vehicles: in turn, these may yield small additions to transit share and small reductions in auto use, with correspondingly low impacts on energy use.

Will Ridership Be Available?

Demographic factors will play a critical role in defining potential ridership for a major expansion of transit services. Although an attempt to increase mass transit ridership would certainly aim at new constituencies, increasing transit's share among its traditional constituencies—the urban poor, women, and the old and young-would take first priority. There are substantial concerns associated with attracting additional ridership among these groups.

Transit use has dropped substantially among poor households; basically, the same travel trends that are occurring nationally are occurring among people living in poverty, particularly an increase in driving alone—from 55 to 60 percent of all trips during 1985-89.[163] This trend may be very fragile, however; virtually any increase in driving costs associated with strategies designed to shift travel away from single-occupancy vehicles or toward transit could have an especially powerful effect on the travel habits of the poor. Also, the Clean Air Act Amendments demand that cities with inspection and maintenance programs raise their" waiver limits" (the dollar amount of repairs necessary to qualify a vehicle for a waiver from emissions requirements) to $450. This change conceivably might reduce the access of lower-income households to automobiles, since presumably many of the vehicles they currently own are old and in poor repair.

Women have traditionally been more inclined than men to use transit; for example, in 1977, women used transit for about 2.7 percent of their trips versus men's 2.4 percent share. This higher share was probably due to a combination of women's lower income levels, lower access to automobiles, and lower incidence of auto licensing. These factors are changing, and women now appear to be a less inviting target for transit use.

Having a driver's license is a particularly powerful indicator of transit use: although women with driver's licenses travel much more than women without licenses (twice the number of daily trips and three times the daily travel mileage), women with licenses use mass transit for about 1 percent of their trips, whereas those without licenses use transit for more than 13 percent of their trips.[164] Over time, the percentage of adult

[162] L.S. Bourne, "Self-Fulfilling Prophecies? Decentralization, Inner City Decline, and the Quality of Urban Life," *American Planning Association Journal*, autumn 1992, pp. 509-513.

[163] Pisarski, op. cit., footnote 128.

[164] Ibid.

women with licenses has risen rapidly, from 77 percent in 1983 to 85 percent in 1990,[165] and thus the propensity of women to use mass transit has dropped. Indeed, transit use has followed this trend. By 1990, both men's and women's transit shares had dropped substantially, to an average of 2.0 percent for both, but women's share had dropped more radically, presumably as a consequence of their increased attainment of driver licenses as well as their increased independent income and auto ownership. The difference between men's and women's transit use is now only about 0.1 percent, because women's transit share declined more than 20 percent from 1977 to 1990. whereas men's declined less than 10 percent in the same period.

Mass transit may be losing its traditional market among the old and very young, but may be gaining a market among young adults. Although transit's declining share of travel is spread broadly across age groups, it recently (1983-90) increased in share among the 20 to 29-year-old group.[166] This may be a promising indicator of future transit potential. As a guess, this rise in transit share might reflect declining prospects for high-paying jobs among this age group. Continuation of this trend may depend on the economy's ability to provide good jobs to this age cohort. Another reason for the rise in share among this group may be the increased number of singles and childless couples in the group, and their willingness to live in high-density urban areas during this stage of their lives. To the extent that this is true, the prospects for transit potential will depend on their future lifestyle decisions.

On the other hand, transit share declined markedly in the age group over 50 and the age group from 5 to 15, both traditional transit markets.[167] Among the older groups, this trend probably reflects an increasing income, as well as driving ability: many in this group grew up with automobiles, in contrast to past years. The declining share among the young may simply reflect continuing suburbanization of households with children, and perhaps also growing concerns about urban crime. Parents appear far less likely to let their children travel alone than in past years: thus they may prefer to drive them to activities rather than let them use transit.

What Are the Physical Circumstances?

The Urban Mass Transit Administration's[168] 1984 Report to Congress [169] identified four different types of urban areas that any attempt to expand transit services would have to address (note that these descriptions are of the status quo, with no major policy changes):

1. *The largest, older urban areas.* New York, Chicago, Philadelphia, Washington, and San Francisco are typical: most are in the North, but a few are in the South and West. The structure of these metropolitan areas includes a relatively dense central city with a stable or growing CBD (in terms of both floor space and economic activity, and sometimes in jobs), moderate-density older suburbs, and lower-density newer suburbs around the perimeters. Little change in this basic structure is anticipated over the next 15 years. The CBD should remain important, albeit with continued population dispersion from the central city. Annexation of new territory is often difficult.
2. *Large, older urban areas in decline.* These areas—Buffalo. Cleveland, and St. Louis are examples—have the same basic structure as the

[165] Ibid.

[166] Ibid., fig. 16.

[167] Ibid.

[168] Now the Federal Transit Administration (FTA).

[169] Urban Mass Transit Administration, *Status of the Nation's Local Public Transportation: Conditions and Performance*, Report to Congress (Washington, DC: U.S. Department of Transportation, September 1984).

previous group but both the central city and the CBD are in marked decline, largely because of the erosion of the city's traditional industrial base. Since the ability of such places to attract compensating growth industries has frequently proved limited, continued decline is to be expected for many of them.

3. *Newer large urban areas.* Los Angeles, Denver, Houston, Phoenix, and San Diego are representative. Such cities are predominantly in the South and West, because the existing density of major cities in the North inhibits the emergence of new centers there. The rate of growth of the newer cities will probably decline from that in the 1970s. Since the major growth of these areas has occurred relatively recently, there are often substantial sections of the central cities that contain housing and commercial activity at suburban densities. Annexation by the central cities of new territory is often possible.
4. ***Smaller urban areas.*** Many urban areas in all sections of the country (with populations up to about 750,000) will experience growth, the bulk of which will be in MSAs (metropolitan statistical areas) of about half-million population in the Southeast and Mountain States, and MSAs between 50,000 and 100,000 in the Northeast and North Central areas. The reasons for the growth of each are different. In the South and West, growth results from the expansion of energy-related industries, the search for a "better lifestyle," and the process of filling out the pattern of regional centers. In the North and East, the growth is due to continued dispersion of population from the largest metropolitan areas.

New or expanded transit will have to be shaped to these individual circumstances. For the large, older cities with dense central cores and vigorous CBDs, conventional fixed-route services make sense for the downtown-oriented worktrip market, with high-capacity fixed-guideway systems (rapid rail, dedicated busway) where densities are very high and most trip distances are long enough for a high-speed system to provide some real travel time advantage. Many of these cities already have rapid rail systems, but several of these are deteriorating or losing patronage because of fare increases. As discussed below, the budgetary arguments for fare increases often ignore the huge investment in capital embodied in these systems. If the original premises upon which the systems were built remain correct, it makes little sense to let these systems deteriorate or lose patronage to avoid operating losses when the effect is to greatly ***increase*** the total (per-passenger) subsidy. On the other hand, supporters of new rapid rail systems have to recognize the extremely high per-passenger costs of such systems, which become even harder to defend when it is recognized that many of the passengers will have formerly traveled in buses or carpools.[170]

For those cities where trip distances are shorter and existing rights of way are available, light rail systems provide a more cost-effective choice than rapid rail. Express bus service also can play an important role in serving outer areas although, as noted above, this service tends to be expensive.[171]

For "cross-town" travel in larger central cities serving work and nonwork travel needs for lower income or other transit-dependent residents, conventional bus systems may be the most feasible service choice, although this type of service is expensive and will continue to require substantial subsidies.

Finally, for service in smaller central cities and trips to suburban subcenters, paratransit opera-

[170] Ibid.

[171] Federal Transit Administration, op. cit., footnote 130.

(ions (e.g., vanpools, demand-responsive services. jitneys) and ridesharing make considerably more economic sense than conventional bus services.

Bookkeeping Problems and Transit Patronage

One reason for the stagnant or declining patronage on existing rail transit systems is the combination of rising fares and declining service, fed by the reluctance of local jurisdictions to increase operating subsidies as costs rise. The cost-benefit decisions of these jurisdictions in setting fare and subsidy policies bear little relationship, however, to the overall cost-benefit calculus of the original decisions to build the systems. These original decisions offered very high subsidies per new transit passenger. both planned and actual,[172] presumably because the system planners placed a high societal value on moving trips from auto to transit. Because the Federal Government supplied most of these subsidies, however, local jurisdictions tend to ignore the sunken (already spent) costs of the systems and treat their current subsidy calculations as if the total costs of the system were operating costs. Thus, their decisions do not consider the reality that losing passengers spreads the very large capital costs of the system across fewer riders and incurs large costs to society if the original value of moving tripmakers from autos to transit, as assumed in the system construction decision, was correct. In other words, raising transit fares and/or decreasing service may decrease the per-passenger operating subsidy, but greatly increase the per-passenger *total* (operating plus capital) subs id>.

If current decisionmakers maintained the original view of the value of increasing transit ridership, they would realize, with but one possible point of dissension, that *reducing* fares and increasing maintenance and service levels, rather than increasing fares and reducing service, is the more cost-effective strategy. The dissenting point is that system efficiency may be a function of the level of the subsidy: the efficiency of heavily subsidized systems has been poor.

It is worthwhile to examine quantitatively the alternative cost -benefi t choices available to transit decisionmakers--whether or not to incorporate capital costs into decisions about raising fares. Two key values are important to this issue:

1. The elasticity of transit ridership in relation to transit fares is generally thought to be about -0.3; that is, a 10 percent fare increase will decrease ridership by about 3 percent.[173]
2. In rail systems, the function of total costs associated with capital charges is quite variable, but a typical value might be 80 percent.[174]

Box 5-4 describes the effects of the alternative choices for a hypothetical rail transit system with 100,000 daily passenger trips, a total (capital plus operating) cost per trip of $10, a $1 fare, and a $1-per-trip operating subsidy. For this system, raising fares by $0.50 per trip leads to a loss of 15,000 passenger trips a day but yields a significant reduction in the total and per-trip operating subsidy: from the perspective of total costs, however, this is a situation in which society previously had been willing to subsidize each trip by $9 but will save only $1.83 for each trip lost to the system.

Conclusions

Although there will be intense disagreement about the potential for success of *any* plan to greatly enlarge transit service in the United States, there would likely be general agreement with the proposition that with a few' exceptions (e.g., rehabilitation of some systems in very dense cities). funnel -

[172] As shown by Pickrell, op. cit., footnote 152, actual costs were higher and patronage was lower than originally projected, so that per-passenger subsidies were considerably higher than projected. Nevertheless, even the planned per-passenger subsidies were extremely high.

[173] Ibid., p. 28.

[174] Based on the values associated with the systems examined by Pickrell, ibid.

BOX 5-4: Capital and Operating Subsidies and Fare Decisions

In urban rail systems, capital subsidies are typically much higher than operating subsidies It is not unusual for capital charges to represent 80 percent of total system costs Despite the magnitude of these charges, however, local decisions about transit agencies' operating budgets may take little consideration of capital costs. There are several potential reasons for this the Federal Government heavily subsidizes these costs; the costs are "sunk," that is, already spent, and/or local governments accept the proposition that the costs cannot be repaid out of the fare box Where capital costs are not carefully considered in operating decisions, however, decisions about fares may be based primarily on concerns about operating subsidies This narrow focus can create inconsistencies between societal objectives and transit operating strategies

A sample case will illustrate the problem A hypothetical rail system serves 100,000 passenger trips daily and has operating costs of $2.00 per trip and capital costs of $800,000 per day The capital costs are covered by a capital subsidy of $8 per trip, and operating costs are covered by fares of $1 per trip and an operating subsidy of $1 per trip ($100,000 per day)

The transit agency, if it is concerned that the operating subsidy IS too large, may examine the possibility of raising fares to $1.50 per trip. In focusing on the operating subsidy only, this looks like a reasonable move If ridership has a price sensitivity of O 3, the 50-percent fare increase might reduce passenger volume by (50 percent O 3), or 15 percent—1 5,000 passenger trips daily. The new passenger volume will generate fare revenues of $127,500 daily, reducing operating subsidies by at least $27,500 daily (and more if operating costs are reduced because of the lower volume of passengers) The operating subsidy per *passenger trip* is reduced to about $085

If the capital subsidy is included in the calculations, the results look somewhat different, however. The capital subsidy will rise to about $941, and the total subsidy from $9 to $1026 per passenger trip In other words, although passengers are paying more in fares, the per-passenger subsidy is actually higher than before

Another way of looking at the results is that the system has lost 15,000 passengers to save $27,500 a savings of $1 83 per passenger lost. With a focus only on operating subsidies, this seems to make sense the agency previously placed a value of $1 on having a traveler use transit presumably instead of driving, so it ended up saving more than each lost passenger was worth However, with a focus on all subsidies, society was paying $9 to have a traveler use transit. Saving only $1 83 for each passenger lost to transit looks like a bad bargain from this vantage point

The math in this example will change somewhat if the lower passenger volume allows both operating and capital savings from either or both reduced service frequency and train length, but it is unlikely that the change will be substantial enough to alter the basic conclusions

This example also provides ammunition for proposals to reduce transit fares substantially where excess capacity exists. If society really does value shifting auto riders to transit as highly as implied by the subsidies pay to rail systems, reducing fares would be an extremely cost-effective method of "buying" additional passengers Other issues that might arise in evaluating a fare reduction proposal include the desire to avoid frivolous use of the system (otherwise, there is a clear basis for arguing for elimination of fares) and the need to clearly Identify what the system's primary goals are The latter issue arises in examining questions about fares for off-peak periods If society makes no value distinction between peak and off-peak ridership, sharp fare reductions for off-peak use make excellent sense However if society values the transit system primarily as a way to ease congestion and the need for new highway capacity, off-peak ridership may be valued considerably less than peak ridership In this case. there may be less Incentive to lower off-peak fares—and increase the operating subsidy—to increase ridership

SOURCE Off Ice of Technology Assessment, 1994 ing large amounts into public transportation will not shift large numbers of trips from autos and will not save large amounts of energy unless it is coupled with intense efforts to restrain automobile travel and shift development to more transit-friendly patterns.

It is, however, unwise to point to previous (poor) experience and conclude that mass transit cannot work in the United States. The only conclusion offered by our previous experience is the one above. Whatever transit good points, it is not preferred by most travelers under the current system of incentives. Thus, any failure of previous attempts at funneling resources into transit proves only that transit cannot succeed very well within the existing system, but does not indicate what might happen with changes in the system.

For most rail transit systems, capital expenditures are subsidized 100 percent and operating expenses are subsidized partially, with authorities trying to get as much of the operating expenses as possible out of the fare box and focusing primarily or exclusively on operating expenses in trading off fares versus ridership. This funding system creates incentives to raise fares and accept lower ridership in order to reduce operating subsidies, even though capital subsidies per passenger would go up sharply'. Increasing fares 10 percent produces only about a 3-percent drop in ridership and thus seems to make sense from an operating cost standpoint.[175] The fare increase probably does not make sense from a total costs standpoint, however: minimizing the total subsidy per rider would, under most circumstances, require a fare reduction (and an increase in ridership), maybe even to the point of making the system almost free.

URBAN FORM AND TRANSPORTATION

Transportation analysts point to the structure of most American cities—the low population density, the importance of suburbs and exurbs, and the separation of residential and commercial development, as well as the enormous land area and investment given to roadways and parking facilities—as a principal cause of the very high gasoline usage, low proportion of transit trips, and low use of walking and bicycling modes characteristic of U.S. urban transportation.

The general relationship between transportation and land use is widely recognized in the transportation and urban planning community and among environmental groups, but different individuals draw widely varying conclusions from this relationship. Some view the processes of suburbanization that have dominated the development of U.S. cities for decades as being essential] y unchangeable and a natural response to a confluence of interrelated factors: the mobility provided by the automobile; Americans' preference for single-family, low-density development; the lessening of the economic advantages to businesses of close proximity to each other; the desire of businesses to gain better access to a growing suburban workforce; and a continuing drive to escape growing congestion. In this view, continuing suburbanization will cause the automobile to remain the dominant mode of transportation for the foreseeable future, with travel demand continuing to grow. These individuals conclude that urban and transportation planning agencies should accept the continued dominance of the automobile and should seek to reduce adverse environmental impacts through technical and administrative improvements (improved emission controls, higher fuel economy, improved inspection and maintenance programs) while maintaining auto mobility through a combination of transportation initiatives (to increase vehicle load factors, initiate intelligent highways, including congestion pricing to rationalize highway use, and increase highway capacity) and planning flexible enough to allow land use shifts that will reduce congestion (e.g., removal of zoning constraints that artificially separate business and residential land uses).

[175] Ron Jensen-Fisher, Federal Transit Administration, personal communication, 1993.

A second group believes that U.S. suburban growth patterns and automobile dominance are not inevitable but are instead the result of flawed public policies: that low-density development carries with it very large societal and environmental costs; and that changes in public policies, focusing on new transit services and denser land use, can shift U.S. land use and transit ridership toward European norms (i.e., higher densities and more balanced transport patterns). From their perspective. major shifts in land use toward denser urban and suburban centers can be achieved through suburban-rural development restrictions, minimum-density rules, restrictions on parking, fuel taxes, changes in income taxes, and so forth. These changes would then promote transit use as well as walking and bicycling, and would reduce overall tripmaking. At the same time, the introduction of new transit services would help to push land development patterns toward increased density, especially around the stations. In other words, the new transit services and land use controls would interact synergistically, each assisting the other-dense land use making transit work better, transit promoting denser land use.[176]

This section explores the role of urban structure in shaping, and being shaped by, the transportation system.

Evidence for a Strong Relationship Between Urban Form and Transportation Energy Use

Demonstrating quantitative relationships between land use characteristics and transportation is made exceedingly difficult by our inability to examine the "control" case (what would have happened if the transit system had never been built or if the land use controls had never been applied?), the impossibility of proving cause and effect through statistical analysis, the complexity of land use and transportation interactions, and the great variability among cities that complicates cross-sectional analysis.

Although arguments favoring the ability of public policy choices to transform urban form and urban transportation patterns come from a variety of sources, one of the most prominent is a cross-sectional study of the urban structure and transportation systems of many of the world's medium and large cities performed in 1980 by Peter Newman and Jeffrey Ken worthy of Murdoch University in Perth, Australia (hereafter referred to as N& K).[177] This study concludes that there exist statistically significant relationships between transportation variables and variables describing urban structure, and highlights differences between "auto-oriented" U.S. cities and the more transit/walking/bicycling-oriented cities of Europe and Asia. This analysis cannot prove cause and effect, it does not account for some important city-to-city differences that affect transportation (e.g., differences in income levels and stage of development), and it is extremely sensitive to the manner in which boundaries are drawn defining cities' components (central business district, central city, metropolitan area, etc.). Further, it does not account for differences in the age of cities and the dominant transportation technologies present when the cities were formed. However, many of the relationships described (especially those that remain strong when the range of cities is narrowed to the subset of prosperous European, North American, and Australian cities) appear to transcend these differences and analytic problems and to express truths about transportation-urban structure relationships that should be robust over time.

[176]See E.A. Deakin, "Jobs, Housing, and Transportation: Theory and Evidence on Interactions Between Land Use and Transportation," *Transportation, Urban Form, and the Environment*, Transportation Research Board Special Report 231 (Washington, DC: National Academy Press, 1991).

[177]P.G. Newman and J.R. Kenworthy, *Cities and Automobile Dependence: A Sourcebook* (Hants, England: Gower Publishing Co., 1989).

And despite criticisms from a number of transportation analysts, many of N&K's numerical results for U.S. and European cities agree well with other sources.[178]

Density and Job Balance

Although there are some conspicuous exceptions (e.g., New York City), N&K found that the U.S. cities in their sample could be characterized generally as low density—residential densities below 20 persons per hectare (ha, or 8 persons per acre), compared with European cities' 50/ha and Asian cities' 150/ha. Whereas European and Asian central cities tend to have balanced job and residential concentrations, U.S. central cities tend to have high job concentrations with few residents. If a few of the old U.S. cities such as New York and Chicago are excluded, the remaining U.S. inner cities in N&K's survey are one-half to one-third as dense as European inner cities, and one-tenth as dense as the Asian cities they examined. And the outer areas of the U.S. cities have very low density, perhaps one-fourth of that in Europe. Finally, despite the dedication of U.S. central cities to jobs rather than residences, these cities are less centralized in jobs than European and Asian cities; in the United States, jobs are scattered throughout the metropolitan areas.

Automobile Orientation

Along with the above differences in basic structure, the U.S. cities in N&K sample are far more automobile-oriented than their European counterparts. In 1980, the U.S. cities had three to four times the road area per capita of European cities, 80 percent more parking spaces per 1,000 workers, and considerably less public transport service—about 30 vehicle-kilometers (19 vehicle-miles) per person versus 79 vehicle-kilometers per person in Europe. Not surprisingly, measures of auto and transit use are substantially different, as well. In 1980, only about 4 percent of passenger miles in the U.S. cities were captured by public transport, versus about 25 percent in Europe (65 percent in Asia). In commuting, about 12 percent of worktrips were on mass transit in U.S. cities versus 35 percent in Europe and 60 percent in Asia. Furthermore, in U.S. cities, most of the non-transit trips were by automobile; only about 5 percent of workers walked or bicycled to their jobs, versus 21 percent in Europe and 25 percent in Asia.

Travel Volume

Besides traveling more often in private vehicles, Americans also traveled much farther than Europeans or Asians. In 1980, people in U.S. cities averaged about 13,000 kilometers of travel in highway vehicles, versus 7,400 kilometers per person in European cities and 4,900 kilometers in Asian cities. Presumably, the cause of these travel differences is a combination of the higher density and more mixed residential-employment development of European and Asian cities (i.e., less *need* to travel long distances to obtain services, reach jobs, or visit friends) and, perhaps, some amount of lower "mobility" in the European and Asian cities, where mobility might measure in part the opportunity to travel but might also reflect free choice to travel based on lifestyle differences.

Energy Use Per Capita

In any case, the differences in per capita annual travel distances and modal choices create a large disparity between U.S. and European or Asian cities in the amount of energy per person expended on transportation. N&K estimated that in 1980, the U.S. cities averaged nearly 59,000 megajoules (MJ; about 55 million Btu, or 450 gallons) per capita of gasoline use versus 13,000 MJ for the

[178] E.g., Pucher, Pisarski.

European cities and 5,500 MJ for Asian cities.[179] Although the European and Asian cities probably use more electricity y for train transport, and the per capita energy values do not include air travel, there remain huge disparities in total energy use for transportation between the United States and Europe or Asia. For example, the Lawrence Berkeley Laboratory estimates that total per capita transportation energy use in 1987 was 57,700 MJ for the United States and only 21,200 MJ for France, 13,200 MJ for Italy, 18,300 MJ for Great Britain, and 12,400 MJ for Japan.[180]

Vehicle Efficiency

Part of the disparities in transportation energy use between U.S. and European or Asian cities reflects differences in the technical efficiencies of the vehicle fleets in these cities (e.g., the average fuel economy of the auto fleets). For example, in 1980, the U.S. light-duty vehicle fleet averaged 14.9 mpg, versus 19.6 mpg for Japan, 27.5 mpg for France, 28.7 mpg for Italy, and 22.6 mpg for Great Britain.[181] In 1987, the disparity of efficiencies had lessened somewhat: Japan's fleet averaged 21.4 mpg, France's 26.9 mpg, Italy's 29.9 mpg, and Great Britain's 25.3, that is, in general a modest increase in efficiency over 1980, whereas U.S. efficiency levels had increased 17 percent to 17.5 mpg.[182] Thus, while Italy total per capita transportation energy use in 1987 was but one-fifth that of the United States, its auto fuel efficiency was only 70 percent better. An examination of the other values indicates that most of the transportation energy differential between the United States and Europe must be accounted for by factors other than technical efficiency.

Residential Density and Gasoline Use

Urban structure, with its effect on a variety of transportation variables, appears to be a major explanatory factor in the differential energy use. N&K believe that urban population density is a key explanatory variable for per capita gasoline usage. Their plot of gasoline use versus urban densit y in figure 5-3 appears to show a strong relationship between population density and gasoline use. In the graph, per capita gasoline consumption rises steeply at population densities of about 30 persons per hectare (12 persons per acre); N&K consider this to be a breakpoint for the success of nonautomobile modes. N&K further assert that a strong role of density in influencing gasoline use appears *within* single urban areas as well as across different cities: according to their data, in 1980 the average resident of the New York Tri-State region used 44,000 MJ (42 million B(u); residents of the less-dense outer area of the region used 60,000 MJ; residents of New York City used 20,120 MJ; and residents of Manhattan used 11,860 MJ. For comparison sake, they cite the exurban residents of the outer Denver area, who they claim used an astonishing 137,000 MJ—more than a thousand gallons-of gasoline per year.

An examination of the curve reveals some problems with the concept of a simple density-energy use relationship, however. First, the entire right-hand side of the curve consists of only two points (for Moscow and Hong Kong), the first of which represents a city that exercises an extraordinary authority over transportation choices—an authority not possible in most of the cities in the sample. Second, for cities with annual per capita gasoline usages greater than 20,000 MJ, there ap-

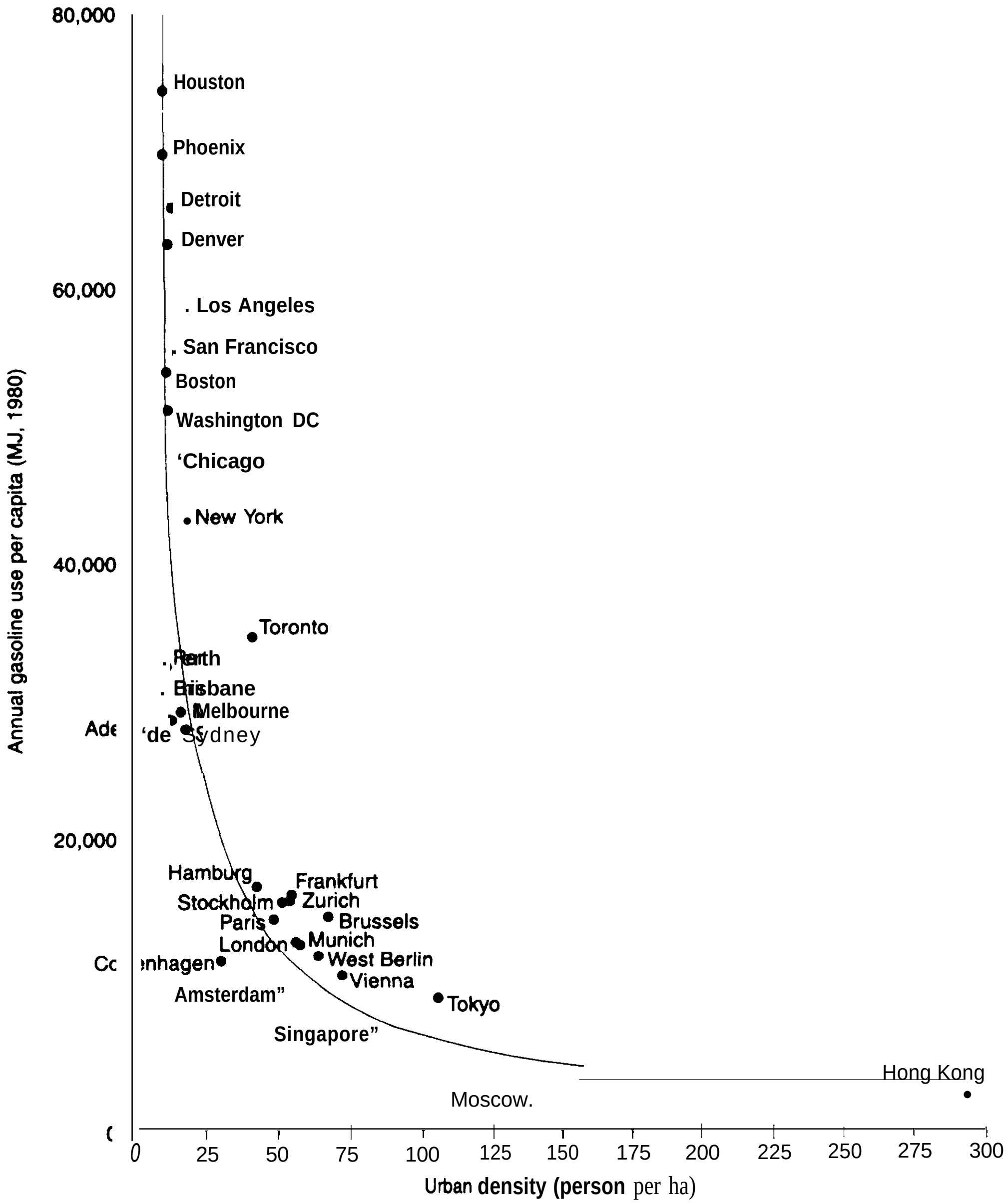
[179] These values appear to be overestimates although the relative values appear about right. Note that the LBL values for 1987 (below) for *national* per capita energy use are lower than the N&K values for gasoline {rely even though 1987 per capita energy use was higher than 1980 energy use. The LBL values include nongasoline energy. and city per capita transportation energy use seems likely to be lower than national per capita use (since, according to N&K, higher density areas such as cities are associated with less travel than lower density rural areas.

[180] L Schipper "Energy Use in Passenger Transport in OECD Countries Changes Between 1970 and 1987, " *Transportation: The International Journal*, April 1992.

[181] Davis and Morris, op. cit., footnote 9. table 1.7.

[182] Ibid.

FIGURE 5-3: Gasoline Use Per Capita Versus Urban Density, 1980



SOURCE PG Newman and J R Kenworthy, *Cities and Automobile Dependence A Sourcebook* (Hants, England Gower Publishing Co 1989)

pears to be virtually no relationship between density and gasoline use; cities with very similar (1ow) density development have an extraordinarily wide range of gasoline usage. And between about 32,000 and 6,000 MJ per year, although there appears to be a functional relationship, the "spread" among the data points is very large. Finally, some of the data appear suspect—for example, Los Angeles is shown to have approximately the same urban density as New York. The reason presumably is that N&K have included very large geographic areas in their definition of "urban area," thus incorporating a wide range of high-density inner-city and low-density suburban areas. It is difficult to believe that merging such areas does not weaken the reliability of the relationships uncovered.

Role of Other Variables

N&K contend that other urban and transportation attributes, some related to population density but not in lockstep with it, also influence gasoline use and overall transportation energy consumption. For example, they assert that an area's orientation to private vehicle usage impacts gasoline use. This orientation is measured by variables such as the length of road available per vehicle, the parking spaces per 1,000 vehicles, and the average speed of highway travel. Interestingly, cities with the highest average traffic speeds tend to have the highest per capita gasoline consumption even though their ability to keep traffic flowing freely leads to an efficiency advantage per vehicle-mile. One interpretation of this relationship is that travel demand is encouraged by greater ease of travel, so that providing more road space and more parking spaces encourages increases in auto trips. This, in turn, would imply that measures designed to reduce congestion by increasing capacity, which are supported by arguments that they will save time and energy, may instead increase energy use and time spent in travel by encouraging auto travel and urban sprawl. And the converse might be true: congestion may be useful in encouraging behavioral and land use changes that reduce energy use. The argument that providing more road capacity will tend to increase travel and energy use is strongly disputed by some analysts, who claim that it applies only to situations where there is unmet travel demand and that this is not now the case in the United States.[183] Further, there is an alternate explanation of the relationship between travel speed and gasoline usage: that it is low density (and the resulting separation of destinations) that is actually driving travel demand and gasoline use. The apparent speed/gasoline use relationship could be a statistical artifact caused by the strong collinearity between speed and density.

Another important variable closely associated with energy use is the degree of centralization of the city. Maintaining a strong central focus allows alternative modes, including walking and bicycling, to function, while diffusing population and employment throughout an urban area actively encourages private vehicle use and makes efficient transit difficult or impossible.

Public transport performance represents another set of variables that are strongly correlated to gasoline use and overall transportation energy consumption. In this case, gasoline usage is negatively associated with variables such as the amount of transit vehicle service, measured in vehicle-miles per capita. This relationship seems almost a tautology rather than a cause-and-effect relation, however, because the existence of an intensive transit network is most likely in those cities with high densities and centralization of activities-cities likely to have relatively low levels of both vehicular travel and gasoline usage.

The conclusion N&K draw here is that major savings in transportation energy use beyond those achievable with improvements in the technical efficiency of vehicles will require *both* improvements in mass transit systems and significant shifts in land use configurations. The land use shifts can be termed "reurbanization," designed to increase the density of residential and commercial activity, to centralize this activity, and to mix the two activities together. Specific physical shifts include in-filling vacant land that has been "leapfrogged" in the rush toward suburbanization; redevelopment of industrial and warehousing sites to more suitable uses; rezoning and rebuilding old, declining low-density districts; building intensive mixed-use developments; developing the air rights over rapid transit uses; developing un-

183 C.A. Lave "Future Growth Of Auto Travel in the U. S.: A Non-Problem," paper presented at Energy and Environment in the 21st Century, Massachusetts Institute of Technology Conference, Mar. 26-28, 1990.

used highway rights of way; physically restricting outer area growth (e.g., by preventing the subdivision of rural land); and expanding housing development in the central city.

For this report, the obvious question raised by N&K's work is, what does it imply for U.S. prospects for reducing transportation energy use? This question breaks down into three components:

1. Are the relationships described by N&K reliable?
2. Do the relationships represent cause and effect, that is, will changing urban structure lead to changes in transportation energy use, and will changing transportation systems tend to lead to changes in urban structure?
3. If the answers to question 1 and 2 are yes, can we effect the necessary changes? The latter is an issue especially when changes in urban structure are contemplated.

Reliability of the Data

As discussed above, questions can be raised about N&K's data. Anybody who has worked in transportation analysis knows that data on travel behavior are highly variable from country to country and often between different cities within the same country, including the United States. Further. most data are collected by political jurisdiction rather than by agreed-upon segments in urban structures (e.g., central business district or central city). In reality. urban analysts have no quantitative agreement about where urban boundaries should be drawn. Thus, it is difficult to know how reliable N&K's data are or whether their boundaries have been selected in a consistent analytic framework; N&K themselves take care to discuss the numerous data problems they faced. One of the more disturbing problems that N&K (and most other analyses of transportation energy use) faced was getting accurate measures of per capita gasoline consumption in cities. For the most part, consumption has been measured by using data from gasoline sales. but these sales may be poorly related to actual consumption within urban boundaries. OTA draws no conclusions about the reliability of the data and the relationships drawn from them, but notes that the latter generally agree with conventional thought about transportation and urban structure.

Cause and Effect

Cause and effect is a critical issue for the policymaker, because it clearly is important to know whether policies that tend to yield increases in urban density can be a useful part of a transportation energy conservation strategy. Also, it is useful to know whether adding a transportation system such as rapid rail will tend to increase urban density, yielding a synergistic impact—reduced travel requirements and better conditions for economic success of the new system.

Although cause and effect cannot be proved by examining statistical relationships, case studies can provide strong prima facie evidence for or against such a relationship. Unfortunately. most Western cities are reducing, not increasing, their densities, so case studies of increasing density are not readily available. It seems logical that increasing density and increasing the mix of land uses would reduce travel requirements by providing closer access to goods and services, but this must be treated as speculative (though probable).

As discussed in the previous section. studies that examine differences in transit usage, land use density, and auto travel at a single point in time[184] cannot show cause and effect or even demonstrate a relationship between land use changes and travel behavior (or between added transit services and travel behavior) over time, even though they may claim to. Further, the role of demographic differences among different land uses, and the impact of these differences on travel behavior, further complicate the issue of cause and effect; as discussed earlier, to the extent that people with" low-travel" characteristics are attracted to urban areas, part of the "cause" of low rates of travel in denser land

[184] For example, Goldstein et al., op. cit., footnote 155.

uses will be the characteristics of the people living there, not the density per se.

Can changes in transportation systems have significant effects on urban structure, that is, can the introduction of new systems encourage development into forms that would support increased use of that system, creating positive feedback between the transport system and urban land use? Because new roads and transit systems have been added to cities, there is opportunity for obtaining better evidence about the effects of such systems on urban structure. Nevertheless, documenting a transport-created impact is difficult, because land use is affected by many factors and changes slowly. In particular, studies of past changes in transportation systems tend to suffer from a range of problems:

> . . . lack of explanatory power for observed correlations, difficulty in distinguishing cause and effect, failure to distinguish economic shifts within a region from (transportation) investment-induced growth, double counting of benefits, (scoping too narrow) to identify possible shifts in production processes and changes in economic and social organizations that might occur as a result of important new transportation investments. [185]

Recent attempts to document such impacts appear to indicate, however, that transport system shifts in the early history of U.S. cities had major impacts on urban form (e.g., the introduction of freeways greatly abetted the decentralization of U.S. cities), but that in recent times there has been less linkage between new transportation system changes and shifts in urban structure. [186] In general, the studies indicate that transportation availability and quality are only two of a number of critical factors in location and development, and by themselves, investments in transportation will do relatively little to change land use, especially if the hoped-for direction in land use is counter to general market trends.

Investigations of new rail transit investments have identified localized benefits, but regional benefits are described as "quite modest." [187] For example, higher-density development will tend to be attracted to land around rail transit stations, but only when other conditions are right-and in some cases, such development might other-wise have occurred elsewhere in the area (e.g., at a freeway intersection). Further, some suburban-oriented rail systems have worked in ways opposite to the densification hoped for by transit proponents; by easing the difficulty of commuting to the central core from some distant suburban locations, thus spurring development at these fringe locations. [188] A key to understanding the likely impacts of transportation system changes is that in most cases, urban residents in modern U.S. cities already have very high levels of mobility; new systems cannot offer the huge increases in mobility that they might have in the early history of cities.

An important variation of the above issue is whether or not the building of new highways—or expansions of existing ones—might lead to land use changes (e.g., shifting development from high-density to low-density areas) that would tend to "use up" the new travel capacity they create. The idea that adding highway capacity to combat congestion is essentially a self-defeating exercise is a common theme of antihighway arguments. Although there is evidence to support the thesis that new highways do create land use shifts that will add to the call on their capacity, the evidence is not sufficient to support reliable estimates of the magnitude of this effect. [189]

Can We Hope To Change Land Use?

Without important shifts in land use, leading to denser, more centralized, more "European-style"

[185] Deakin, Op. cit., footnote 176.

[186] Giuliano, Op. cit., footnote 121; and ibid.

[187] Deakin, op. cit., footnote 176.

[188] Ibid.

[189] Ibid.

urban areas, improvements in transit service are unlikely to have a major effect on transportation energy use. This automatically leads to the question, will Americans support such shifts and find the results desirable? This question, although perhaps unanswerable, can be illuminated by the following observations.

Lack of Examples

Few American cities have actually initiated a series of strong measures to focus development on the central city and restrict it in the suburbs. One is Portland, Oregon, which has established a number of planning measures to maintain compact development, including an Urban Growth Boundary to direct new development into the city rather than its suburbs, development of a light rail system, prohibition of automobiles in a key downtown corridor served by bus transit, and restrictions on parking spaces incorporated into new office development.[190] Claims for success of this effort include a constant volume of cars entering the downtown since the early 1970s, despite a 50 percent employment increase and a 43 percent transit share for commuters to downtown.[191] However, a focus on the city as a whole shows a distinctly different picture: from 1980 to 1990, the overall transit share in Portland dropped from 15.9 to 10.9 percent.[192] In addition, the number of persons driving alone increased by more than 30 percent, while the absolute number of transit users declined.[193] In fact, driving alone actually increased more than the increase in workers during this time period.[194] Further, much of the development channeled within the urban boundary has been low-density, suburban-type development; in response, Portland is now considering adopting minimum densities of development,[195] an unusual approach in a nation where zoning is virtually universally regarded as establishing ***maximum*** densities and land uses.

It maybe too early in the process to expect major improvements to show up in Portland. The Urban Growth Boundary still has within it enough developable land to allow 20 years of growth at suburban sprawl densities, and the light rail system, at this stage of its development, serves only about 15 percent of the population.[196]

What the Portland experience seems to show is that, in some cases, a reasonable local political consensus can be reached that radical and perhaps painful measures must be taken to solve transportation and land use problems; that these measures can make a positive difference in limited areas; and that it remains unproven whether these local measures will succeed on a citywide basis, but in an y case success will not come swiftly. The problem with Portland and other models is that at best, they are "swimming in an automobile-oriented sea"; that is, they must overcome a national policy that seems designed to promote automobile travel by keeping gasoline cheap, encourage single-family home ownership, and build lots of roads.

Convergence of European and U.S. Transport Patterns

Although European cities, which are more oriented toward transit, bicycling, and walking than most U.S. cities, are often held up as models for the United States to emulate, in reality European

[190] M D, Lowe, *Shaping Cities: The Environmental and Human Dimensions*, Worldwatch Paper 105 (Washington, DC: Worldwatch Institute, October 1991).

[191] Ibid.

[192] A.E. Pisarski, *New Perspectives in Commuting* (Washington, DC: U.S. Department of Transportation, Office of Highway Information Management, July 1992).

[193] Ibid.

[194] Ibid.

[195] S. Sadler, Oregon Department of Energy, personal communication, Dec. 9 1992.

[196] Elizabeth Deakin, University of California at Berkeley, personal communication, 1992.

land use and transportation patterns are moving somewhat in the U.S. direction, with growing automobile dependency, growing transportation energy use, and increasing levels of suburbanization (this is discussed more fully in chapter 3). For example, between 1970 and 1989, U.S. light-duty vehicle (auto or light truck) ownership per capita went from 0.438 to 0.575, a 31-percent increase. In contrast, France's went from 0.242 to 0.410, an increase of 69 percent; Italy's increased by 140 percent, the United Kingdom's by 79 percent, and West Germany's by 98 percent.[197] Similarly. whereas U.S. travel energy grew only 13 percent between 1973 and 1988, European growth during that period was 55 percent, and Japanese growth was 76 percent.[198] This does not mean, however, that the United States and Europe are moving toward the same developmental and transportation future, although clearly they are converging. It seems quite likely, given their different starting points, basic transportation and urban planning policies, and geography, that European urban structures and transportation patterns will reach an equilibrium point closer to U.S. cities than they are now, but still be substantially more transit-oriented, of higher density, and lower in per capita travel.

Preferences of Residents Themselves

A critical component of a strategy to undertake the significant changes in urban form needed to make cities more transit-friendly and reduce urban tripmaking is the extent to which the goal of the changes—much denser cities with greater centralization and substantial blending of land uses—is desirable to urban residents. Americans may have serious reservations about the value of dense urban areas, but at least some of their reservations are based on false premises or on examples of inner-city life that do not accurately reflect what might be accomplished with proper planning and urban policy. For example, despite some perceptions to the contrary, there appears to be no positive relationship between population density and violent crime in cities: the less dense, automobile-oriented U.S. cities have just as much (and sometimes more) crime per capita as the old transit-oriented cities. On the other hand, the *distribution* of crime throughout a city may be as or more critical than its frequency, especially in influencing those groups most likely to wield political power. In low-density cities, high-crime neighborhoods may be well-separated from the upper- and upper middle-class neighborhoods whose residents wield the preponderance of political power; in denser cities, crime may be less easy for these residents to avoid.

There is no doubt that the quality of life in very dense, European-style cities is intensely different from that in the spread-out, automobile-oriented cities so prevalent in the United States. It may be fruitless to place some abstract value on each urban form, even though they clearly will have different travel consequences. What is important is the perception of the residents, and most important, the perception of those residents most likely to influence the political process. For example, there can be little doubt that residing in the suburbs or in the lower-density portions of auto-oriented cities such as Houston allows residents to have larger houses and often allows private open space and gardens, amenities that are impossible in a dense city except for the extremely wealthy. Similarly, residing on a cul-de-sac in a suburban neighborhood devoid of commercial enterprise allows residents to sustain a relatively "low and slow traffic"' environment and to avoid the traffic concentration and changes in aesthetic values that often accompany commercial development. Although these amenities may come at a price—perhaps less access to cultural amenities and near-total dependence on the auto for mobility—the

[197] Davis and Strang, op. cit., footnote 134.

[198] L. Schipper et al., Lawrence Berkeley Laboratory, "Historic Trends in Transportation Energy Use An International Perspective," paper presented at the Asilomar Conference on Transportation and Global Climate Change, 1991.

majority of Americans have appeared willing to pay this price up to now. And although the price of continuing this style of development will increase in the future (e.g., with higher levels of congestion), one can only guess at the likelihood that these increased costs will great] y alter Americans' apparent preference for spreading out their cities.

Incentives for, and Time Frames of, Changes

Reductions in energy use hardly qualify as strong incentives for individuals to favor changes in their transportation choices. The cost of energy is a relatively minor part of both the monetary (quantitative) and the total personal costs of transport, and for auto travel, it is at a historic low in proportional terms.[199] Consequently, transportation choices are less likely to be based on energy than on factors such as travel time and comfort. This makes the attractiveness of different urban forms and different travel modes less easy to characterize. For example, although high urban density and concentration lead to generally shorter-length work trips, work travel *time* in these cities is often longer than in cities with lower population and employment densities because of the differential levels of congestion[200] and because sprawl "offers more diverse opportunities for faster commutes through changes of residence or jobs, the relocation of firms, or the choice of uncontested route s." 201 On the other hand, because worktrips represent only about one-quarter of all trips, the lower overall number of trips per capita in denser urban areas will likely yield significantly lower total travel time budgets for their residents than for the residents of lower-density, auto-oriented cities. As for the differential lifestyles and accessibility to alternative activities offered by different urban forms, the subjective nature of these differences prevents a fair comparison.

Because energy costs are highly visible to motorists (i.e., they see them at the gas pump every week), however, large increases in gasoline price may have an impact on travel behavior somewhat disproportionate to their impacts on total travel costs. Fuel cost is not irrelevant.

With regard to the improvement of public transport, N&K observe that only cities with extensive rail transit networks have succeeded in maintaining a high proportion of total trips on mass transit.[202] The authors relate this to the ability of trains to maintain comparatively high speeds—average speeds for urban buses are low (about 13 mph in both the United States and Europe, less than 10 mph in Asian cities), whereas train systems are much faster everywhere (typically about 25 mph).[203] In Europe and Asia, trains have substantially higher average speeds than private vehicles, although door-to-door times still suffer from time spent waiting for them and getting to and from stations, and it is likely that commuters "weigh" minutes of waiting time more heavily than minutes spent in a vehicle.[204] On the other hand, the relative success of rail transit may occur only because the majority of rail systems have been built in very densely populated cities where auto ownership is expensive, auto (and regular bus) traffic is extremely congested, and guideway transit is a particularly viable option for travel.

[199] U.s. Congress, Office of Technology Assessment, *Improving Automobile Fuel Economy: New Standards, New Approaches*, OTA-E-504 (Washington, DC'. U. S. Government Printing office, October 1991).

[200] Giuliano, op. cit., footnote 121.

[201] P. Gordon et al., "The Commuting Paradox: Evidence From the Top Twenty, " *American Planning Association Journal*, autumn 1991, pp. -116-420.

[202] Newman and Kenworthy, op. cit., footnote 177.

[203] Ibid. N&K do not say whether their values for trains apply (rely to mass transit, or to all trains in an area including commuter rail.

[204] Especially for minutes spent sitting in a car sea--if they are standing on a bus or train, vchicle time may be just as onerous as waiting time, but the point to be made here is even stronger then.

Because station waiting times and required transfers are weighted heavily in travel decisions, a bus system that allows neighborhood collection coupled with travel on exclusive rights of way might offer strong competition to trains even though top speeds are lower.

Another key question here is the time frame in which potentially significant changes in urban form could take place. Critics of transportation analyses that rely on changes in urban form to alter the transportation system note the long life of urban structures, the significant expected slowdown in U.S. population growth, and the highly developed nature of the existing auto-oriented transport system, as well as the multitude of factors *aside* from transportation considerations that play an important role in household and business locational decisions.[205] On the other hand, projections of growing urban congestion, with substantial increases in travel times and, presumably, with transportation considerations playing a renewed role in locating residences and offices, imply that transportation characteristics could become a major focus of locational decisions. As noted in chapter 4, the available forecasts of future congestion levels are likely to be overestimates, in part because they ignore likely changes in travel patterns.

Policy Questions

As a final point, support for changes in urban structure clearly will depend on the nature of the policy mechanisms necessary to achieve the desired changes. Although it is easy to draw up lists of measures that would contribute to denser urban forms and improved transit services, it is far from obvious how much money will have to be spent and how draconian the various taxation and zoning measures might need to be. If the differences in cities observed by N&K could be attributed to differences in urban and transportation policies among the cities, this knowledge would help quantify the measures necessary. Unfortunately, statistical analyses cannot identify cause and effect, as noted earlier.

The causes of the U.S. pattern of suburbanization are matters of considerable disagreement. One point of view holds that government policy is not the major cause—that the most powerful forces affecting urban land use in the United States and worldwide are more likely to be consumer preference, income, geography, and time (i.e. when was the city, or section of the city, developed?) than land use policies and economic incentives, although the latter are important. There are strong empirical arguments for this point of view: for example, the densest cities in the developed world are old cities whose land use patterns and densities were shaped by reliance on pedestrian travel. Portions of cities built during the era of horse-drawn carriages, trolleys, rail systems, and autos appear to reflect the availability of these new transportation systems more than they reflect the price of gasoline; in looking at the different districts of older cities, the more recently developed districts generally are substantially less dense. And residential densities, especially as reflected in the size of homes and propensity for high-rise apartments rather than townhouses, appear to reflect income as much as they reflect zoning, as implied by the extreme densities of cities in developing countries.

A contrary point of view does not necessarily deny that single-family homeownership is a widespread goal of families throughout the developed world, but considers the pattern of public policy choices to be a critical element of the extent to which this desire is satisfied and the extent to which high-density living represents a satisfactory alternative.

It is certainly true that there are substantial differences between the United States and other, more densely developed Western nations in both land use and those public policies that might potentially affect land use. Aside from obvious dif-

[205] Giuliano, op. cit., footnote 121.

ferences in urban residential density, even the suburban developments of Europe and Canada are more densely developed and more planned than those in the United States.[206] As for policy differences, U.S. local zoning policies tend to strongly favor separation of residential from commercial uses and low densities, whereas European policies favor mixed use and compact development. In Europe, much urban land is publicly owned, so government directly controls development of this land. U.S. State and local governments often provide essential capital infrastructure and services for suburban development, whereas European governments tend to provide selective infrastructure support to channel growth into compact development. Some European authorities simply prohibit low-density, scattered development, whereas this type of prohibition is extremely rare in the United States.[207]

Some analysts also question whether market surveys that show widespread preference for low-density over high-density environment truly demonstrate anything more than the natural result of policies that have undermined central cities and transformed them into places that are intensely undesirable.[208] Because most residents of urban areas cannot afford the few places remaining in central cities that are relatively safe, physically attractive. and socially vibrant, it is not surprising that they gravitate toward the low-density alternative. The argument here is that policies to nurture central cities, including provision of excellent transit services, restrictions on freeways, parking limits, and provision of open space, would allow virtually the entire central city to duplicate what is available only in small enclaves today, and would allow these areas to be affordable enough to reverse suburbanization trends and, in consequence, substantially reduce travel requirements and auto use in urban areas.

Conclusions

Policy makers wishing to make significant changes in urban areas and their transportation systems+. g., increasing urban density and degree of centralization, and increasing the role of mass transit—are faced with substantial uncertainty about the effectiveness of various policy options. In particular, there remains substantial controversy about the role government policy can play in shaping urban structure and transportation, and about how the patterns of urban development and urban transportation systems interact with and help shape each other. This uncertainty means that policy makers will have to accept substantial risk that the results of expensive and politically difficult policies will be less than they hoped for. The available evidence does strongly imply, however, that attempts to achieve large changes in urban transportation are unlikely to be successful without policies that integrate transport changes—for example, development of new mass transit systems—with conscious efforts to direct development into patterns that will support the changes. Thus, new rail transit systems are unlikely by themselves to transform urban areas or even to make large inroads in private vehicle use. On the other hand. a strategy that combined new transit systems with strong development controls and incentives, and changes in the travel incentives that currently favor private vehicles (parking restrictions. removal of free parking incentives, congestion charges, and so forth) represents a far more credible potential for success. However, many of the necessary policy changes will be politically controversial, and the trends in urban development and travel they seek to change are long-established and accepted in this country, and indeed are beginning to take hold, albeit in modified form. in Western Europe and elsewhere. This de-

[206] Pucher, op. cit., footnote 112.

[207] Ibid.

[208] Bourne, op. cit., footnote 162.

gree of controversy, coupled with the uncertainty about the results of the policies, will mean that elected officials may have a difficult time winning political approval for such strategies.

INTERCITY TRAVEL AND HIGH-SPEED GROUND TRANSPORTATION SYSTEMS

Although the great majority of passenger trips are local, the greater length of intercity trips means that a much larger percentage of passenger miles traveled are intercity. According to data from the 1990 National Personal Transportation Survey, only 1.2 percent of all personal trips in private vehicles are at least 75 miles in length, but these trips represent 26 percent of all *person-miles* of personal travel. Similarly, only 1.2 percent of all personal trips using *all* modes of transport are at least 75 miles in length, but these longer trips represent nearly 28 percent of all travel.

The automobile is the dominant intercity travel mode in the United States, with commercial aviation also having a strong share. The automobile's primary advantages are low cost, especially for group travel, door-to-door service, and convenience—it provides continuing transportation service after arrival. For trips less than 100 miles, the automobile is generally faster than other modes, since there is no need to reach a station or to wait for a ride. For longer trips, air travel may offer a significant time advantage and accounted for about 17 percent of intercity passenger miles in 1989;[209] it undoubtedly captured a much higher percentage of passenger-miles for trips greater than 100 or 150 miles. Bus and rail play minor roles nationally—in 1989, 1.2 and 0.6 percent, respectively[210]—but rail service is significant in some Northeast and California markets.

As discussed in chapter 2, intercity travel is expected to continue to grow strongly well into the next century. It is not clear, however, how well the road and air networks will accommodate increased travel. For example, during the past decade, road congestion has grown significantly in major metropolitan areas, especial 1 y Los Angeles, Washington, DC, San Francisco, and San Diego, and urban congestion is widely expected to increase substantially during the coming decades. Unfortunately, data on *intercity* highway travel are crude, and travel patterns and congestion severity frequency are uncertain, making projections of future congestion problems quite difficult.

Similar problems exist with forecasts of air traffic congest ion. The Federal Aviation Administration indicates that the average delay time per flight increased by one-third during 1980-88, and it projects that the number of congested airports (those experiencing annual flight delays of at least 20,000 hours) will nearly double, to 41, by 1998.[211] However, these forecasts are based on rather poor data and the assumption that airlines will continue to funnel passengers into saturated airports. Much airport congestion is due to airline routing strategies rather than to an outright shortage of facilities. For example, at Chicago O'Hare, Dallas-Fort Worth, Atlanta, and Denver, the critical congestion trouble spots, most passengers are making connections rather than arriving at their final destinations. If the airlines using these airports as their hubs were to change their operating practices, they could substantially lower congestion levels.[212]

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[209] Motor Vehicle Manufacturers Association (now American Automobile Manufacturers Association), *Facts & Figures '91* (Detroit, MI 1991), p. 55.

[210] Ibid.

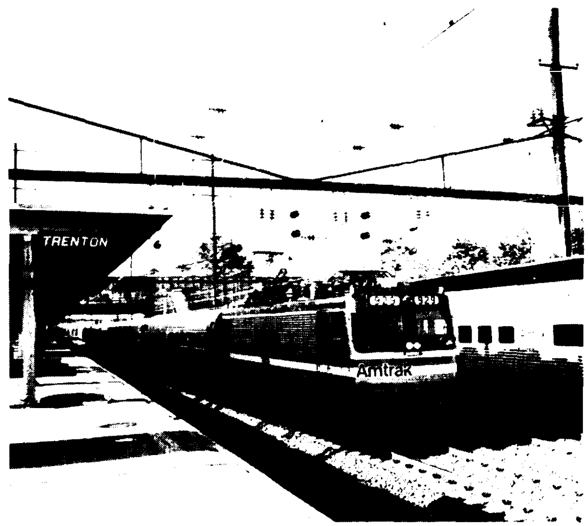
[211] U.S. Department of Transportation, Federal Aviation Administration data, reported in U.S. Congress, Office of Technology Assessment, *New Ways: Tiltrotor Aircraft and Magnetically Levitated Vehicles*, OTA-SET-507 (Washington, DC: U.S. Government Printing Office, October 1991).

[212] Ibid.

Despite these uncertainties, it is likely that both auto and air travel will experience significant increases in congestion over the coming decades. These potential problems may offer an opportunity to shift travelers to more energy-efficient modes in the denser and more congested intercity corridors. This is the thesis behind current attempts to promote HSGT (high-speed ground transportation) systems in several markets—Miami-Orlando-Tampa, Cleveland-Columbus. San Diego-Los Angeles-San Francisco-Sacramento-Reno-Las Vegas, Atlanta-Columbus/Macon-Savannah, the Northeast Corridor (Boston-New York City-Washington, DC), and others. These systems are either high-speed steel-wheel-on-steel-rail trains capable of speeds well in excess of 100 mph (the French TGV—Train a Grand Vitesse--can go about 185 mph, and speeds of 200 mph or more are anticipated soon) or magnetically y levitated (maglev) trains capable of even higher speeds (the fastest systems are expected to be able to achieve more than 300 mph). Ideally, such systems would be linked to major airports and would serve trips primarily in the 150- to 500-mile range, freeing airport capacity for longer-range trips where the superior speed of air travel is critical. These systems are described in more detail in box 5-5.

The potential of high-speed ground transportation systems for intercity trips less than 500 miles long has been studied by the Transportation Research Board[213] (TRB) and by OTA.[214] The results of the studies are quite similar.

Both OTA and TRB found that high-speed ground transportation systems were technically feasible but expensive: there are very few intercity corridors in which an HSGT system is likely to pay for itself. so government subsidies would be necessary. TRB also concluded that "considerable development and testing remain before maglev systems can be shown to operate safely and reliably in revenue service,"[215] whereas high-speed rail systems are available today. TRB found that new HSGT systems would require ridership levels between 2 million and 17 million per year to cover their capital and operating costs, with the range associated with differences in capital costs, operating costs, and fare levels.[216] The "most likely" break-even passenger volume for a HSR system was estimated at 6 million riders annually. At present. only one city pair in the United States—Los Angeles-San Francisco--has air ridership greater than this. By 2010, only four city pairs are expected to exceed this mark—Los Angeles-San Francisco. Boston-New' York, Washington, DC-New York, and Los Angeles-Phoenix.



NATIONAL RAILROAD PASSENGER CORP

Amtraks Metroliner is the fastest train in North America, reaching 125 mph. Proposals for new U S high speed rail systems envision much higher speeds to 200 mph or even higher

[213]Transportation Research Board, *In Pursuit of Speed: New Options for Intercity Passenger Transport*, Special Report 233 (Washington, DC: National Research Council, 1991).

[214]Office of Technology Assessment, op. cit., footnote 211.

[215]Transportation Research Board, op. cit., footnote 213, Executive Summary.

[216]Capital costs will vary with rights-of-way costs, type of system and requirements for precision alignment, geological-topological conditions of the rights-of-way, and other factors. Operating costs will depend on speed, frequency of service, train size, and so forth. Fare levels will depend heavily on competition for ridership, especially with airlines.

BOX 5-5: High-Speed Ground Transportation Systems

The two primary candidates for high-speed ground transportation (HSGT) systems in the United States are steel-wheel-on-steel-rail trams and magnetically levitated ("maglev") systems The two systems are described below

High-speed rail (HSR) systems range from Improvements to conventional rail systems producing speeds of up to 125 mph to new train technologies operating on exclusive, grade-separated tracks that can achieve speeds close to 190 mph in actual passenger service and have achieved speeds greater than 300 mph in prototype testing Improvements to *conventional systems* include eliminating grade crossings, switching from diesel to electric motors, straightening curves and Improving track quality, improving overhead power transfer systems, introducing advanced trains that run on conventional track (e g , tilt trams with improved suspension/wheel tracking systems that allow high speeds on curves without compromising safety or discomfiting passengers), and improving signaling and train controlling systems *A//-new* HSR systems demand a new track and more radical technology to achieve speeds considerably higher than the 125-mph limit for upgraded conventional systems The current state of the art is represented by the latest Japanese Shinkansen ("bullet tram"), at about 170-mph top speed, and the French Train a Grande Vitesse (TGV), at about 185 mph.[1] These systems have completely grade-separated, very high-quality track dedicated to high-speed service, with rights-of-way that have mlnlmal curvature and grades Propulsion systems are electric, cars are lightweight and aerodynamic, and signaling, communications, and train control systems are automated and very precise Although a version of the TGV has achieved more than 300 mph, the costs of speed in terms of energy use, costs, and, potentially, safety are extremely high, and many consider 200 to 220 mph a more likely goal for sustained service

Maglev systems are trains that operate suspended in air on fixed, dedicated guideways, held up by magnetic forces and propelled by linear electric motors High-speed versions are considered capable of speeds of 300 mph or greater The two most advanced high-speed systems are quite different: a German system wraps around its guideway and uses ordinary electromagnets onboard to lift the lower portion of the vehicle up toward the guideway by attraction, and a Japanese system uses onboard

(continued)

[1] Transportation Research Board, *In Pursuit of Speed New Opt/ens for Intercity Passenger Transport* Special Report 233 (Washington, DC National Research Council, 1991)

For most proposed corridors, HSGT breaks even only if costs are low compared with typical estimates, fares high compared with current air fares, and ridership at least as great as current air travel volume—all of which is unlikely.

Although maglev systems may well have lower operating costs than HSR systems (see below), capital costs are the primary components of high-speed systems, and maglev capital costs maybe as much as twice as high (per seat-mile) as high-speed rail systems. OTA found that infrastructure for a high-speed rail system in the Northeast Corridor based on the French TGV system would cost about 9 cents per seat-mile versus about 18 cents per seat-mile for a maglev system based on the German Transrapid.[217]

[217] Office of Technology Assessment, op. cit., footnote 211, table 5-2. Assumes 20-year amortization, 6-percent interest, 3.4 billion seat-miles per year.

BOX 5-5: High-Speed Ground Transportation Systems (cont'd.)

superconducting magnets to repel the vehicle upward from the guideway The German system maintains a very small (3/8 inch) gap, which requires a very precisely built guideway and a sophisticated control system to maintain the correct gap width;[2] the Japanese system maintains a much larger (4 inch) gap and can use a guideway built to less stringent standards The Japanese system must use wheels at speeds less than 60 mph because it cannot maintain the gap below these speeds

The high speeds of maglev systems demand minimum curves and very gradual grade changes, complicating the assembly of a suitable right of way

There are no commercial high-speed maglev systems in operation The most advanced system is the German one, which has been in testing since 1989 and has reached speeds of 270 mph However, low-speed maglevs are in commercial service in Berlin, Germany and Birmingham, England

HSR and maglev systems will compete in basically the same markets and in many ways are quite similar Although maglev systems probably will be faster than HSR systems, for the faster HSRs and for most trips, the speed differential should not make much difference in total travel time Both systems will require dedicated rights-of-way with few curves both will be electrically propelled, and both will require sophisticated control systems Maglev systems may require less maintenance than HSRs because there are no moving parts, and no physical contact occurs between vehicle and guideway A potentially critical advantage of HSRs is their ability to operate on existing track, giving them easy access to urban centers Conceivably, the Japanese system might gain similar access if the wheels required for less than 60-mph travel were designed to be compatible with existing track This would however create some challenging engineering problems (e g protection of the guideway induction coits from stresses exerted by ordinary rail traffic)

[2] A system based on attraction as is the German train is inherently unstable, because the force attracting the train to the guideway gels stronger as the train gels closer to the guideway This creates the need for the sophisticated control system

SOURCE Transportation Research Board *In Pursuit of Speed New Options for Intercity Passenger Transport* Special Report 233 (Washington DC National Research Council, 1991)

Why have high-speed rail systems been so successful in Europe and Japan but not appeared in the United States? Although proponents of these systems argue that the only reason is the failure of U.S. transportation policy to promote them, the actual reasons are more complicated (though it is true that the U.S. government has not made much of an institutional commitment to rail service). In particular, intercity corridors in the United States generally are less densely populated, with cities farther apart, than in Europe and Japan; therefore the potential ridership market in the United States is considerably smaller than in these regions. Further, both the European and the Japanese systems were built to add capacity to preexisting heavily traveled rail links, so they had a built-in baseline market. In contrast, a United States system would have to claim a huge percentage of the airlines' current market in 150- to 500-mile trips to have any chance at all of succeeding.

European HSR systems have other advantages. In particular, European and Japanese high-speed rail networks connect to well-established networks of intracity trains, enabling them to capture passengers who might be more likely to drive if (as in the United States) they needed an automobile once their destination was reached. Also, competition from autos and airlines is far less in Europe and Japan, because governments there have made a conscious policy decision to keep fuel prices very high and to limit air flights and keep air fares high,

The close spacing of European cities will provide into an even stronger advantage over the United States in the future. Completion of proposed European HSGT routes will yield a unified network, offering enormous options to train travelers throughout Europe; completion of proposed U.S. routes will connect, at most, only a few cities in any one network.[218]

Although U.S. HSGT systems maybe unlikely to break even financially, many would argue that this is scarcely a sufficient reason for ruling them out. As discussed in chapter 4, the competing highway system enjoys considerable subsidies and generates external costs (air pollution, energy security impacts of oil imports) that HSGT systems may be able to avoid. Also, although the costs of expanding highway or air networks may be quite high, their users generally pay average, not marginal, costs (except in the case of new toll roads). In contrast, a new HSGT system will rarely have any existing infrastructure with which to average costs, and its customers will face full marginal costs. For the highway and air networks, this represents a subsidy of new capacity by users of the current systems.

If governments chose to subsidize the capital costs of new HSGT systems—as is done with new urban transit projects—the financial prospects for these systems would appear attractive. Like urban rapid rail systems, the capital costs are the largest component of total costs. TRB estimated operating and maintenance (O&M) costs for an HSR and maglev system in a hypothetical corridor to be 9 cents per passenger-mile for either system; the range of estimated operating costs computed by various corridor studies is 8 to 26 cents per passenger-mile for HSR and 4 to 20 cents per passenger-mile for maglev.[219] Although all of these estimates are uncertain, if they are connect, HSGT systems with full capital subsidies would be competitive with air travel and even low-occupancy automobile travel. However, the principal competitor with an HSR or maglev system is likely to be air travel, which is essentially self-supporting; there will be substantial challenges to a complete capital subsidy for such a system.

SOCIAL COST PRICING POLICY

Key Issues

As discussed in chapter 4, motor vehicle users do not pay all the social costs of such use, nor do they fully account for the expenditures they do make in their travel decisions. In some instances, governments pay highway costs out of general funds (e.g., in the case of police and fire services) rather than from such user fees as gasoline taxes; in other instances, costs are hidden in the price of other goods (e.g., when "free" parking costs in shopping malls are hidden in the prices of the goods sold). Also, motor vehicle use creates nonmonetary costs that affect either other motorists on the road (uncompensated pain and suffering inflicted on others) or society as a whole (air pollution, global warming damages). Even when motorists pay their share as a class and account for the costs in their travel decisions, they may not be seeing the correct price (e.g., gasoline excise taxes may be meant to pay for highways, but tax charges per unit of travel bear only a modest relationship to the highway resources consumed by that travel).

The effect of motor vehicle user prices that are too low or are unaccounted for is an excess of travel; the added travel that occurs because of inadequate pricing costs society more to produce than it is worth. The effect of motorists' paying the wrong price, one that bears little relationship to costs, may be either too much or too little travel. In general, the greatest share of inefficiently priced highway expenditures identified in chapter 4 would tend to lead to excess travel, and most analyses of social costs conclude that more efficient

[218] S.J. Thompson, *High Speed Ground Transportation (HSGT): Prospects and Public Policy*, 89-221 E (Washington. DC: Congressional Research Service, Apr. 6, 1989).

[219] Transportation Research Board, op. cit., footnote 213.

pricing of motor vehicle use would lead to lower overall use and lower energy consumption. Therefore, the concept of "full social cost accounting" for motor vehicle use is general] y viewed as an energy conservation strategy. Another potential effect of incorrect prices is the neglect of alternative travel modes that may have higher net societal value than motor vehicles, e.g., rail transit. Such neglect cannot be established, however, without careful analysis of the full social costs of *all* travel modes. This is not attempted here.

Four critical issues associated with applying social cost accounting to motor vehicle use are those of marginal versus average costs, accuracy in measuring and valuing costs, incorporation of social benefits into the accounting scheme, and identifying appropriate mechanisms for capturing the previously unaccounted for (or inefficiently accounted for) costs.

Marginal Versus Average Costs

As noted in chapter 4, the social costs calculated in this report are the total costs of all motor vehicle travel, not the marginal costs. In other words, if the estimates are accurate, we would know how much could be saved if *all* motor-vehicle travel were eliminated. Unless every increment of additional travel costs the same amount, however, it cannot be assumed that reducing motor-vehicle travel by 10 percent will save 10 percent of the total costs, even in the long run. Actually, a 10-percent reduction in travel will likely save much more than 10 percent of the total congestion costs;[220] much less of the costs of ecosystem destruction by highway building, at least in the short run; more than 10 percent of travel-related air pollution damages; [221] and so forth. Also, the marginal cost savings of a travel reduction will depend critically on what types of travel are reduced; for example, reductions in urban commuting will have cost savings implications very different from those associated with reductions in recreational travel. In other words, these estimates cannot automatically be used to calculate the cost savings associated with a policy measure that promises to reduce travel by a certain amount. On the other hand, the estimates discussed in chapter 4, and others of this kind, represent a good first step in allowing policy makers to begin to correct inefficient pricing in the transportation sector. In at least some scenarios of relatively large changes in motor vehicle use, the average costs derived from these estimates should be a serviceable approximation of the actual marginal costs.

Accuracy

Accuracy in measuring and valuing costs is particularly problematic for external costs such as air pollution damages, global warming impacts, and so forth. The only remedy for reducing existing uncertainty about these costs is continued research and analysis, which will require time and resources. However. problems with accuracy may be of less importance than meets the eye unless policymakers wish to capture all unaccounted-for social costs immediately. Given the general U.S. reluctance to raise transportation prices, it seems clear that the "universe" of politically feasible policy measures does not go beyond gradual moves to capture some of these costs. If this is so. the critical short-term need is to get a strong sense of their lower limit and a reasonable sense of the *relative* magnitude of different cost categories.

Benefits

The need to incorporate social benefits into an accounting system is obvious: the analysis of costs presented in chapter 4 indicates that motor vehicle use costs considerably more than is generally realized (i.e., the total social cost exceeds by a substantial amount the commonly recognized private cost). This is not necessarily enough information to set policy, however. Even if the estimate of unaccounted-for costs is correct, it does not mean

[220] Because congestion costs remain zero until a threshold of [ravel is reached.

[221] Because health-related and other damages appear to have a threshold below which damage is minimal.

that motor vehicle use is underpriced to the extent implied by these costs. It is conceivable that there are large unaccounted-for *benefits*[222] in motor vehicle travel in which case the degree of underpricing is associated with the ***net*** of unaccounted-for costs and benefits. However, most analyses of the social costs of transportation assume implicitly or explicitly that the social benefits of transportation are equal to the sum of the private benefits. That is, they assume that there are no benefits of transportation that are not accounted for by the relevant decisionmakers. The FHWA, in a landmark study of highway cost allocation, stated that "the preponderance of expert opinion probably lies on the side of saying that there are no external benefits of highway consumption beyond the benefits to users."[223] However, this complex issue deserves further evaluation.

Policy Mechanisms

A final and critical issue is the selection of mechanisms for capturing the previously unaccounted-for (or inefficiently accounted for) costs. A key point is that *no* ***one measure*** can effectively incorporate all of these costs. For example, it is definitely ***not*** efficient to incorporate these costs into, say, the cost of gasoline and use a tax to capture them. In fact, as shown below, the most effective way to deal with some of these costs (e.g., parking costs in some shopping areas) is to ignore them or simply to educate travelers about them. On the other hand, it may be worthwhile to incorporate some costs into transportation services even when the match between costs and services is not strong; a weak linkage between the pattern of incurring costs and the pattern of paying for them may be better than leaving the costs entirely unpaid.

Policy prescriptions for social cost accounting

The goal of introducing social cost accounting into transportation policy is to find ways to price transportation so that a potential traveler accounts for the full marginal cost to society of transportation. The key word is *accounts;* if a user does not take a cost into account, it does not matter if the user pays it or if nonusers pay it; the nature of the inefficiency is the same, regardless of who pays. Consider the case of unpriced commercial parking, wherein the cost of parking is incorporated into the price of goods and services. Because drivers face no parking charge, they do not account for the cost of parking in their travel decisions. Hence, there is too much parking and, as a consequence, probably too many trips. Now, those who buy the goods and services pay for the parking whether or not they use it. It may turn out that those who pay for the parking indirectly are the ones who use it (this is usually the case at suburban malls, where virtually all shoppers drive and park at the mall, with the possible exception of teenagers dropped off by their parents). Yet even if the users pay, this does not eliminate the inefficiency—if the users do not face the cost and account for it, they will over consume parking.

Table 5-9 summarizes the causes of inefficient or unaccounted-for costs and prescriptions for dealing with them, based on the classification scheme introduced in table 4-1. Each class of cost has unique features and requires particular policy solutions.

Efficiently Priced But Often Overlooked Items

Several important costs of motor vehicle use are priced fairly in the market and are paid for by

[222] That is, benefits aside from private benefits such as access, reliability and flexibility of service, and carrying capacity, which are accounted for in travel decisions.

[223] U.S. Department of Transportation Federal Highway Administration, *Final Report on the Federal Highway Cost Allocation Study* (Washington, DC: 1982), p. E-9.

TABLE 5-9: Inefficiently Priced or Unpriced Items: Causes and Prescrip

Efficiently priced items	Public infrastructure and services (government subsidies)	"Hidden" private-sector costs	"Classical" externalities
Why some items are excluded from estimates of MV ownership and operating costs	Why there is not an efficient price	Why there is not an efficient, direct, or explicit price:	Why there is no price
They are more naturally classified as medical, legal, or homeowning expenses than as transportation expenses.	Possibly indivisibility in consumption (MC = O. e.g., defense) or decreasing long-run MC (e.g., highways); government is concerned with generating revenue, encouraging or discouraging behavior, distributing benefits, providing security and justice, and other factors besides economic efficiency.	Perceived economic benefits of free municipal parking; perceived high transaction costs (compared with benefits), institutional barriers, or tax disincentives, and presence of external benefits (parking, local roads); failure to make perpetrators liable for costs (accident costs); pecuniary effects of a price change are not seen in the sector that causes them (monopsony effects).	Impossible, too costly, or otherwise undesirable to assign and enforce property rights to the unpriced resources or effects.
What should be done economically	What should be done economically	What should be done economically.	What should be done economically.
Remind analysts and motor vehicle users that these are costs of MV use.	Long-run MC pricing, where possible (highway users charged optimal congestion tolls for highways; registration and license fees set at marginal administration costs; fines set so that marginal revenues equal marginal enforcement costs; parking prices at marginal cost, etc.); otherwise, allocate costs based on some measure of use; for public goods, aim for a level of output at which the marginal value summed over all consumers equals the marginal cost of supplying the quantity.	If there are no external benefits to pricing and no distorting taxes, and if transaction costs cannot be lowered and private assessments are not wrong, then do nothing (parking, unpriced roads); remove institutional barriers to private ownership and operation of roads; make those who cause accidents pay (but no direct compensation from perpetrators to victims); adjust cost accounting to attribute monopsony costs to causing sector.	Establish property rights if possible and if transaction costs do not outweigh benefits; otherwise, if few parties are involved, use collective bargaining; otherwise, set a Pigouvian tax dynamically equal to marginal external costs (i.e., damage costs not otherwise accounted for) and do not compensate victims.

KEY: MC marginal cost; MV motor vehicle

SOURCE: M. DeLuchi, University of California-Davis users, yet may not be accounted for in travel decisions. The more prominent are monetary accident costs not paid by insurance (generally lost productivity and some types of medical, legal, and property costs) and the costs of garages and driveways. These costs are definitely costs of motor vehicle use and generally efficiently priced, but they tend not to be considered when individuals account for their costs of travel. For example, in most jurisdictions there are sufficient housing choices that homebuyers can purchase the amount of garage space they desire[224] (or if they want, they often can convert garage to living space or add garage space), so it is likely that garages are reasonably efficiently priced. Thus, most people probably recognize an implicit cost of garages, e.g., they know their house cost $10,000 more (less) because of the presence (absence) of a two-car garage. Similarly, people will face squarely the uncompensated costs of accidents they cause. Yet, many people do not make either short- or long-term travel choices based on these costs.

No clear solution is apparent for the problem of overlooked internal costs, except education—continually reminding people of the risks they bear and the investment decisions they have made in response to their travel choices. It makes no sense to tax garages, because the problem here is not price at all, but accounting for a correct price.

Public Infrastructure and Services

Two separate factors create efficiency problems in paying for public infrastructure and services: government subsidies and inefficient pricing. According to the analyses discussed in chapter 4, in 1990, motor vehicle users paid for only 62 to 72 percent of public expenditures for highway infrastructure and services (53 to 68 percent if military expenditures are counted as motor vehicle service costs), with governments at all levels paying the rest. Further, much of the private payments are collected at rates that are poorly related to the costs incurred.

Correcting the problem of government subsidization of motor vehicle use is relatively straightforward, at least at a general conceptual level: it necessitates shifting expenditures from general revenues to some form of user fees. Establishing an appropriate form for the user fees is *not* straightforward, however. Most of the established pricing mechanisms were never meant to maximize economic efficiency because governments tend to be far more interested in other values: generating revenue; ease of collection: political feasibility, including values such as simplicity and attractive distribution of cost burden; and so forth. Unless there is widespread consensus that economic efficiency is a critical goal of transportation pricing, there will be little support for measures that correct inefficient pricing mechanisms. Further, some important costs of motor vehicle travel—the cost of protecting vulnerable oil supplies, for example—probably cannot find an efficient pricing mechanism, because small-to-moderate changes in travel demand are unlikely to affect defense expenditures at all; defense costs either are not divisible or will change only in large steps, with significant changes in gasoline consumption. Also, there is no agreement about the magnitude of these costs.

Some interest groups would like to increase taxes on gasoline to cover the subsidized costs of public infrastructure and services (as well as other items). If the total revenues collected by gasoline taxes were equal to the magnitude of the subsidized infrastructure and services, equity among transportation alternatives would be served, but not economic efficiency.[225] For example, the current Federal excise tax on gasoline is designed to raise revenue to build new Federal highways, but the costs incurred for these highways depend primarily on the capacity required during peak hours

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[224] In some jurisdictions, it is virtually impossible to purchase houses without two-car garages, but this is not the norm.

[225] Economic efficiency is a concept of how effectively the economy transforms available resources to outputs desired by members of the economy. Economic efficiency is served by prices that reflect the true marginal costs to society of the goods and services purchased.

and the types of vehicles that must be served (with heavy trucks requiring far more expensive roadways than light-duty vehicles) and secondarily on vehicle-miles traveled. The revenues collected from the excise tax do not correspond well to highway costs; they are proportional to gasoline use, which depends only mildly on miles of travel (because of the very wide range of fuel economies among road vehicles) and hardly at all on peak hour travel. Similarly, gasoline tax revenues do not track well with highway service costs such as law enforcement, which depend more on vehicle-miles traveled, level of congestion, and mix of trucks and autos than on gasoline use. Consequently, raising the price of gasoline to cover currently subsidized infrastructure and services may improve economic efficiency somewhat, by eliminating the subsidies, but it leaves much to be desired on other grounds. However, gasoline taxes remain attractive because they are extraordinarily easy to collect (the mechanism is already in place) and they are at least moderately tied to road usage.

Economic efficiency will be best served by pricing travel at the long-run marginal costs of public goods and services provided. For example, the costs of expanding highways to combat congestion might best be paid for by charging congestion tolls using electronic sensors; this should minimize transaction costs (collecting tolls mechanically exacts very high public and private costs) and focus payments on that travel most responsible for creating the costs. Congestion pricing is discussed in more detail below.

Much work remains to be done in both *defining* the marginal costs of various government services and devising pricing mechanisms that track these costs. The relative infancy of policy research on these subjects may explain the attraction of using a gasoline tax as the collection mechanism for public highway costs.

"Hidden" Private-Sector Costs

Private-sector costs that are inefficiently priced include: parking, which is usually provided free to users; local roads provided by developers and included in home prices; and monetary costs of accidents to those not responsible and not covered either by insurance or by those responsible.

Parking

Nobody forces businesses to provide free parking, and there is in fact a theoretical benefit to charging separately for parking: it would lower the price of goods and increase consumption, as well as increasing the efficiency of travel. That businesses do not charge for parking is likely due to their perception that the cost of setting up and administering a pricing system exceeds the benefits to themselves, especially if the "costs" of customer annoyance and inconvenience are thrown in. The striking preponderance of free commercial parking is evidence that this is in fact the case.

There are benefits to both businesses and consumers from charging separately for parking, but businesses count only the benefits to themselves in their decisions. Therefore there is an unaccounted-for external benefit to pricing parking. To account for this external benefit, governments could subsidize the cost of establishing a paid parking system, with the subsidy set at the marginal external benefit (not at the amount required to induce producers to price parking). With such a subsidy, businesses would institute priced parking only where the private plus external benefits exceeded the costs. Also, future widespread institution of electronic billing for other services (e. g.. for paying congestion charges or bridge tolls) would likely help achieve priced parking at low transaction costs and eliminate one of the roadblocks to unbundling parking costs from the costs of goods and services.

The provision of free parking to employees stems from a different cause than free commercial parking: the U.S. tax system counts free parking as a nontaxable employee benefit and a tax-deductible expense for employers, providing a clear incentive for businesses to substitute free employee parking for its equivalent in employee income. There are at least two ways to correct this: tax the value of free parking as income and disallow parking costs as a business deduction, or else simply force employers to offer cash in lieu of parking. California has chosen the latter approach, as discussed later.

Local roads

There may be little reason to try to "correct" the inefficiency caused by embedding some local road costs in the prices of homes. The marginal cost of an additional car or vehicle-mile on a local road is very small, because these roads are rarely congested, which implies that there is no efficient short-run price to charge users. Further, it seems unlikely that any pricing arrangement to charge for the use of local roads would be worth more than it cost. Simply leaving the cost of the roads embedded in the price of the houses served by the roads may be as good an arrangement as any.

Uncompensated accidents

The appropriate solution for uncompensated accident costs is to make those who cause accidents pay. Of course, this is easier said than done; the justice system already tries to do this, and the existence of these uncompensated costs is due less to a lack of trying than to flaws in the system that cannot be corrected easily.

A corollary to this solution is that according to economic theory, victims should not receive direct compensation from those responsible but instead should pay for insurance against the risk of accidents. This follows from the economic reasoning that a potential victim who expected to be compensated fully for any injury would not take injury risk into account when making a travel decision; paying insurance is one way of accounting for the risk.

Externalities

From the standpoint of economic efficiency, the appropriate hierarchy of treatment for externalities (nonmonetary damages that motor vehicle users impose on others without accounting for themselves) is first, if possible, to assign true property rights to the resources that are damaged by externalities (e.g., breathable air and clean water); next, if this is not possible, to try collective bargaining among the parties affected; and finally, to enact taxes that raise costs to account for the marginal external costs (but without compensating victims).

The assigning of property rights to resources such as clean air and water, if it were possible, would allow a market in these resources to be created. Polluters would have to buy the rights to use up the resources from individual sellers, in the same way that industries in some areas must buy water rights from farmers if they wish to divert water from a local river. Theoretically, individuals would measure the risks to themselves of giving up a clean air or clean water resource, and decide whether or not to accept a particular monetary offer.

Assignment of individual property rights might be possible in rural areas where the number of parties is small, but under most circumstances it would be extremely difficult to implement, especially attempting to keep track of damages to each individual allotment of clean air, clean water, or other "property." A more likely solution in most areas is collective bargaining: a would-be polluter would negotiate with a town council or citizen group about the extent to which it would accept degradation of group property rights (in clean water, in the absence of noise, etc.) in exchange for a payment. Although this is more practical than a system of individual rights, it also allows some individuals to bear costs much larger than the payment they receive (e.g., individuals with asthma would value clean air far more than the average resident and would lose more if pollution were allowed).

The third option is to collect a tax that raises the price paid by the persons creating the externalities to the marginal cost to society,[226] without compensating victims. One example of such a tax

[226] A tax that would accomplish this is called a "Pigouvian tax.

would be an air emissions tax that exactly compensated for the damage the emissions would cause. With such a tax, polluters would seek to control emissions up to the point at which the cost of controlling the next bit of pollution was higher than the cost of the tax for that pollution; this would be the economically optimal level of pollution.

The idea of not compensating victims seems abhorrent at first glance, because they are innocent parties. The reason for avoiding compensation is that assurance of compensation theoretically would cause potential victims to fail to avoid dangerous situations and to engage in riskier behavior than they would otherwise consider (because all of the risk is borne by others). For example, even though the risk of accidents caused by others might add $10 per trip to society's cost of travel, travelers would ignore this cost if they knew they would automatically be fully compensated. If the traveler (potential victims) has to bear the "accident risk cost," that cost would presumably be considered in travel decisions, and trips would be taken only when the benefits of the travel outweigh the full societal cost-which is socially optimum.

The clash between the above viewpoint and that generally held by social norms is the clash between strict economic efficiency and a wider view of social justice. This clash might be lessened by a more lenient view about the rule of avoiding victim compensation: that it apply only to direct participants in motor vehicle travel (e.g., other drivers and passengers), and not to victims outside the system (e. g., pedestrians).

The values for externalities estimated in chapter 4 may serve as the starting point for constructing Pigouvian taxes,[227] with the following caveats:

1. The values are preliminary and controversial, and will change as environmental restrictions change. For example, new emission regulations for automobiles should gradually reduce the level of air quality external costs, as cleaner automobiles infiltrate the fleet.
2. As pointed out in chapter 4, inclusion of externalities into travel costs should lead to more optimal levels of travel, but failure to apply external costing systems to other sectors of the economy may sabotage this. All sectors of the U.S. economy, and all economic activities competing with transportation, generate external costs; "internalizing" these costs only in the transportation sector risks overpricing transportation in relation to competing activities. The only justification for introducing Pigouvian taxes solely into the transportation sector would be if transportation generated external costs that are so much higher than those in competing sectors that ignoring the latter would not greatly affect activity levels. This may well be the case, but OTA is aware of no analytical demonstration of such a conclusion.
3. Instituting taxes on externalities should not be a question simply of computing the total external costs of motor vehicle travel and calculating a simple tax, such as a tax on gasoline and diesel fuels, that will produce revenues equal to these costs. To have travelers incorporate into their decisions the full marginal costs of their travel to society, taxes must closely track the generation of actual costs. For example, damage to roadways depends on miles traveled, type of vehicle, and type of roadway; a tax on fuels to compensate for road damage would not closely track this damage and therefore would not exert a strong influence on travelers to take actions that would minimize such damage. **The construction of a set of taxes to" internalize" the external costs of motor vehicle travel is a major analytical undertaking that goes well beyond calculating the magnitude of external costs.**

[227] Pigouvian taxes have tax rates that just equal the marginal external costs; at this tax rate, economic efficiency is maximized.

GASOLINE TAXES[228]

This section examines the desirability of gasoline or fuel use taxes in terms of their impacts on the macroeconomy and on economic efficiency. Little attention is given to issues of distributional equity among geographic regions or income classes, since other tax and expenditure policies can more than compensate for any broad distributional impacts of gasoline taxes. Estimates of the short-run and long-run economic consequences of gasoline taxes depend on how the tax revenues are spent (or which taxes they are used to offset), the magnitude of externalities, related macroeconomic policies, and the variability of externalities from vehicle to vehicle, at different locations, and over time. One must examine each of these issues to analyze the economic impacts of increased gasoline taxes.

Impacts on unemployment and gross national product (GNP) must be central to the assessment of short-run economic impacts of a gasoline tax. Although the overall economy would be damaged by *any* tax increase in the first few years after the tax is imposed, these impacts are temporary and will disappear as the economy adjusts to the new tax regime.

The magnitude of driving-related externalities and unpriced inputs must be central to an evaluation of the long-run economic consequences of motor fuel taxes. Taxes can change the overall efficiency of the economy. The direction of this change depends on the magnitude of these externalities and unpriced inputs relative to the magnitude of the tax. And these impacts are long-term, or permanent, in nature.

In addition, even with externalities, one must examine the degree to which the instrument—gasoline taxes—is matched to the problem being addressed-externalities associated with driving. Gasoline taxes are matched well with some. but poorly with most, of the externalities associated with driving. Thus to address most of the very real externalities, gasoline taxation is not the appropriate instrument.

Impacts on Economic Variables

In addition to providing a source of Federal revenue, increasing gasoline taxes would impact the overall economy. Some impacts would show up in standard statistics published by the Federal Government, such as the national income and product accounts, whereas others will not be directly measurable based on standard statistics.

In the first few years after a gasoline tax increase, in fact, after any large tax increase, overall economic performance would decline relative to performance expected absent the increase. One central measure of overall performance is the monetary value of the total output of the economy. GNP would be reduced for several years by an amount comparable to the total additional gasoline tax revenue. During that period, unemployment and inflation would increase.

There are several pathways by which gasoline taxes influence GNP. Increases in gasoline tax directly reduce the demand for gasoline and for new cars. In addition, the gasoline tax reduces aftertax income for most people. With less income, demands for goods and services decline. This reduction in aftertax income reduces demand for new cars, gasoline, and other goods and services. These two direct effects together reduce the overall demand for goods and services in the U.S. economy. Automobile manufacturers, oil refiners, and other companies react to declines in demand by reducing production of goods and services. This reduction in output throughout the economy would translate directly into a GNP reduction.

The reduction in output also implies that U.S. companies will need fewer workers: the demand for labor will be reduced. As people are laid off and others are simply not hired, unemployment increases. The reduction in employment implies

[228] Based on J.L. Sweeney, Stanford University, "Gasoline Taxes: An Economic Assessment," contractor report prepared for the Office of Technology Assessment, Sept. 20, 1993.

that incomes decline. Again, income reductions reduce the demand for most goods and services in the economy, which leads to even more reductions in output, further reductions in GNP, and so forth. This so-called multiplier effect thus amplifies the initial direct impacts of the gasoline tax on GNP.

A similar effect operates through corporate profits. Reductions in demand for various goods and services and associated reductions in their outputs lead to reduced corporate profits. But corporations are owned collectively by people. Thus reduced corporate profits imply reduced total aftertax income, which in turn implies reduced demand for goods and services produced in the U.S. economy and leads to further reductions in labor demand, labor incomes, and corporate profits. This "feedback loop" further amplifies the GNP reduction caused by a gasoline tax increase.

Gasoline taxes also have a direct impact on inflation, since they directly increase gas prices. Businesses whose vehicles use gasoline will find their costs increasing, and there will be pressure to increase the prices of their outputs. The net result of these price increases is increased inflation.

While the overall economy would be damaged by a gasoline tax increase taken alone, it is not meaningful to estimate short-term macroeconomic impacts of a fuel tax increase without examining impacts of the linked changes by the government and by the Federal Reserve System. Short-run macroeconomic impacts will depend on: 1) whether motor fuel tax revenues are linked to reduction of other taxes, and which other taxes; 2) whether tax revenues are linked to additional expenditure programs, and which expenditure programs: 3) whether revenues are linked to deficit reduction; and 4) the degree to which the Federal Reserve System accommodates the tax changes with monetary policy. Thus a gasoline tax increase that reduces the deficit will have a very different impact than one that allows more government spending. This in turn will have a different impact than a gasoline tax whose revenues allow a reduction in other taxes.

If motor fuel tax revenues were linked to a reduction of other taxes, then the short-run impacts of reducing these other taxes must be added to the impacts of raising gasoline taxes. Economic modeling suggests that changes in personal income taxes will normally impact the economy less than changes in corporate taxes, and that changes in general corporate taxes will impact less than changes associated with investment, such as investment tax credits. For example, the models predict that if a gasoline tax were coupled with an equal-revenue increase in investment tax credits, short-run macroeconomic losses resulting from the motor fuel tax increases would be more than offset by the short-run macroeconomic gains resulting from the investment tax credit increase. In other words, there would likely be short-run macroeconomic gains from the package of tax changes.

Monetary policy can have important impacts on GNP, employment, and inflation. Monetary policy changes may be directly coupled to changes in taxes and spending. In particular, in response to a gasoline tax increase that would increase unemployment, the Federal Reserve Bank may use accommodating monetary policy to reduce the unemployment impact, although at the expense of more inflation. With such accommodating monetary policy, the short-run impacts of a gasoline tax on GNP can be greatly reduced or even eliminated, while the short-run inflationary impacts would be amplified.

A gasoline tax, not coupled with any other tax change, would increase revenues by about $10 billion for every 1O-cent increase in the per-gallon tax rate, or about $1 billion for every 1-cent increase. But with the short-run increase in unemployment and the reduction in GNP, Federal expenditures for unemployment compensation and other "safety net" programs will increase and tax collections will decrease. Thus in the short run, the actual Federal deficit will be reduced by far less than the $10-billion increase in tax revenues. In the longer run, the reduction in the Federal defic it will be roughly equal to the increase in gasoline tax revenues, since the unemployment impacts will disappear over time.

A gasoline tax would reduce gasoline consumption through reductions in total miles driven and possibly through increased sales of fuel-efficient vehicles. Unless the reduced consumption is large enough to affect world oil prices, there would be virtually no impact on the production of oil in the United States, and thus almost all of the reduced consumption would be from imports.

A tax-encouraged increase in gasoline price of 10 percent would reduce vehicle-miles between 1 and 2.5 percent from the "no tax increase" gr owth path.[229] The fuel efficiency of old cars would be virtually unaffected. Under the current CAFE standards, for small tax increases there probably would be no increase in average fuel efficiency of new cars, while large enough price increases would increase average fuel efficiency.[230]

The reduction in total miles driven would imply a reduction in the environmental damages associated with driving, although emissions per mile of travel would not change substantially. Traffic accidents would decrease by a small amount. Congestion on highways could decline, very slightly, since driving during congested times would decline far less than total driving.

A second measure of the effect on the economy, one applicable particularly to the longer run, is economic efficiency. Economic efficiency is a theoretical concept of "goodness" of resource allocation, a concept designed to indicate how effective the economy is in transforming available resources to outputs desired by its members. Changes in economic efficiency include all changes that influence how well off individuals are, including their attitudes about environmental impacts and the value they place on time spent for leisure and other activities within the home. In practice, economic efficiency cannot be measured directly and one can only discuss changes in economic efficiency or economic efficiency losses associated with some policy or arrangement.

If there were no externalities or unpriced economic inputs associated with driving, and no other taxes in the economy, competitive markets would lead to the economically efficient use of gasoline. In that case, increases in gasoline taxes, taken alone, would always reduce economic efficiency.

On the other hand, with externalities or unpriced economic inputs associated with driving, competitive markets would lead to an underpricing of driving costs and thus to more driving and more gasoline use than would be economical] y efficient. In this case, absent distortionary income taxes or other taxes, a gasoline tax equal to the marginal value of the unpriced inputs plus the externalities would bring competitive markets back to economic efficiency by correcting the underpricing problem. Thus if the existing motor fuel tax were initially lower than the marginal externalities (measured on a basis of external costs per gallon of gasoline used) plus the marginal value of unpriced inputs, an increase in the tax could reduce economic efficiency losses. If the existing motor fuel tax were initially higher than the marginal externalities plus marginal value of unpriced inputs, then a decrease in the tax could reduce economic efficiency losses.

However, there are, in fact, income taxes and other distortionary taxes in the economy. A gasoline tax increase would raise revenue, revenue that could allow government to reduce other distortionary taxes, increase expenditures, reduce the fiscal deficit, or take some combination of these actions. Thus in assessing actual motor fuel taxes, one cannot escape assessing the effects of whatever other actions are linked to those tax revenues.

If fuel use taxes are coupled with reductions in the "typical" bundle of preexisting taxes, then economic efficiency would still increase as the gasoline tax increases, up to the level at which the

[229] See C.A. Dahl, "Gasoline Demand Survey," *The Energy Journal*, vol. 7, No. 1, 1986, pp. 67-82.

[230] CAFE standards appear to be maintaining fleet fuel economy values at higher levels than current low gasoline prices would produce *if there were no standards*. Small gasoline price increases would be less likely to raise fuel economy levels than to allow automakers to relax their current efforts to boost market shares of small, fuel-efficient cars. See J.L. Sweeney, "Effects of Federal Policies on Gasoline Consumption," *Resources and Energy*, vol. 2, September 1979, pp. 3-26.

gasoline tax is equal to the value of the marginal externalities plus the value of unpriced inputs. Further gasoline price increases linked to the reduction of other taxes would reduce economic efficiency. Similarly, if imposition of fuel taxes were linked to Federal expenditure programs, economic efficiency would increase with gasoline tax increases (above the value of the marginal externality plus the value of unpriced inputs) if and only if the additional expenditures would be economically attractive when financed by an equally distortionary mix of taxes. However, once the gasoline tax rate is increased to equal the marginal cost of externality plus marginal value of unpriced inputs, any further tax increase would be less economically efficient than a broadly based tax that raised the same additional revenue.

In general, three key elements determine the impacts of additional gasoline taxes on economic efficiency: 1) the marginal value of externalities and unpriced inputs in motor fuel use; 2) linkages between revenues raised from motor fuel taxes and governmental expenditures, other tax reductions, or deficit reductions; and 3) the existing gasoline tax magnitude. One cannot examine the consequences of gasoline tax increases in terms of economic efficiency without examining each of these three issues.

Using Gasoline Taxes To Address Externalities

When externalities or unpriced inputs are associated with the use of motor fuel, taxes on motor fuel can motivate individual drivers to account for costs and thus increase economic efficiency. Gasoline taxes could be increased, and other distortionary taxes simultaneously decreased, so as to have minimal short-term macroeconomic losses. To strive for maximum economic efficiency, the gasoline tax rate should be made equal to the marginal value of externalities plus unpriced inputs, but to do so requires understanding of these externalities and inputs.

Unpriced Highway Services

Driving requires the use of roads and highways. In the absence of motor fuel taxes, the costs of roads and highways are typically not borne by the vehicle driver. Historically, Federal gasoline taxes have provided revenues for the Highway Trust Fund. On average, however, for trucks and cars taken together, current motor fuels taxes are lower than the unpriced costs of highway and roadway services: the current tax rates cover only part of the unpriced inputs associated with driving (see the discussion in chapter 4).

Unpriced highway services are only imperfectly linked to the fuel consumed in an automobile or truck; motor fuel taxes typically are proportional to fuel use. Although two different cars might require the same highway services per mile of driving, the old car with a fuel economy of 10 mpg faces three times the per-mile tax as the new car having a fuel efficiency of 30 mpg. The problem is even more severe when heavy trucks are compared with automobiles. Trucks probably cause the majority of highway damages yet pay the minority of fuel taxes.[231] Since average taxes cover only part of the costs, the driver of the heavy truck would be paying considerably less than costs. But automobile drivers may be paying more or less than costs, even though the average cost of all vehicles (cars and trucks) exceeds the current average tax revenues.

With this high variability across vehicles, additional Federal gasoline taxes are not particularly good instruments for addressing unpriced highway services.

Subsidized Parking

Federal tax code allows employers to provide free parking to employees as a tax-free benefit. These

[231] U.S. Congress, Congressional Budget Office, *Paying for Highways, Airways, and Waterways: How Can Users Be Charged?* (Washington, DC: May 1992).

parking services represent unpriced inputs for employees. Free parking encourages more people to drive alone to work than would otherwise be economically efficient.

The subsidy may be larger than the cost of gasoline needed to drive to work. But this subsidy, in terms of dollars per gallon of gasoline, is highly dependent on automobile efficiency, distance between a person's home and work, and current use of the vehicle (the subsidy is available only for trips to work and does not apply for other vehicle uses).

Although the subsidy may be large, this problem would be difficult to address with a gasoline tax, since the tax would apply to all vehicles in all uses, not simply to vehicles being driven to workplaces with subsidized parking. Other instruments (e.g., changes in the Federal tax code) are more appropriate for addressing this problem. Thus although current practice implies an unpriced input, a gasoline tax would be a poor instrument to address the problem.

Congestion

Highway congestion is an important and growing externality in urban and many suburban areas. Whenever roads are congested, more driving imposes costs on other drivers and passengers. But congestion is very time and location dependent. Thus this externality leads to too much driving during periods of congestion and too little driving during off-peak periods. Optimally more people should shift their driving times from the more congested periods to the less congested.

If a gasoline tax were used for addressing problems of congestion, the tax would be zero for fuel used in noncongested times or locations, but might be $10 per gallon or more for fuel to be used in congested times. However, the motor fuel marketer has no information about whether the fuel would be consumed during highly congested times, times of no congestion, or some combination of the two. A gasoline tax cannot track the congestion variability over time and location. Thus a gasoline tax is not a useful instrument to deal with time-varying or location-varying congestion.

Environmental Harm: Air Pollution and Carbon Dioxide Emissions

A large portion of urban air pollution derives from motor vehicle evaporative and tailpipe emissions. The cost of these externalities, per gram of emissions, depends heavily on the air basin dynamics and the affected population. The amount of emissions per mile driven depends on the age of the car as well as its maintenance history. And the amount of emissions per gallon of gasoline depends on both the auto vintage and its fuel efficiency. These three factors, taken together, imply that the variation in external costs, measured on a per-gallon-of-gasoline basis, varies radically among vehicle vintages and fuel efficiencies, as well as across locations. Therefore, although these externalities are important, a national gasoline tax is not an appropriate instrument for dealing with this problem. A regionally specific State gasoline tax could be more effectively matched to the particular air basins, but even such a vocationally specific tax would not be vehicle-specific.

A second environmental externality is carbon dioxide released into the atmosphere. Carbon dioxide, working through the greenhouse effect, is expected to lead to global climate change. Each gallon of gasoline consumed releases about the same amount of carbon dioxide, independent of automobile efficiency, and each ton of carbon dioxide has the same impact, no matter where it is emitted. Therefore impacts per gallon are the same across geographic area, time, and vehicle. Thus Federal fuel taxes could readily incorporate the costs of this externality, once the appropriate cost per additional kilogram of CO_2-equivalent emissions was determined. For this purpose, fuel use taxes, differentiated by particular fuel, would be very appropriate.

Energy Security

Increases in oil use increase expected economic losses from world energy market disruptions.

First, such increases reduce worldwide spare oil extraction capacity, at least temporarily. Decreases in spare capacity exacerbate price jumps during disruptions, if the spare capacity would have been located in nondisrupted regions. Second, oil use increases magnify economic losses stemming from a given magnitude oil price jump. Thus reduced economic security is an externality associated with additional gasoline use.

In addition, if world oil prices are increased in response to increased U.S. oil imports, that increased price would apply to all oil imported into the United States. Thus, there are "terms of trade" costs to the United States associated with increases in oil use.

Each of these externalities changes over time as the "tightness" in the world oil market changes, but the rate of change is often gradual (except during oil supply disruptions). When there is little spare oil production capacity, the externality is large, and conversely, in times of much worldwide spare capacity, the externality is small. Currently. with a large worldwide excess capacity and the reasonably large U.S. Strategic Petroleum Reserve, these externalities are small.

The magnitude of this externality is the same for each gallon of gasoline used, independent of location (in the United States) and the specific vehicle in Which it is consumed. Therefore, a time-varying national gasoline tax could be an appropriate instrument for dealing with this externality.

Automobile Accidents

A significant component of driving cost is the expected cost of automobile accidents. The more a person drives, the greater is the probability of an accident. Risk and mileage ratings in automobile insurance include only part of the marginal accident costs of additional driving. To the extent that the marginal accident costs of additional driving are not reflected in increased insurance rates, there is an accident-related externality.

This externality, expressed on a per-gallon-of-gasoline basis, differs widely by automobile and by individual driver. Since there is so much variability measured on a per-mile basis, and even greater variability in the externality measured on the basis of cost per gallon of gasoline, a gasoline tax is not an efficient instrument for dealing with this problem.

Alternative Fuel Technology "Chicken-and-Egg" Problem

Recently there have been efforts to promote "alternative fuel" vehicles, vehicles fueled by methanol, compressed natural gas (CNG), ethanol. or electricity. Behind policies to promote these technologies is the idea that the unaided market will not invest sufficient funds in the development of technologies that might underlie a fundamental transformation to alternative fuels, so individuals will buy fewer alternative fuel vehicles than would be economically efficient. Part of the argument is that alternative fuels face a chicken-and-egg problem: it is not economical for individuals to purchase alternative fuels absent sufficient refueling stations, and it is not economical for fuel dealers to open stations absent sufficient alternative fuel vehicles.[232] The argument is that a large change, involving many refueling stations and vehicles would be beneficial to the overall economy. but that market forces will not move the economy past the "hump," This problem creates a type of dynamic externality. in that the history of past investment and vehicle use tends to constrain future use.

Contrary to this argument is the observation that such chicken-and-egg situations can be overcome by individual firms and people willing to take risks based on their own beliefs or guesses about the future. Examples include the transition

[232] D. Sperling, *New Transportation Fuels: A Strategic Approach to Technological Change* (Berkeley, CA: University of California Press, 1988).

to compact discs in preference to records or musical tapes and the development of the personal computer and associated software. Although there is real disagreement about the magnitude of the externality, it could be addressed either through a subsidy for the alternative fuel vehicles or through a tax on gasoline or gasoline-fueled vehicles. These externality differentials could appropriately be addressed through differences in motor fuel taxes.

Matching the Instrument With the Externality

Fuel use taxes could motivate consumers to account for externalities associated with the use of gasoline and other motor fuels. Some externalities are fairly stable over time, location, and vehicle, and could be addressed through the use of a fuel tax. Others are highly variable, and this mechanism would be less appropriate. Although several externalities are important, only the externality components associated with unpriced road services, carbon dioxide, energy security, and the chicken-and-egg problem could appropriately be addressed with a Federal gasoline tax.

Model-Based Results

The various impacts can, in principle, be estimated by using mathematical models. Three general classes of models typically are available for such estimation: 1) partial equilibrium models of the energy sector or parts of the energy sector, 2) computable general equilibrium models of the overall economy, and 3) aggregate macroeconomic models.

Partial equilibrium models of the energy system may represent one market such as that for gasoline, many linked markets (e.g., for each of the refined petroleum products), or the entire energy supply and demand system. Partial equilibrium models generally can have the most detail about the particular energy markets being examined.

Computable general equilibrium (CGE) models represent the economy as a complete system, including each major factor of production: labor, capital, energy, materials. Such models typically allow less detail about the structure of particular energy markets.

Macroeconomic models typically represent the entire economy, focusing particular attention on determination of the overall level of economic activity as measured by GNP or gross domestic product (GDP), on employment or unemployment of labor; money supply and demand; interest rates; and inflation. Such models typically allow even less detail about particular components of the energy system, although some of the commercial macroeconomic models have incorporated extensive energy sector details.

None of the model classes is suitable for examining all of phenomena discussed above, as suggested by table 5-10, which summarizes the variables typically represented in the three classes of models. Rather, each class has its own particular strengths.

The three classes of models should be used in a complementary fashion in order to examine the relevant issues. The OTA contractor report on which this section is based provides several examples of the use of these models to examine the impacts of gasoline tax increases.[233]

TRANSPORTATION DEMAND MANAGEMENT

Transportation demand management (TDM) entails any effort to improve the efficiency of the transportation system by reducing traffic volume, especially during peak travel times, increasing vehicle occupancy, improving traffic flow, and encouraging modal shifts. Recent Federal legislation has pushed the development of TDM programs. The Clean Air Act Amendments of

[233] Sweeney, op. cit., footnote 228.

TABLE 5-10: Variables Represented in Models

Variables	Partial equilibrium	Computable general equilibrium	Macroeconomic
GNP	No	Yes	Yes
Unemployment	No	No	Yes
Inflation	No	No	Yes
Tax revenues	Yes	Yes	Yes
Federal deficit	No	Yes	Yes
Total driving	Yes	No	No
Fuel efficiency of automobiles	Yes	No	No
Gasoline consumption	Yes	Yes	Yes
Oil Imports	Yes	Yes	Yes
Economic efficiency	Yes	Yes	No
Environmental harm	Yes	No	No
Automobile accidents	Yes	No	No
Congestion	Yes	No	No

SOURCE J L Sweeney Stanford University

1990 (Public Law 101-549) prohibit Federal agencies from approving or funding State transportation plans that do not include transportation control measures.[234] In addition, the Intermodal Surface Transportation Efficiency Act of 1991 (Public Law 102-240) established several TDM requirements and programs, including a congestion pricing pilot program; occupancy requirements for HOV lanes; State requirements for managing traffic congestion; and a six-year, $659-million intelligent vehicle-highway system program (IVHS).[235]

TDM approaches include economic incentives, regulatory mandates, and public investment and information programs. TDM measures, such as employee ridesharing programs and congestion pricing, may reduce traffic congestion, gasoline use, and vehicular emissions, but measuring these outcomes in an entire metropolitan or regional area can be extremely difficult. Because most current programs are concerned with reducing traffic congestion not gasoline use, the gasoline savings potential of many TDM options is still undetermined.

Because congestion may discourage some travel, relieving congestion through successful TDM strategies—such as parking pricing, staggered work hours, and HOV lanes—may stimulate some additional travel, thus canceling part of the potential savings. In some extreme cases, especially with IVHS programs, net travel may increase. The rapid onset of congestion on many newly constructed roads indicates that limits to the existing road supply may indeed suppress travel demand. Thus, reducing traffic congestion could in some cases lead to more trips, miles traveled, and gasoline use.

This section reviews primarily U.S. experience with various TDM efforts. The discussion is meant to be illustrative rather than comprehensive; in most cases, these, options have not been attempted on a large scale or have not been evaluated for their impact on gasoline use. Given the limited experience with TDM and the large number of factors that determine worker travel behavior (e.g., travel time, vehicle and fuel costs, parking costs, day care requirements, and travel requirements during the workday), calculations of

[234] Public Law 101-549, 104 Stat. 2410, sec. 101(f), see 42 U.S.C. 7506(c)(2),

[235] These provisions are codified at 23 U.S.C. 102(a), 149 note, 303(c), and 307 note

congestion and travel demand reduction and gasoline savings based on theoretical calculations or extrapolations from case studies should be considered preliminary and highly uncertain.

Economic Incentives

Economic incentives are potentially powerful strategies to improve the efficiency of the road transport system. Not surprisingly, travel choices (frequency, mode, and timing) are strongly affected by prices, including those of fuel, parking, mass transit, and other transport-related costs.[236] Unlike regulatory mandates, economic incentives—including congestion and parking pricing options--allow consumers to choose their best combinations of mode choice, travel times, travel frequency, and vehicle occupancy; mandates, on the other hand, predetermine those choices.

There are several kinds of economic incentives designed to manage transportation demand: pricing parking, pricing travel (congestion and road use pricing), and other financial options related to travel demand (parking fees, automobile ownership and use fees, employee mass transit allowances). (Gasoline taxes also fit into this category, although generally they are used in this country to raise revenue rather than to depress demand; they are discussed in the preceding section.) Major options within each group are discussed here.

Pricing Parking

Among all TDM options, pricing parking may have one of the most significant impacts on travel demand, because parking is a valuable transport service paid only partially (if at all) by drivers. Roughly 95 million civilian commuters in the United States drive to work, and an estimated 90 percent of them do not pay for parking.[237] For commuting trips, the value of free parking often exceeds ownership and operating costs combined.[238] As a result, by substantially reducing commuting costs, free parking encourages solo driving, which increases traffic congestion and gasoline consumption.

Increasing parking costs to match prevailing market prices would reduce the incentives for solo driving. One study found that an average of 27-percent fewer auto trips were made by employees who paid for their parking at work compared with those who did not pay.[239] When a Los Angeles government agency introduced market rates for employee parking, solo driving dropped substantially (from 42 to 8 percent) and ridesharing increased substantially (from 17 to 58 percent). In Washington, DC, parking charges representing half of the local market rates were imposed briefly at several Federal buildings in 1979 and 1980, and solo driving decreased as much as 40 percent.[240]

Employers offer free parking as an employee benefit, in part because these costs are currently treated as a normal business expense, deductible from corporate income taxes, and employees are not taxed for free parking. One way to eliminate parking subsidies, therefore, is to tax employees for the value of parking; employers could be re-

[236] M. Wachs, "Pricing Urban Transportation: A Critique of Current Policy," *Journal of the American Planning Association*, vol. 47, July 1981, pp. 24--245.

[237] D.C. Shoup and R. W. Willson, "Employer-Paid Parking: The Problem and Proposed Solutions," *Transportation Quarterly*, vol. 46, No. 2, April 1992, pp. 169, 185. This source does not clarify whether these figures are actual or estimated.

[238] Average ownership (depreciation, financing, licensing, and registration lees) and operations costs (gasoline at $1.50 per gallon) total about $4.90 per roundtrip commute, while daily parking costs in both urban and suburban areas commonly exceed $5 per vehicle. D.H. Pickrel 1, testimony at hearings before the Senate Committee on Environment and Public Works, Subcommittee on Water Resources, Transportation, and Infrastructure, Mar. 21, 1991, p. 2.

[239] Shoup and Willson, op. cit., footnote 237, p. 181. The results are corrected for income, since higher paid employees are both more likely to receive paid parking and more likely to drive alone regardless (because of both their income and their greater likelihood of having erratic schedules).

[240] Pickrell, op. cit., footnote 238, p. 4.

quired to determine the value of a parking subsidy and report that value as a taxable employee benefit. Eliminating the tax exemption of free parking would be politically unpopular, but it would reduce auto travel demand and could raise between $3 billion and $4 billion in Federal revenues annually, although those revenues would decrease with time as solo driving decreased and mass transit use increased.[241]

Alternatively, employers could be required to offer their employees the cash value of their subsidized parking spaces. This option could be implemented without changing the current tax exemption on employer-subsidized parking, and it would allow employees to determine which alternative represented the greater value for them: using free parking or receiving its cash equivalent. A cash option has the advantage of being voluntary and still raising significant revenues, if the cash is taxable as income.

Shoup and Willson estimate that if 20 percent of the 85 million U.S. auto commuters who currently park free at work chose a cash option *and ceased to drive* (carpooling or using mass transit), Federal tax revenues would increase more than $1 billion,[242] and gasoline consumption would decrease by an estimated 4.5 billion gallons annually,[243] or about 4 percent of the national total.[244] However, aside from being a rough extrapolation from limited experience, the gasoline savings estimate given here is overstated to the extent that any workers with access to free parking currently commute by means other than solo auto travel (e.g., transit, walking, biking). In addition, drivers using a cash option might still drive but use their money to park on streets or less expensive lots. Better data on the availability, use, and value of subsidized parking could improve estimates of potential gasoline savings from taxing or cashing out free parking.

Pricing Travel

Congestion (or peak) pricing is designed to capture the added costs of road use during peak periods, which are generally the rush commuting hours. A basic principle behind this and other pricing strategies is that traffic congestion imposes costs not captured in existing travel prices. During peak travel periods, each marginal user imposes costs on all other users by increasing travel times. fuel use, and air emissions. These costs increase as the number of vehicles increases, but marginal users do not pay the marginal (incremental) costs of the congestion they impose on others.

A major policy concern with congestion pricing (like other transport pricing options such as gasoline taxes) is the potential for regressive impacts. As with gasoline taxes. however, the total impacts of congestion pricing depend critically on how revenues are used. According to one analysis, if revenues are used to reduce gasoline taxes and vehicle registration fees or to subsidize transit costs, a congestion pricing program may have positive economic impacts on all income groups

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[241] About 28 million U.S. commuters work in central cities with populations exceeding 500,000. Given an estimated average monthly value of $58 per parking space in those areas, the annual added tax liability per commuter totals about $167, with taxation at the marginal federal income tax rate of 24 percent (1991). If 75 percent of these commuters receive free parking, taxing this benefit would generate annual revenues of about $3.5 billion, Ibid., pp. 3, 6. Note: This source lists annual revenue gains of $4.7 billion, because the author multiplied the annual tax liability ($167) by all 28 million commuters. Here. however, the original assumption is used that only 21 million commuters (75 percent) receive free parking, which explains the discrepancy from the original source.

[242] This estimate assumes an average monthly parking value of $30 for all U.S. auto commuters, equaling an increase in total taxable income of $6.1 billion annually. With an effective marginal tax rate of 20 percent, federal revenue gains would total $1.2 billion. Ibid., pp. 179-181.

[243] Based on D.C. Shoup, "Cashing Out Employer-Paid Parking," forthcoming, as cited in J. Kessler and W. Schroeer, U.S. Environmental Protection Agency, Office of Policy Analysis, "Meeting Mobility and Air Quality Goals: Strategies That Work," draft report, Apr. 20, 1993, p. 20.

[244] In 1991, total U.S. gasoline consumption was approximately 112 billion gallons. U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics 1991*, FHWA-PL-92-025 (Washington, DC: 1992), p. 6.

by reducing both travel times and other costs of using the transportation system.[245] Reducing gasoline and vehicle registration costs, however, is likely to increase travel demand, during both on- and off-peak periods, resulting in some rebound (i.e., loss) of the expected gasoline savings from congestion pricing.

Modeling studies of congestion pricing for major cities in North America and Britain have concluded that peak period travel could be reduced between 10 and 25 percent, depending on the site and the study assumptions. Such studies estimate that economically efficient charges during peak periods would range from 5 to 30 cents per mile, or about $1 to $2 per day for typical commuting distances.[246]

The studies estimate that daily congestion charges of this magnitude would reduce round-(rip commute times 10 to 15 minutes on congested routes and would generate tens of billions of dollars in annual revenues nationally.[247] Estimating the impact of peak pricing schemes on gasoline consumption, however, is more difficult. largely due to expected changes in vehicle speeds and efficiencies with changes in road use. Congestion pricing would likely shift some auto use to other routes and reduce overall use and travel time, and average commute speeds could increase with mixed effects on gasoline use. The net effect on total gasoline consumption from congestion pricing is uncertain and deserves further study.

In some circumstances, such as major highway corridors, travel demand may be relatively unresponsive to price changes (price inelastic) during peak periods, particularly if travel alternatives are limited or unavailable. For example, New York City bridge and tunnel tolls doubled several years ago, but there was no major traffic reduction. For Southern California, one estimate suggests that congestion pricing of 65 cents per mile in urban areas and 21 cents per mile in suburban areas is necessary for effective demand management, a cost far higher than normal toll road rates of 2 to 4 cents per mile.[248]

Imposing high congestion fees (such as 65 cents per mile in the example above) is likely to be politically difficult. The annual added cost of driving could be almost $900 with a fee of 65 cents per mile.[249] Implementing effective suburban-based congestion pricing schemes based on the same Southern California estimate (21 cents per mile) may be difficult as well; the added cost under the same operating conditions would be about $290 per year.

A summary of the major advantages and disadvantages of congestion pricing is given in table 5-11. Although congestion pricing has been advanced by many economists since the 1960s, the strategy has not been applied on any major U.S. highway, and international experience is also very limited,[250] Several recent developments, however, have revived interest in this strategy: increasing levels of traffic congestion and associated air pollution;[251] increasing political acceptance for market-based over regulatory approaches to address public policy problems such

[245] K.A. Small et. al., Road *Work: A New Highway Pricing and Investment Policy* (Washington, DC: The Brookings Institution, 1989), pp. 95-98.

[246] Ibid., p. 94.

[247] Ibid., p. 98.

[248] C. K. Orski, "Congestion Pricing: Promise and Limitations,'" *Transportation Quarterly,* vol. 46, No. 2, April 1992, p. 165.

[249] Assuming an average work commute of 11 miles (the national average length of the worktrip in 1990). P.S. Hu and J. Young, *Summary of Travel Trends: 1990 Nationwide Personal Transportation Survey,* FHWA-PL-92-027 (Washington, DC: U.S. Department of Transportation, Federal Highway Administration, March 1992. p. 18). Also assuming that urban drivers travel half this distance in a peak-priced roadway for half of their trips to work and work 50 weeks per year.

[250] J A. Gomez-Ibanez, "The Political Economy of Highway Tolls and Congestion Pricing," *Transportation Quarterly,* vol. 46. No. 3, July 1992, p. 344.

[251] Ibid., p. 345.

TABLE 5-11: Advantages and Disadvantages of Congestion Pricing

Advantages	Disadvantages
Allocating and rationing limited (congested) road space efficiently.	Due to potential price inelasticity of commuter travel demand, limited change in work travel
Capturing market externalities associated with traffic congestion	Potential scarcity or absence of alternate, less expensive routes or modes
Reduction in demand for new road construction.	
Retaining consumer flexibility in travel decisions	Reduction in competitiveness of one locality versus another by uneven application
Fixing market distortions that discourage the use of other modes	
Providing revenues for road maintenance and new construction.	Difficulty (or impossibility) of implementing effective or optimal pricing schemes politically

SOURCE Adapted from C K Orski, "Congestion Pricing Promise and Limitations," *Transportation Quarterly*, vol **46, No 2** April 1992 pp 157-167

as environmental degradation; and the development of technologies such as electronic toll collection that improve the feasibility of implementing congestion pricing by avoiding the delays imposed by stopping to make toll payments.[252]

The first congestion pricing program began in Singapore in 1975, with the imposition of a flat morning peak permit fee of $2.50 per day for autos driving to the central business district. Participants display permits in their windows. Technically, a flat fee is not the most efficient pricing scheme because there are no price adjustments for differing levels of peak travel, but the effort in Singapore led to an immediate decrease of nearly 60 percent in morning peak automobile trips. At the time the program was introduced, auto trips declined from 56 to 23 percent of total CBD work-trips. A decade later, CBD traffic levels remained lower than predicted. Congestion pricing has also been implemented in Bergen, Norway (6 to 7 percent travel reduction) and Milan, Italy (50 percent peak travel reduction in the city center) and is being developed in Hong Kong (postponed); Oslo and Trondheim, Norway (imposition of flat fees); the Netherlands (testing stage); and Cambridge, England (proposed).[253]

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) authorizes up to $25 million annually for a Congestion Pricing Pilot Program to fund a maximum of five congestion pricing projects.[254] However, the national impacts of a congestion pricing program on travel demand nationwide and gasoline use are difficult to assess, because the most effective congestion pricing schemes will vary greatly by community. depending on road volumes, patterns of auto ownership and use, job distributions, commute distances, and other factors.

Nonpeak road use pricing

The rationale for regular (nonpeak) road pricing is similar to that for congestion pricing: to reflect better the costs of building and maintaining roads, as well as the costs of vehicular emissions and other potential market externalities associated with road use. Similar to congestion pricing, tolls are commonly discussed in the context of nonpeak

252 Orski, op. cit., footnote 248, p. 159.

253 Ibid., pp. 163-] 64.

254 Public Law 102-240, 105 Stat. 1938, sec. 1012(b).

road pricing scenarios, including the use of private toll roads. However, there are fewer data on the impacts of nonpeak pricing. If nonpeak pricing is based on current national average toll road rates of 2 to 4 cents per mile, travel demand could be affected significant] y because these rates translate to between 40 and 80 cents per gallon of gasoline consumed (based on an average fleet efficiency of 20 mpg). The net effect of nonpeak pricing as a strategy to reduce total travel demand and gasoline consumption warrants further study.

Ridesharing Incentives

Ridesharing (or carpooling) for all trips (work, shopping, recreation) has declined for more than a decade. Between 1977 and 1990, average vehicle occupancy for all trips decreased about 16 percent (from 1.9 to 1.6 per vehicle), and occupancy for work commutes declined about the same amount (from 1.3 to 1.1, about 15 percent).[255] Ridesharing incentives to slow or reverse the recent historical decline in vehicle occupancy may apply to either peak or nonpeak travel and may take the form of subsidized van pools, free parking, or subsidized tolls. In addition, as noted above, parking charges and congestion pricing would encourage ridesharing.

The most extensive metropolitan ridesharing program stems from a regulatory program initiated in December 1987 in the Los Angeles area. The program, known as Regulation XV, requires employers of 100 or more people to develop and implement plans to increase vehicle occupancy for commute trips to their sites from 1.13 (the 1987 average) to 1.25-1.75, depending on the site, which represents an average increase in occupancy of 11 to 55 percent.[256] Bonus credits are awarded to telecommuting programs. The 8,900 affected employers are required to develop their own incentive programs and submit plans and progress reports annually. The plans commonly include economic incentives to rideshare. For example, employees of the city of Pasadena receive a monthly travel allowance of $20 but pay a $45 "trip reduction fee" each month they drive alone.[257] Employers are subject to fines if they fail to submit or implement plans, but not if they fail to achieve the ridership goals.[258]

Early results of the Regulation XV program vary greatly by work site, but there are several major trends. First, ridesharing increased significantly when parking subsidies were reduced and mass transit subsidies increased. Second, the use of onsite transportation coordinators improved performance. Third, a survey of more than 1,100 sites after the first year of the program indicated that ridesharing increased about 33 percent and solo driving decreased about 6 percent; telecommuting, walking, and biking, on the other hand, actually decreased somewhat but not significantly. Based on these early results, total daily trips in the area declined between 0.5 and 2 percent. The net impact of Regulation XV on gasoline consumption for the Los Angeles metropolitan area, however, is not known.

Regulatory Mandates

Regulatory mandates are enforceable provisions designed to ensure that transportation demand goals are attained. Implementing such options, however, may be politically difficult, and may reduce the amount or kinds of economic activity otherwise expected from a less restricted transportation system. Of course, where congestion is severe enough, the transport system already imposes economic costs (delays, accidents, poor air

[255] Hu and Young, op. cit., footnote 249. p. 20.

[256] Unless noted otherwise, all information on the Regulation XV program given here is from R. Guensler and D. Sperling, "Solving the Problem Through Behavioral Change," unpublished manuscript, June 1992, pp. 6-12.

[257] C. K. Orski, "Can Management of Transportation Demand Help Solve Our Growing Traffic Congestion and Air Pollution Problems?" *Transportation Quarterly*, vol. 44, No. 4, October 1990, p. 489.

[258] Ibid., p. 492.

quality). The feasibility and efficacy of managing transportation demand by regulator-y mandates will depend on the severity or perceived severity of the traffic problem, as well as public acceptance and response to any proposed mandates.

Major TDM options in this group are discussed below. Many of these strategies are currently used in Europe and Japan, areas with high standards of living and similar but not identical traffic problems.

Restrictions on Automobile Ownership and Use

Restricting auto ownership or use can be accomplished by imposing higher age requirements for auto licenses, restricting automobile ownership in highly congested areas, limiting driving days, and restricting driving times or vehicle use in congested areas (such as central business districts). In a nation where restricted access to road travel is politically difficult to consider, imposing higher age requirements for auto licenses may accomplish little travel reduction and may offend many. The percentage of licensed drivers who are very young is low: less than 3 percent are aged 16 to 17, and only about 7 percent are 18 to 21.

One argument for restricting licenses for these first two age groups is that they account for a disproportionate share of auto deaths, about 5 and 14 percent, respectively.[259] When compared with their relative share of licensed drivers, however, auto fatalities occur disproportionately in all census age groupings up to age 34.[260] Even if younger drivers consume a disproportionate share of transportation energy, outright bans on their automobile use seem drastic as a means of saving energy in transport, especially as historical land use and transportation policies tie mobility to automobile travel. In addition, most men and women aged 16 to 19 already work[261] and presumably must travel to their job sites on a regular basis; restricting vehicle licenses for these age groups. therefore, could seriously complicate or prevent their ability to work, particularly if they live in rural areas. As an alternative, restricted licenses for young drivers that limit auto use to work-related travel may be more politically acceptable and fair, although they could create difficult enforcement problems.

Other options to reduce vehicle use are potentially inequitable and regressive, particularly if affordable and accessible transportation alternatives such as mass transit are not available or are limited. For example. uniformly increasing auto registration fees will consume a greater portion of earnings from lower-income households. Restricting driving days will have the greatest impact on one-car households, which are probably predominantly lower-income households. Another problem is that multiple-vehicle households, which will be less affected by driving restrictions, are becoming more prevalent. For example, between 1969 and 1990 the number of households wit h two or more vehicles more than doubled, and those with three or more vehicles increased fivefold. whereas the number of one-vehicle households increased only 1 percent.[262] Selectively raising registration fees for second and third vehicles may be a less regressive option.

Mandatory Ridesharing

Some jurisdictions may determine that ridesharing requirements are appropriate for highly congested areas or roads, but most are likely to prefer voluntary programs. Mandatory programs are likely to encounter more political resistance than voluntary ones and may not address the significant incentives (e.g., free parking) that currently encourage solo driving. In addition, mandatory

[259] U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States: 1992*, 112th ed. (Washington, DC: 1992), p. 612.

[260] Ibid.

[261] Ibid., p. 381.

[262] Hu and Young, op. cit., footnote 249, p. 12.

programs introduce enforcement costs without raising revenues (unless monetary penalties are imposed).

In Los Angeles, an area considered to have the worst urban traffic congestion and air pollution problem in the United States, the major regulatory TDM program (Regulation XV) is substantially a voluntary incentive program. Hybrid programs such as Regulation XV may represent a more balanced mix of mandatory and voluntary elements by requiring the development and implementation of plans, while allowing employers to determine the best package of incentives for their commuting workers.

Incorporation of Parking Requirements in Zoning Ordinances

Off-street parking requirements have been a common element of zoning ordinances for new buildings since the 1920s. These requirements have several purposes, such as preventing drivers from searching surrounding areas for available parking spots and limiting parking spillover from commercial to residential areas. Nonetheless, zoning requirements that maintain a large supply of parking spaces lower parking costs and thus encourage auto travel.[263] By eliminating or modifying these mandatory requirements, the amount and cost of local parking may better match market demand and thereby reduce travel and gasoline consumption.

Efforts to limit urban parking spaces appear rare. In Munich, Germany, a gradual but aggressive effort to eliminate more than 70 percent of inner-city parking spaces was initiated in 1965. A 1988 Organization for Economic Cooperation and Development (OECD) study described this program as effective in reducing travel to the inner city.[264] To help local markets better determine the optimal allocation of parking spaces and their costs, based on market supply and demand, zoning ordinances could be written without establishing minimum parking quotas, except perhaps for handicapped spaces.

Alteration of Work Schedules

To reduce the volume of peak-hour trips for work commuters, many or most of whom have a typical business day of roughly 9 a.m. to 5 p.m., several alternative work schemes may distribute work travel more evenly across more hours: flextime, compressed work weeks, and staggered work hours. In 1988, a staggered work hour demonstration project was implemented for one month in Honolulu.[265] The goal of the program was to alter government employee work schedules to distribute peak travel over more hours in the mornings and afternoons. State, local, and county employees were required to participate in the program, which postponed the start and end of the official workday by 45 minutes each, from 7:45 a.m.-4:3O p.m. to 8:30 a.m.-5: 15 p.m. Although many exemptions were granted, about half of all government employees participated in the program, as well as about 8 percent of private employees, for a total of roughly 4,000 workers.

There appear to be no estimates of gasoline savings from the Honolulu demonstration project, but average commute times were reduced about 7 to 9 percent. Savings varied by route and time of day. Those commuting from the most distant suburbs reduced their average commute times by 15 to 25 percent, while those who started work at 7:30 or earlier actually experienced a 30-percent *increase* in their average commute time (this increase was not explained). In addition, nonpartici -

[263] D.C. Shoup and D.H. Pickrell, "Problems with Parking Requirements in Zoning ordinances," *Traffic Quarter/],* vol. 32, October 1978, pp. 545-561.

[264] To offset the loss of inner-clt) parking spaces, an extensive system of park-and-ride facilities was constructed outside the center of the city. Organization for Economic Co-operation and Development, *Cities and Transport* (Paris, France: 1988), pp. 119-123.

[265] Information about the Honolulu program is from G. Giuliano, "Transportation Demand Management: Promise or Panacea')" *Journal of the American Planning Association*, vol. 58, No. 3, summer 1992, pp. 331-332.

pants enjoyed slightly greater reductions in commute times (up to 3 minutes more) than program participants. As the average indicates, however, most commuters experienced small and perhaps unnoticeable reductions in their commute times.

Gasoline savings from alternative work schedules are likely to be small. Savings from efficiency gains associated with decreased congestion may be offset somewhat by potential growth of demand. Schedules that allow workers to reduce their workweeks by a day, or by one day every two weeks, will save on the energy used for commuting, but this may be counterbalanced somewhat by non work travel during the extra day off, or even an increase in long-distance driving associated with more three-day weekends.

Telecommuting

Telecommuting is the practice of allowing people to work either at home or in nearby centers located closer to home during their normal working hours. The relative ease of administration and costs of implementation make telecommuting an attractive option in managing travel demand. An annual random survey estimated that 6.6 million people telecommuted[266] at least part time in 1992. or slightly more than 5 percent of the total adult workforce in the United States.[267] The 1993 survey estimates that about 7.9 million adult workers are telecommuting--a 20-percent increase over 1992.[268] If these estimates are correct. about as many workers telecommute, at least part time, as commute by mass transit.[269] However, the range of estimates of different studies differs by a factor of 3, with the lowest estimate for 1992 at 2.0 million.

Several businesses have found that along with anticipated overhead cost reductions (number of occupied offices and parking spaces), there have been increases in employee productivity and management skills. In a telecommuting project by AT&T and the State of Arizona, 80 percent of the participating supervisors reported increased employee productivity, and 67 percent indicated an increase in the overall efficiency of their departments.[270] Employee morale and productivity both improved, and telecommuting forced managers to improve their managerial skills by setting clearer objectives and managing by results rather than by overseeing. A recent survey of 100 "Fortune 1,000" companies and government organizations found that 30 percent have full-time employees who work from home part time and that 8 percent of the companies are about to begin such programs.[271]

Public policy has already played a direct role in the growth of telecommuting. Regulation XV, adopted in 1987 by the Southern California Air Quality Management District, requires the more than 4,000 district employers with 100 employees or more to develop and promote commuting options such as flexible work schedules, ridesharing, and telecommuting.[272] Several businesses have turned to telecommuting in an attempt to comply

[266] These telecommuters do not include home-based businesses, agricultural businesses, or employees bringing home supplementary work from their offices.

[267] D. Filipowski, "Employees Who Prefer Home Work," *Personnel Journal*, vol. 71, No. 11, November 1992, p. 27. (Assumes 124.3 million workers in the United States.)

[268] P. Braus, "Homework for Grownups," *American Demographics*, vol. 15, No. 8, August 1993, p. 39.

[269] Based on 1990 census data that 5.3 percent of the total commuting population used public transit, down from 6.4 percent in 1980. American Public Transit Association, personal communication, 1993.

[270] S. Caudron, "Working at Home Pays Off," *Personnel Journal*, vol. 71, No. 11, November 1992, p. 40.

[271] A. Bellinger and H. La Van, "Telecommuting, Has Its Time Come?" *Home Office Computing*, vol. 10, No. 12, December 1992, p. 50.

[272] B. Schepp, "The Second Commute," *Home-Office Computing*, vol. 9, No. 12, December 1991, p. 45.

with the regulation's average vehicle occupancy (AVO) requirements. Regulation XV is being studied by several other areas of the United States that are out of compliance with the Federal Clean Air Act Amendments of 1990 (CAAA) standards.

Telecommuting is eligible for travel demand management funding provided by ISTEA. States and municipal planning organizations may use funds from several programs for eligible telecommuting activities. Eligible activities include the planning, development, and marketing of an area-wide telecommuting strategy designed to improve air quality and reduce congestion.[273]

The most significant barriers to telecommuting will probably be largely nontechnical factors such as lack of business and worker acceptance. Employers and workers must become familiar and comfortable with this new way of working. Employers are concerned with the cost-benefit implications. Other concerns center around remote] y supervised employees and potential problems of lack of communication, extended breaks, and drug abuse. Workers are concerned with the potential lack of communication. social isolation, loss of benefits, lack of career advancement, and stress from mixing work and home life.[274] Other potential barriers to telecommuting including local zoning codes restricting home-based work and union opposition (especially the issue of employers identifying workers as independent contractors rather than employees).

Impact on Travel Behavior

Although telecommuting eliminates many commuting trips, theoretically these could be replaced by other trips or longer, unlinked trips. Some examples of new or longer trips include: shopping and/or child care trips normally made en route to work; trips by other household members due to the availability of the vehicle;[275] trips made possible due to increased flexibility of the work schedule; trips necessitated by working at home, for example, to the post office or the supply store; and relocation of residence, yielding longer commutes on office work days.

The results of some recently completed and ongoing studies suggest that many of these new trips are not occurring, and reductions in commute trips have not been offset noticeably by the generation of new trips.[276] For example, on telecommuting days, participants in the State of California Telecommunications Pilot Project made virtually no commute trips, reduced peak-period trips by 60 percent, reduced total distance traveled by 75 percent, and reduced freeway miles by 90 percent.[277]

Impacts on Energy Use

The U.S. Department of Transportation (DOT) has made tentative estimates of the future impacts on travel and energy use of a large increase in telecommuting.[278]

1. Potential telecommuters. To estimate the number of potential telecommuters, DOT focuses

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[273] U.S. Department of Transportation, Federal Highway Administration, *Transportation Implications of Telecommuting* (Washington, DC: U.S. Government Printing Office, April 1993), p. 6.

[274] These concerns have been disputed by the results of several demonstration projects and an extensive survey by the Small Business Administration.

[275] Over the long term, presumably many of the newly available vehicles would no longer be available.

[276] These studies include the Southern California Association of Governments, the State of California, the Hawaii Telework Center, the Netherlands Ministry of Transport, Puget Sound multiemployer program, Los Angeles County, the Travelers Insurance Co. in Hartford, Connecticut, AT&T in New York City, and several employers in Southern California.

[277] Federal Highway Administration, op. cit., footnote 273, pp. 64-65. There is little analysis of the effects of telecommuting on mode choice. Small-sample findings indicate that mass transit and van and carpool ridership will go down slight] y. However, the built-in flexibility of paratransit service will allow most van and carpools to continue to function and thus not affect their share of vmt. See P. Mokhtarian, "Telecommuting and Travel: State of the Practice. State of the Art. " *Transportation*, vol. 18, No. 4, 1991, pp. 319-342.

[278] Federal Highway Administration, op. cit., footnote 273, pp. 53-87.

on white collar workers with a managerial and professional specialty, or workers in sales and clerical jobs.[279] These information workers, those who deal primarily with creating, distributing, or using information. are the most likely to be telecommuters in the next several years.

Approximately 50 to 60 percent of contemporary U.S. civilian jobs, or 73.3 million of the 129 million workforce, are information jobs.[280] By 2002, this number is expected to increase to 85.5 million, or 59 percent of the workforce. DOT's projected upper bound of telecommuters in 2002 is 15 million, about 10.5 percent of the workforce or 17.5 percent of information workers. This is a gain of 650 percent over the next 10 years, with half of the growth occurring in the last 3 years. The lower projection is half of the upper bound and assumes a gain of 250 percent over the same period.[281]

2. Reductions in trips and vehicle-miles traveled. According to National Personal Transportation Survey statistics for vmt, 3.7 billion vmt (or 0.7 percent of the total passenger car commuting vmt) were avoided in 1992 by the 1.6 percent of the work force that telecommuted. DOT's upper forecasts of the annual commuter passenger car vmt avoided in 1997 and 2002 are, respectively, 12.9 billion and 35.1 billion, or 0.63 and 1.4 percent of the total passenger car vmt (2.0 and 4.5 percent of total passenger car *commuting* vmt).[282] The lower bound of vmt avoided is 10 billion in 1997 and 17.6 billion in 2002, or 0.49 and 0.70 percent of total passenger car vmt (1.6 and 2.3 percent of total passenger car commuting vmt), respectively.
3. Reductions in energy use. According to the upper bound of vmt reductions presented above, telecommuting will save619 million gallons of gasoline in 1997 (14.7 million barrels), or 0.8 percent of the total used by passenger cars, and 1,679 million gallons in 2002 (40 million barrels), or 2.1 percent of the total.[283] These savings will reduce Federal and State fuel tax revenues by $57.5 million in 1992 and $540.8 million in 2002 as an upper bound ($270.3 million as a lower bound).

Policies To Stimulate Telecommuting

Although there can be substantial marketplace incentives for companies to initiate telecommuting, including enhanced access to skilled workers, increased worker satisfaction and productivity, and savings in office space, the substantial public benefits in reduced congestion, oil use, and air pollution may justify government promotional incentives. These may include changes in tax policy to allow companies to deduct some of the direct costs of the initial startup of telecommuting programs, such as worker training and telecommunication equipment costs, and to allow teleworkers to deduct computer and telecommunications equipment as a business expense on personal income taxes. Local governments can amend zoning requirements to allow a reduction in the minimum number of parking places in office buildings to

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[279] J. H. Pratt, *Myths and Realities of Working at Home: Characteristics of Homebased Business Owners and Telecommuters*, SBA-6647-OA-91 (Washington, DC Small Business Administration, March 1993), p. 26.

[280] Ashok B. Boghani et al., "Can Telecommunications Help Solve America's Transportation Problems?" (Cambridge, MA: Arthur D. Little, Inc., 1991), Reference 65740, p. 25. See also J. Nilles, "Traffic Reduction by Telecommuting: A Status Review and Selected Bibliography," *Transportation Research*, Part A, vol. 22A, No. 4, July 1988; and Federal Highway Administration, op. cit., footnote 273, pp. 53-55.

[281] The higher figures are derived from a forecasting model developed by Jack Nines, by using his "business as usual" nominal case. His high.gr[]~th and acceptance scenario starts with 4.4 million telecommuters in 1992 and ends with 30.5 million telecommuters in 2002. See J. Nilles, Telecommuting Research Institute, Inc., "Telecommuting Forecasts," informational document, 1991, table 1, pp. 1, 3.

[282] Assuming an annual vmt growth rate of 3.7 percent.

[283] Assumptions fuel efficiency is held steady at 20,92 mpg, average rtmnd-trip distance avoided is also held constant at 21 .4 miles and the average distance to regional telecommuting centers is 9 miles; average price per gallon is held constant at $1.14. These are the direct savings only and do not include savings from congestion relief.

give incentives to new businesses locating in an area to implement a telecommuting program.

One of the biggest impediments to telecommuting is the lack of information on successful projects. California has a Telecommuting Advisory Council with more than 300 members, which acts as a clearing house for information and advice on telecommuting.[284] Several cities and Federal agencies have taken part in Federal- and State-sponsored telecommuting demonstration projects. An increase in the number of projects combined with a careful documentation of the economic and environmental effects of these projects could decrease employer resistance to telecommuting.

Public Investments, Information, and Other Efforts To Manage Transportation Demand

High-Occupancy Vehicle Lanes

HOV lanes are freeway, highway, or city arterial lanes restricted to vehicles containing two or more passengers. By providing a congestion-free alternative to normally congested traffic lanes, HOV lanes encourage ridesharing by reducing or reversing the time penalty generally incurred in picking up passengers (which often requires adding to trip length). And by encouraging ridesharing, HOV lanes may reduce the number of vehicles in use at any one time and thereby reduce gasoline consumption. This is especially important during rush hours, when congestion is at a maximum.

HOV lanes may be converted from existing highway lanes or newly constructed. All HOV lanes are likely to face enforcement problems from encroachment of nonqualifying vehicles. The benefits of newly built HOV lanes tend to be uncertain because to the extent that they relieve congestion in parallel lanes, they may encourage additional traffic. The likely magnitude of this “latent demand” for additional travel remains a source of controversy in the planning community, although experience with opening new highway lanes shows it clearly exists. Also, newly built HOV lanes introduce substantial costs for construction and maintenance. Where HOVs are developed from existing lanes, on the other hand, congestion may increase in the remaining lanes, thereby increasing fuel use (and emissions) in nonparticipating automobiles but providing a more certain incentive for carpooling and a more certain net fuel savings.

Both CAAA and ISTEA encourage construction or conversion of HOV lanes. CAAA lists HOV lanes as an allowed transportation control measure for air quality implementation plans and exempts HOV construction funds from any sanctions induced by failure to comply with the Act’s requirements. ISTEA makes HOV lanes in air quality nonattainment areas eligible for Congestion Mitigation and Air Quality funding.[285] ISTEA also permits State authorities to designate a two-passenger vehicle as a high-occupancy vehicle, a shift from previous FHWA policy limiting HOV designations to vehicles with three or more passengers.[286]

In North America, there are 40 HOV projects on freeways and other separate rights of way. These projects are dispersed among 20 metropolitan areas and cover roughly 340 miles. These projects vary by hours of operation (from 2 to 24 hours per day) and occupancy requirements (two to three or more passengers, and bus-only lanes). Under current plans, this capacity will more than double in the next decade, increasing to 880 miles by the year 2000. In addition, there are many more

[284] Boghani et al., op. cit., footnote 280, p. 8.

[285] C.K. Leman et al., Institute for Transportation and the Environment, “Rethinking H, O. V.: High Occupancy Vehicle Lanes and the Public Interest, ” discussion draft, May 1993.

[286] Ibid.

projects in off-freeway settings, such as urban arterial streets and bus-only lanes, ranging in length from several city blocks to as many as 10 miles.[287]

Two recent studies suggest both the potential of HOV lanes to reduce the growth of vehicle travel and the difficult y of accurately measuring their effectiveness. The first study examined the effectiveness of HOV lanes on Interstate 5, linking downtown Seattle with its northern suburbs. based on vehicle counts before and after HOV construction.[288] The HOV lane was available in late 1983, and vehicle counts were taken from 1978 to 1989. Adjusting for the growth in the number of households and their income, the study determined that the increase in vehicles was less than had originally been projected (with no HOV lane) for every year after the HOV became available. (As the authors stressed, HOV lanes are judged effective if vehicle counts for the corridor increase more slowly than projected. As population and auto ownership rates increase, travel volume is projected to increase even *with* effective HOV projects.)

In fact, the study determined that the reduction from expected demand levels increased over time, with a 6 percent reduction from projected levels in 1984 and a 35-percent reduction in 1989. The study concluded that based on this reduction of projected travel demand, HOV lane effectiveness in Seattle was comparable to the 10- to 25-percent reduction in congestion thought possible by using road pricing along congested routes.

Despite these encouraging results, the basic assumption of the study—that the HOV lanes were the reason for the decrease—is speculative. In particular, the study did not evaluate or consider other potential factors that may have slowed actual growth in travel demand, such as the availability and use of alternative routes, possible changes in mass transit capacity and use. and especially. shifts in the geographic distribution of employment and residential settlement over the 12-year period. Although the HOV lanes may have had a significant (if not the major) impact in reducing travel demand on Interstate 5, this example illustrates the complex challenge in evaluating precisely the impacts of TDM measures such as HOV lanes, because other factors may increase ridesharing or reduce travel demand.

Using a different measure of effectiveness, another study examined changes in carpooling rates after the construction of a 13-mile HOV lane on Route 55 in Orange County, California.[289] The HOV lane opened in 1987, and within a few years, vehicle occupancy increased between 7 and 9.5 percent. The increased occupancy was significant and greatest for workers using more than half of the 13-mile HOV lane (a 12.3-percent increase in carpooling). Other statisticall y significant changes in carpooling applied to workers retaining the same jobs and residences for at least two years (6.7-percent carpooling increase) and workers traveling between 6 and 9 a.m. (3.5-percent increase). Unfortunatel y. although the increase in ridesharing is clear in this case. the net impact on total transportation demand requires separate measurement because of the potential for increased travel demand caused by reductions in congestion and increased total road capacity. Another source of potential error in HOV lane effectiveness calculations is the potential for such lanes to pull passengers from transit: according to

[287] K.F. Turnbull and D.L. Christiansen, "HOV Lessons," *Civil Engineering*, September 1992, p. 74; and K.F. Turnbull and D.L. Christiansen, "High-Occupancy Vehicle Facilities: An Approach to Solving Congestion and Mobility Problems," *Transportation Research News*, No. 160, May-June 1992, pp. 16-20, 35.

[288] B.S. McMullen and T. Gut, "HOV Lane Effectiveness in Controlling Traffic Congestion," *Transportation Quarterly*, vol. 46, No. 3, July 1992, pp. 429-434.

[289] G. Giuliano, "Transportation Demand Management: Promise or Panacea?" *Journal of the American Planning Association*, vol. 58, No. 3, summer 1992, pp. 329-331.

Pisarski, the socioeconomic characteristics of carpool riders and transit riders are very similar.[290] When carpools pull passengers from transit, measured increases in vehicle occupancy overstate actual declines in vehicle travel.

In conclusion, HOV lanes' effectiveness in reducing vehicle travel is difficult to measure, and the value of HOV lanes, relative to other investments, as a strategy to improve air quality, reduce congestion, and reduce energy use is being increasingly questioned by transportation planners. At the very least, each proposed use of HOV lanes should be carefully evaluated, with the potential for conflicts with transit systems and stimulation of travel fully accounted for in the analysis.

Intelligent Vehicle-Highway System

IVHS encompasses a range of technologies, many still under development, that provide one or both of two basic tools for drivers: so-called smart cars (intelligent vehicles) and smart highways (intelligent highways). These technologies taken together are designed to provide drivers with an array of real-time information, including road and traffic conditions, directions to unfamiliar or distant sites, identification of alternative routes, and determinations of optimal and safe driving speeds and automobile spacing on roads. A 1989 OTA staff paper concluded that existing IVHS technologies could increase road capacity by 10 to 20 percent but that this group of technologies alone is not sufficient to eliminate urban traffic congestion.[291]

IVHS has been presented as a means to reduce gasoline use based on the improved technical efficiency of vehicles in free-flowing traffic. However, IVHS may lead to increased travel and gasoline use by reducing congestion and travel times, so energy savings from improvements in operating conditions must be balanced by this potential travel take back. There is nothing about IVHS, per se, that would encourage ridesharing.

IVHS technologies include advanced traffic sensing and signal control technologies to improve traffic flow, as well as advanced on-board systems to help drivers interpret highway system data to reduce travel time, improve safety, or both. Although at least 60 IVHS-related technologies exist,[292] their broad functions are far less numerous, consisting of three major groups of systems: advanced traffic management (ATMS), advanced traveler information (ATIS), and automated vehicle control (AVCS). Each of these categories possesses technologies with unique roles and differing merits.

Many observers regard the ATMS as the most promising group of IVHS technologies,[293] but that perception is arguably related more to the unique nature of this technological approach than anything else about these technologies. In short, ATMS technologies are designed to monitor traffic via radar and other remote tracking systems, to analyze these data, and to alter traffic flow electronically and automatically by adjusting signal timing and freeway ramp controls, and by providing information on roadside bulletin boards. Unlike the other two major groups of IVHS technologies, therefore, ATMS bypasses direct participation and interaction with the driver and reduces the chance that drivers may not possess, understand,

[290] Pisarski, op. cit., footnote 128.

[291] U.S. Congress, Office of Technology Assessment, Science, Education, and Transportation Program, "Advanced Vehicle/Highway Systems and Urban Traffic problems," staff paper, September 1989, p. i.

[292] P.F. Rothberg, Congressional Research Service, "Intelligent Vehicle Highway Systems: Challenges, Constraints, and Federal Programs," 92-189 SPR, Feb. 18, 1992, p. 1.

[293] See, e.g., D.K. Willis, "IVHS Technologies: Promising Palliative or Popular Poppycock?" *Transportation Quarterly*, vol. 44, No. 1, January 1990, pp. 73-84.

or act on other on-board IVHS technologies. By acting outside the vehicle on the larger transportation system, ATMS technologies may also reduce the potential safety hazards that a complicated or distracting on-board technology could introduce by drawing the driver's attention away from the road, even if only briefly.

ATIS technologies may be used to enhance ATMS tools. ATIS technologies are on-board systems that impart information about traffic conditions and alternative routes and may include electronic maps and navigational tools. Unlike major ATMS technologies, ATIS information may be tailored to an individual driver travel plans and thus, in principle. provide complete information that assists a driver for the entire trip, from departure to final destination. These technologies, therefore, may be especially useful for drivers with multiple route options, assisting both local residents and visiting travelers seeking the best routes during a given day or time.

The third major IVHS category, AVCS technologies. is geared toward traffic safety. These on-board technologies may assist or, in the most extreme cases, replace or override drivers. Assistive AVCS technologies include adaptive cruise control, obstacle detection, and infrared sensing to improve safety for night driving. Other AVCS technologies are designed to intervene directly in driving, including automatic braking, cruise control, and maneuvering: the rationale behind these technologies is to maintain optimal but safe distances between vehicles to improve driving and traffic flow. The most ambitious AVCS technologies under development involve automated driving, where human drivers essentially become passengers until reaching their destinations.

In principle, IVHS technologies aim to make optimal use of road space, while maintaining safe distances from other vehicles and objects. By improving the efficiency of road and lane use, IVHS technologies promise to reduce traffic congestion and driving times, which could reduce vehicle emissions and fuel use per vehicle-mile of travel. but such road improvements could lead to more vehicle-miles traveled.

There are other potential drawbacks to IVHS technologies. First. absent changes in production and implementation costs, their expected expense is substantial]. According to the Federal Highway Administration, installing ATMS technologies on the more than 15.()()0 miles of U.S. urban highways will cost $30 billion to $35 billion,[294] and the costs for on-board technologies will increase this amount further, adding an estimated $1 ,500(0 $2,000 per vehicle, although these costs are expected to decline as production volumes increase.[295] However, if reported estimates of *annual* congestion costs ($30 billion to $100 billion, current dollars) and traffic accident costs ($75 billion to $100 billion, current dollars) are reasonably accurate, then a $30-billion investment in ATMS would be fairly cost-effective If congestion and accident costs were reduced as little as 5 percent per year.[296]

Second, many IVHS technologies may not work well (or at all) incrementally; that is, they require broad applications of road system and vehicular technologies. As a result, incremental investments may not be fruitful, thus limiting the chances of gradual implementation. Third, many on-board ("smart car") technologies require driver interaction and attention, which may reduce safety by distracting drivers, particularly in challenging congestion and weather conditions when they are most likely to use the technologies. Finally. concerns about legal liability in cases when AVCS technologies fail and cause accidents may limit industry interest in these tools.

[294] "Back to the Future, Part II: Smart Cars," *The CQ Researcher*, vol. 3, No. 14, Apr. 16, 1993, p. 330.

[295] Rothberg, op. cit., footnote 292, p. 21.

[296] This would allow a simple payback within 3 to 7 years. The $30-billion annual congestion cost figure is from U.S. Congress, Office of Technology Assessment, *Delivering the Goods: Public Works Technologies, Management, and Financing*, OTA-SET-478 (Washington, DC: U.S. Government Printing Office, April 1991), Summary, pp. 1-2. The remaining congestion and accident cost figures are from ibid., pp. 16-17.

Despite these potential drawbacks, congressional interest in IVHS technologies has increased markedly in the last several years. The Intermodal Surface Transportation Efficiency Act of 1991 (Public Law 102-240) authorizes a total $659 million for IVHS research and development for fiscal years 1992 through 1997.[297] Also, at least $150 million in additional IVHS funds are authorized by 1992 Department of Transportation funding. This amount represents a major increase from earlier IVHS authorizations, which totaled about $4 million in 1990 and $24 million in 1991.[298] These projects will help determine IVHS impacts on traffic flow, congestion, and road safety, but the impacts on total vehicle travel and energy consumption (the focus of this report) are worth examining as well.

Improved traffic signaling

Although this is often discussed in the context of broader IVHS applications, changes in traffic signaling have already demonstrated their potential to reduce traffic congestion without major investments in IVHS projects. For example, urban travel times have been reduced as much as 25 percent by improved timing of traffic lights. In Los Angeles, the Smart Street project around the University of Southern California has reportedly reduced both travel time and fuel use about 13 percent.[299]

Conclusions

Some of the more optimistic evaluations of transportation demand management strategies suggest that they may reduce peak hour travel volumes by 10 to **25** percent, depending on the strategy chosen and how aggressively it is applied, and they conclude that in some cases, travel volume and congestion may be reduced even further, although the political and economic costs would likely prevent implementation.

OTA believes that estimates such as these should be treated as highly uncertain, and policymakers should recognize the large variability of TDM effectiveness, depending on location and circumstance, as well as the experimental nature of many TDM initiatives. Nevertheless, there is enough positive experience with certain types of TDM measures—moving to paid parking is an obvious example—that policy makers can expect strong] y positive results with well-designed TDM programs.

Current information suggests, however, that no TDM measure by itself will eliminate traffic congestion, and no TDM measure will significantly reduce congestion in all circumstances. Moreover, some TDM strategies may increase transport energy use by improving traffic flow, thereby encouraging more and perhaps longer trips. Identifying the best TDM strategies for a city or region will depend on the nature of the major problem (congestion, air emissions, energy use) and the particular conditions of the corridor under consideration, whether city, county, or region.

Finally, transportation policy planners should appreciate several other points about current TDM strategies:

- State and local authorities generally do not pursue TDM to conserve energy.
- Most TDM strategies have not been implemented on a large scale, and most have not yet been adequately evaluated, particularly from the perspective of energy consumption.
- Most TDM strategies implemented thus far have focused on worktrips, although these represent only about one-quarter of all trips.
- Any reduction in existing transportation demand has the potential to spur latent demand. Consequent] y, promising results from employer-based or metropolitan-based programs should be considered tentative until the effect on total regional travel (and energy use) is understood.

[297] Public Law 102-240, 105 Stat. 2194, sec. 6058(a)-(b),

[298] Rothberg, op. cit., footnote 292, summary page, p. 1.

[299] Willis, op. cit., footnote 293, p. 77.

- Given the variety of TDM options and the conditions that determine which will be optimal in addressing travel demand, selecting or implementing specific programs is necessarily a local exercise. Thus, Federal transportation policy planners would do well to support and encourage (rather than direct) local choices in the selection of optimal TDM strategies.

REDUCING FREIGHT ENERGY USE

Policy Context

This section offers policy options to increase the energy efficiency of the freight transport system. Several points, which are common to all policy options, provide the setting within which to consider them.

1. **Freight transport plays a key role in the economy,** and national goals for the freight transport system may not always be consistent with energy efficiency. Desirable attributes of a freight transport system include low cost, high reliability, high speed, high flexibility, minimal losses and theft, and high availability. In many cases, increased energy efficiency can reduce costs and thereby improve the freight system overall;[300] however some policy options to increase energy efficiency-such as reducing speed limits—may adversely affect other goals (in this case, speed of goods delivery). These tradeoffs must be recognized when making policy decisions.
2. **The freight transport industry itself is a significant part of the economy—for example,** about 2.1 million people are directly employed in the industry.[301] Policies affecting the energy efficiency of the industry could significantly affect the industry in other ways as well—for example, shifting freight from trucks to trains would certainly shift employment as well—and these effects must be recognized.
3. **The Federal Government has long played a role in the freight industry: 1)** The national highway system was initially rationalized in part for national defense and is now used by trucks, which are responsible for a significant fraction of the maintenance requirements of these highways.[302] 2)Navigable Waterways used by freight barges are often dredged and maintained by the Army Corps of Engineers. (3) Railroads, which operate on privately owned rail networks, were originally regulated as a response to monopoly pricing practices and an attempt to ensure appropriate pricing. At present, many freight modes are regulated and subsidized in different ways, and policy changes affecting the industry should recognize the history of regulation and the current pattern of subsidies in the industry.
4. **Evidence from past successes and failures in policies to influence automobile energy efficiency should be used to craft successful policies for truck energy efficiency.** In the last 20 years the Federal Government has tried a variety of approaches to increase the energy efficiency of the private automobile fleet, including requiring energy consumption labels, fuel economy standards, and financial incentives (e.g., the gas guzzler tax). Many of these ap-

[300] For trains, energy is 7 percent of total operating expenses (including depreciation, from Interstate Commerce Commission, Office of Economics, *Transport Statistics of the United States* (Washington, DC: 1991), pp. 9-10). For trucks, the figure is about 8 percent (including depreciation), from U.S. Department of Commerce, *Motor Freight Transportation and Warehousing Survey: 1990*, BT/90 (Washington, DC: November 1991).

[301] Bureau of the Census, op. cit., footnote 259, p. 407.

[302] Whether or not trucks pay their "fair share" of these costs is a contentious issue; however, a Congressional Research Service analysis of Department of Transportation research states, "Most heavy trucks do not pay their fait share for use of Federal-ai(i highways, according to the U.S. DOT.'" Congressional Research Service, "Trucks and Public Policy," 91-15E, p. 5.

preaches could be used with freight trucks as well.

What Is the Potential?

The future potential for energy conservation in the freight sector lies largely with reducing truck energy use, because trucks consume the major part of U.S. freight energy—more than 80 percent. The technical and operational potentials for reducing truck energy use were discussed in chapter 2. As noted there, demonstration runs combining commercially available technology, highly trained drivers, and ideal operating conditions yield impressive efficiencies--50 to 70 percent greater than the existing fleet. These results may not be achievable in day-to-day operation, but they do provide an upper bound on what could be achieved with today's technologies. If all heavy trucks achieved this level of energy efficiency, energy use would drop by about 0.9 quads, or 15 percent of total freight transport energy use.[303]

Aside from these technical improvements, truck energy use can be reduced by shifting to alternative freight modes. Each freight mode has characteristics (see table 5-12) that are best suited for certain cargo. For example, trains and barges can move high volumes of goods at low cost, yet tend to be slower than trucks and are restricted to existing tracks and waterways; they are therefore best suited for long-distance transport of high-density basic commodities such as coal and grain. Trucks and air can respond quickly to new demands, can go almost anywhere, and are generally fast and reliable, but cost more as well; they are therefore best suited for distribution of higher-value-added intermediate and consumer goods.

TABLE 5-12: Attributes of Freight Transport Modes

	Rail	Truck	Barge	Air
Geographic coverage	M	H	L	H
Speed	M	H	L	H
Energy efficiency	H	M	H	L
cost	L/M	M/H	L	H

KEY H = high M = medium L = low

SOURCE Off Ice of Technology Assessment 1994

In recognition of these varied attributes, intermodal transport (use of multiple modes) has been growing rapidly. This typically involves using trucks for local pickup and delivery, and trains for long-distance hauling. The same container or trailer is used by both trucks and trains to reduce transfer delays and minimize losses and theft. Some transportation companies are investing in multiple modes: one large trucking firm, for example, recently made agreements with several railroad companies, and is investing in containers that can be carried by both trucks and trains.[304] The growth of intermodal movements--especially double-stack containers on flatcars--has led to trains taking an increasing share of these long-distance movements in corridors where train service is available.

Although each mode has markets that are best suited for it (e.g., commodities by train and barge, shorter-haul time-valued goods by truck), trains and trucks do compete in some markets. One analysis identified commodities-including motor vehicles, paper, and chemicals—that collectively account for more than one-third of both truck and train ton-miles.[305] Although data on just where trucks and trains carry these products are not available, there is general agreement that trucks and trains do sometimes compete for the same movements.

These competitive markets are not well defined, but in general, for long-distance move-

[303] The best commercially available trucks are 62 percent more efficient than the existing fleet (see chapter 2, table 2-6, average of 72 and 51 percent, respectively), therefore replacing the fleet will reduce energy use (1-1/1.62) or 38 percent. Heavy trucks account for about 51 percent of truck energy use (chapter 2, table 2-3). trucks use 4.9 quads per year (table 2-2); therefore savings = 4.9 x 0.38 x 0.51 = 0.9 quads.

[304] "Every Problem Is an Opportunity (J. B. Hunt Transport Services)," *Fortune*, Nov. 16, 1992.

[305] In 1987 "Key Commodities in Rail Truck Competition," *Intermodal Trends*, published by the American Association of Railroads, Mar. 3, 1989.

ments of basic commodities, trains (and barges, if waterways are available) are the dominant mode. For long-distance movement of intermediate and manufactured goods, trains and trucks often compete; however the trend in recent years is toward greater use of intermodal transport (containers or trailers on trains). For intermediate movements—600 to 1,600 miles—the two modes often compete, and neither mode dominates.[306] For short-distance movements—less than about 600 miles—trucks are used almost exclusively because the y offer door-to-door service and minimal loading time.

The energy savings of shifting freight from truck to rail is made uncertain by the nature of most freight energy data; they measure total energy use by mode, but the mix of products carried by different modes is quite different. For example, in 1990, the average energy intensity for intercity freight movement by truck was 3,357 Btu per ton-mile, whereas the average intensity for intercity freight movement by train was 411 Btu per ton-mile,[307] or a ratio of 8: 1. However, an examination of the energy consumption by both trucks and trains for moving *identical cargo over the same route,* for a few specific cargoes and routes, suggests that *trucks use* 1.3 to 5.1 *times as much energy as do trains to move the same cargo over the same route.*[308] *This* study found that trains generally use 150 to 310 Btu per ton-mile to move mixed freight over long distances, whereas trucks use about 770 to 980 Btu per ton-mile for the same service.[309] Many other estimates have been made of modal energy efficiency-including some that try to include not only the propulsion energy (i.e., energy required to move freight from one point to another), but also the energy associated with vehicle manufacturing, road and rail construction, maintenance, and access (getting freight to and from the terminal). A comprehensive but dated review of these estimates found that they vary widely (suggesting that such numbers be used carefully); and estimated that including all of these factors would yield about a 1.7:1 truck-to-train energy use ratio.[310] These estimates suggest that for long-distance movement of some commodities, the energy savings from shifting freight from trucks to trains could be significant, but much less than would seem to be the case from a simple examination of average energy intensities.

A second key unknown in estimating the energy savings potential of mode shifts is the amount of freight that could be shifted. One study estimated that trucks move 54 percent. and trains 46 percent, of the nonbulk, long-haul (more than 500 miles) freight traffic.[311] For an extreme case in which *all* 308-billion ton-miles of this long-distance truck traffic shifted to trains, net savings would be about 0.2 quad if only propulsion energy is considered,[312] and about 0.4 quad with propulsion, vehicle and infrastructure construction, maintenance, and access energy.[313]

Shifting *all* the competitive freight would represent a doubling of present-day king-haul nonbulk train movements, and therefore would re-

306.. Trends in Truck/Rail Market Share, " *Intermodal Trends,* published by the American Association of Railroads, Apr. 17, 1992.

307 Davis and Strang, op. cit, footnote I 34, p. 2-25.

308 Abacus Technology Corp. *Rail vs. Truck* Energy *Efficiency,* contractor" report for the Federal Railroad Administration, April]991, p. 7-15. For long-haul service, including effects of circuity.

309 Ibid., p. 7-4.

310 Congressional Budget Office, ""Energy Use in Freight Transportation," staff working paper, February 1982. This estimate is for a trailer on flatcar train and an intercity truck.

311 ". Trends in Truck/Rail Market Share, " op. cit., footnote 306.

312 Assuming 875 Btu per ton-mile for trucks and 230 Btu per ton-mile for trains, as in Abacus Technology Corp., op. cit., footnote 308, p. 7-4.

313 Assuming 3,420 Btu per ton-mile for trucks and 2,040 Btu per ton-mile for [rains, as found by Congressional Budget Office, op. cit., footnote 310. This estimate is for a trailer on a flatcar train and an intercity truck.

quire expansion in the train system. Existing rail networks are not capacity-constrained, and improved information technologies would allow greater use of existing tracks. However, some new tracks would have to be built in areas not presently served, and more locomotives and freight cars would be needed. In addition, some intermodal transfer points are already heavily used and would require expansion or relocation. Such a shift would also have significant effects on the train and truck industries themselves.

Policy Options

Methods to increase freight transport energy efficiency include greater use of commercially available technologies (such as improved aerodynamics, tires, and engines), promotion of the commercial availability of new and developing technologies, operational improvements (notably reduced speed and idling), and truck-to-train mode shifts. Policy options include financial incentives such as taxes and subsidies; regulations such as fuel economy standards and speed limits; changes in Federal testing, research, and development; changes in Federal procurement; early retirement programs; and improvement of intermodal infrastructure (table 5-13).

Financial Incentives

Energy taxes

One policy option for reducing energy use is to increase the price of energy. This can be done with an energy tax. Such a tax could take many forms, including:

- Btu tax based on energy content,
- carbon tax based on carbon content,
- simple percentage tax based on current price, and
- flat tax per gallon.

Diesel fuel is already taxed by both the States and the Federal Government. The current tax is in the form of a flat tax per gallon.

Energy taxes are a contentious issue. Arguments *in favor of* using a fuel tax to promote energy efficiency include the following:

1. It is relatively easy to implement and administer. Mechanisms already exist to collect fuel

TABLE 5-13: Policy Options To Increase Freight Transport Energy Efficiency

	Increased use of technologies	More new technologies	Operational improvements	Mode shifts
Financial Incentives				
Energy taxes	P	P	P	P
Feebates	P	P	—	—
Regulation				
Fleet average requirements	P	P		—
Specific technology requirements	P	—	P	—
Increased truck size/weight limits	—	—	P	N
Enforce/reduce speed limits	—	—	P	—
Federal testing,evaluation, R&D	P	P		—
Federal procurement	P	P		—
Early retirement	P	—		—

KEY P = positive effect, — = little or no effect; N = negative effect.

SOURCE Off Ice of Technology Assessment, 1994 taxes, and the additional administrative cost to the government of increasing the tax would be very low.

2. It can raise considerable revenue. Freight transport consumes about 27 billion gallons of diesel fuel per year,[314] therefore, a diesel tax increase of 1 cent per gallon would generate about 269 million dollars.[315] These funds could then be used to provide incentives to manufacturers and operators for research, development, and purchase of energy-efficient vehicles.
3. From the perspective of economic theory, a tax is preferable to regulation because it guides. but does not constrain, consumer choice. A tax allows users to find their own methods to conserve (e.g., by investing in energy-efficient technologies or by changing driving behavior).
4. It will affect both new vehicle purchase behavior and operation of existing vehicles.
5. U.S. diesel prices are considerably lower than those of other industrialized countries. In Germany, for example, diesel currently costs $2.81 per gallon.[316]

Arguments against using a fuel tax to promote energy efficiency include:

1. The magnitude of energy savings is uncertain. It is generally agreed that, all else being equal, a higher energy price will result in reduced energy use, but there is little agreement on the energy savings per unit of price increase. The savings will depend on the level of price increase, of course. but will also be influenced by the speed and visibility of the price increase (a sudden and widely publicized increase will result in more behavioral change than a gradual, hidden increase).
2. Some users are unaware of the opportunities for efficiency improvements. In these cases, taxes alone without improved information will have no effect on efficiency.
3. It increases the price of goods (to the extent the tax is passed on to consumers). This could have two important detrimental effects: Consumers could reduce consumption, leading to reduced economic output; and the economic competitiveness of U.S. products on world markets could be harmed. The over-al l economic effects, however, will depend on how the tax is structured. A revenue-neutral tax would result in shifts, but not necessarily decreases, in economic output: and if tax revenues were used for economically productive purposes then the net effects on economic output are not clear.
4. It will affect different users different I y—for example, a manufacturer located far from its market will pay more than one nearby. This is not necessarily a disadvantage, because the new price may be "correct" in the economic sense. but the differential effects may have political implications.

Feebates

These programs are discussed earlier in more detail. Feebates, or fee-rebates, combine rebates to purchasers of efficient vehicles with surcharges on purchases of inefficient vehicles. Feebates can be revenue-neutral. by having the surcharges cover the costs of the rebates and the administrative costs. Such a program provides a financial incentive for efficiency without requiring an increase in government expenditures, and is more flexible than a mandated approach such as a fuel economy standard (discussed below). The disadvantages of feebates include: 1) there is no large-scale program experience, 2) they affect only new vehicle purchases, and 3) they provide no incentive for efficient operation of vehicles. The lack of program

[314] Davis and Strang, op. cit., footnote 134, p. 2-14.

[315] Assuming a price elasticity of demand of 0.5, and a diesel price of $1.

[316] U.S. Department of Energy, Energy Information Administration, *International Energy Annual 1991* (Washington, DC: December 1992), p. 153.

experience—specifically the lack of data on behavioral response to the combination of fees and rebates—makes it difficult to estimate the energy savings potential of such a program.

Feebate programs for trucks incur a special disadvantage because combination trucks are sold as separate trailer and engine units, and because trucks haul very disparate types of cargo. Consequently, feebate programs may have difficulty properly grouping competing vehicles. Further, defining the "average fuel economy" necessary to compute fees and rebates presents a special problem.

Regulations and Government Programs

Performance technology mandates

In 1975 Congress passed the Energy Policy and Conservation Act (Public Law 163), which sets energy efficiency requirements for automobiles and light trucks. These requirements were in the form of a minimum fleet average—the sales-weighted average efficiency of new vehicle sales was required to exceed a value set in the legislation. Although the costs and benefits of this legislation are disputed, there is general (although not unanimous) agreement that these requirements played a large part in the doubling of the average fuel economy of new automobiles—from 14 mpg in 1975 to 28 mpg in 1990.[317] More recently, legislation was passed that set energy efficiency requirements for electric motors, refrigerators, lights, and other energy-using devices. For these devices, minimum efficiency levels were set that all units must meet. An evaluation of these standards found that energy and net cost savings were significant.[318]

The precedent for mandated energy-efficiency goals suggests that such an approach be considered for trucks.[319] A mandated approach to increasing truck energy efficiency could take several forms. A fleet average requirement could be set, as it is for automobiles and light trucks, and manufacturers could determine the best mix of technologies and price incentives to meet the requirement. Such a requirement would have to be normalized to account for different truck sizes and purposes, since some manufacturers produce only full-size trucks, whereas others produce a range of trucks. Alternatively, a minimum efficiency level could be set for each class of truck (e.g., all trucks designed for pulling full-size trailers must achieve a minimum number of miles per gallon).

One complicating factor in structuring such a requirement is the interactive effects of trucks and trailers. Most heavy trucks are designed to attach to trailers, and the fuel economy of the combined truck-trailer depends in part on the aerodynamics of the trailer. There is a large existing fleet of trailers that turn over relatively slowly; therefore it would be inappropriate to require truck manufacturers to meet efficiency levels that require the use of new, aerodynamically integrated trailers.

A milder regulatory approach might involve the requirement of excess idle and/or speed warning lights, speed governors (already in use by some truck fleets), and automatic shutdown to eliminate excess idle.

Advantages of a regulatory approach include:

1. It can result in large energy savings. As noted above, regulations setting energy use for electric motors, heating and cooling equipment, lights, automobiles, and light trucks are already in place, and by most accounts have (or are expected to) resulted in large energy savings.
2. It is relatively inexpensive for the government to implement and enforce.
3. It would speed implementation of existing or near-market technologies. As discussed above,

317 See Office of Technology Assessment, op. cit., footnote 7, p. 20-22, and the discussion earlier in this chapter.

318 See discussion in U.S. Congress, Office of Technology Assessment, *Building Energy Efficiency*, OTA-E-518 (Washington, DC: U.S. Government Printing Office, May 1992), p. 111.

319 The setting of appropriate regulations would require much better data on truck size, use, energy consumption, age, and so forth than currently exist.

technologies are available that significantly improve efficiency.

Disadvantages include:

1. It is difficult to determine the optimal level at which to set the requirement. The cost-effective level of efficiency will depend in part on fuel costs, which can fluctuate.
2. It may raise the cost of new trucks, thereby slowing fleet turnover (and reducing energy savings).
3. Regulations limit consumer choice. Some argue that consumers, not the government, are best qualified to choose their preferred efficiency level.
4. It can increase the costs of vehicle production significantly if manufacturers are forced to retool production lines.
5. It affects only new vehicles and provides no incentive for efficient operation of trucks. The very high efficiencies achieved in some trucks (see, for example, table 2-6) resulted from both efficient technologies and careful driving; it would be inappropriate to expect such results from all drivers.

Increasing allowable truck weight and size

All else being equal, larger trucks are more efficient in terms of Btu per ton-mile. However, increasing allowable truck size may encourage mode shifts from trains to trucks, reducing the net energy efficiency gains. In addition, there are safety concerns with larger trucks that are as yet unresolved.[320] These issues suggest that further study is needed before increasing size or weight limits.

Improved enforcement or reduction of speed limits

There is a considerable energy efficiency penalty from higher speeds. One generally accepted rule of thumb is a 2.2-percent mileage penalty for each mile per hour above 55.[321] Despite the energy penalty, however, highway speeds have been increasing since 1974. Improving enforcement of existing speed limits, and reducing speed limits from 65 to 55 mph, are policy options to consider. Reduced speed limits will also enhance safety and, unlike many other options, affect the entire fleet and not just new vehicles. The chief disadvantage is the increased time requirement, with its attendant cost penalty.

Recent data indicate that the average speed for all traffic on rural interstate highways with a 55-mph speed limit is 60 mph. If this average applies to trucks as well, reducing average speeds from 60 to 55 mph would reduce energy use by *2.2* percent/mph x 5 mph, or 11 percent. Trucks currently consume about 5 quads of energy (table 2-2), and about two-thirds of truck miles are for nonlocal service.[322] If three-fourths of nonlocal truck-miles occur on highways, and highway truck-miles are twice as efficient as nonhighway truck-miles, reducing average truck speeds from 60 to 55 mph should save about 0.2 quad per year of freight energy.[323]

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[320] For a discussion of these issues see U.S. General Accounting Office, *The Safety of Longer Combination Vehicles Is Unknown*, GAO/RCED-92-66 (Washington, DC: March 1992).

[321] See L. Johnson et al., "Energy Contingency planning for Freight Transportation," ANL CNSV-34 (Argonne, IL: Argonne National Laboratory, August 1982), also American Trucking Associations, The Maintenance Council, *55 vs. 65: An Equipment Operating Costs Comparison* (Alexandria, VA: 1987), p. 7.

[322] U.S. Department of Commerce, Bureau of the Census, *Truck Inventory and Use Survey*, TC87-T-52 (Washington, DC: August 1990), p. US-6.

[323] Highway truck-miles are two-thirds times three-quarters, or one-half of total truck-miles. Assuming they are twice as efficient suggests that they consume 4.9 times one-third, or 1.63 quads; 11 percent of this is about 0.2 quad.

Federal procurement

The Federal Government currently has about 380,000 trucks.[324] Changes in Federal procurement to encourage or require greater energy efficiency in new trucks would save energy by itself, would demonstrate that energy-efficient technologies are available and effective, and would support markets for such products.[325] Although most of the Federal truck fleet consists of light-duty vehicles, the Federal government does purchase a significant number of medium- and heavy-duty trucks. The General Services Administration, the major purchaser of vehicles for the U.S. government, does not have energy efficiency requirements in its specifications for medium and heavy trucks. These specifications could be modified to include minimum mile-per-gallon requirements.

Federal R&D and information programs

At present, the Federal Government supports little truck energy-related R&D. Although manufacturers do considerable R&D, much of this is targeted at safety, performance, and emissions goals. In an era of flat energy prices, manufacturers see limited market demand for energy efficiency. This suggests that expanded Federal R&D support for energy efficiency may be appropriate.

Investments in energy efficiency require credible and complete information on the costs and savings of such investments. Unfortunately, data on fuel efficiency of trucks are often difficult to find and, where available, difficult to compare across models because there is no standardized testing method. Extending the existing testing and labeling program for light-duty vehicles to freight trucks would provide consumers with the information needed to make optimal energy efficiency choices. There is also a need for testing and certification of energy efficiency retrofit devices, notably aerodynamic add-ens. The effects of labeling programs are difficult to measure,[326] but there are several reasons for the government to implement them: they improve consumer information, they provide manufacturers with a marketing tool to promote highly efficient models, and a government program will probably be seen as more credible than a program run by an entity with a direct economic incentive in the outcome.

Early retirement

One barrier to rapid market penetration of energy-efficient truck technologies is the existence of a large fleet of relatively inefficient (as compared to new units) trucks. Early retirement of old trucks would improve the energy efficiency of the fleet, and offer considerable emissions and safety benefits as well. The disadvantages of such a program include possible adverse equity effects and questions about its cost-effectiveness.[327] There is insufficient experience with such programs to mount a large-scale early retirement effort; however, it may be appropriate to investigate smaller, experimental programs to see how well they work.

Promotion of intermodal freight movement

Intermodal movements have been growing rapidly, but there is room for this growth (o be accelerated. A recent survey of shippers found that the

[324] U.S. General Service Administration, *Federal Motor Vehicle Fleet Report* (Washington, DC: September 1990), pp. 27, 35. Heating value of 122,050 Btu per gallon assumed (average of diesel and gasoline values).

[325] These issues are discussed in U.S. Congress, Office of Technology Assessment, *Energy Efficiency in the Federal Government: Government by Good Example*, OTA-E-492 (Washington, DC: U.S. Government Printing Office, May 1991).

[326] Evaluation of appliance labels is discussed in Office of Technology Assessment, op. cit., footnote 318, pp. 113-116.

[327] Early retirement ~) fears is discussed in (-1. S. Congress Office of Technology Assessment, *Retiring Old Cars: Programs To Save Gasoline and Reduce Emissions*, OTA-E-536 (Washington, DC U.S. Government Printing Office, July 1992).

major barrier to greater use of intermodal movements is the belief that intermodal transport is too slow or unreliable.[328] The causes of delay in intermodal service include excess circuity (i.e., unavailability of direct-route tracks) and, perhaps most important, excessive delays at terminals. Many terminals are located in urban areas, are too small for their volume of traffic, and are difficult for trucks to access. Infrastructure changes, such as truck-only access roads from highways to intermodal terminals, or relocating terminals outside of urban areas, could be considered. The Intermodal Surface Transportation Efficiency Act of 1991 (Public Law 102-240) established a National Commission on Intermodal Transportation (section 5005), and requires the Commission to report to Congress on barriers to greater use of intermodal service. Congress could consider the recommendations of the Commission carefully, with the recognition that improved intermodal service could have significant energy efficiency benefits.

[328] Intermodal Association of North America and the National Industrial Transportation League, 1992 *Intermodal Index* (Riverdale, MD December 1992), p. 14. Railroads in general suffer from a reputation for unreliability and poor service; however, this is starting to change—see "Big Rail Is Finally Rounding the Bend," *Business Week*, Nov. 11, 1991, pp. 128-129.

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