NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 43

ENERGY EFFECTS, EFFICIENCIES, AND PROSPECTS FOR VARIOUS MODES OF TRANSPORTATION

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
- TRANSPORTATION ADMINISTRATION
- TRANSPORTATION ECONOMICS
- URBAN TRANSPORTATION ADMINISTRATION
- URBAN TRANSPORTATION SYSTEMS
- RAIL TRANSPORT
- AIR TRANSPORT
- WATER TRANSPORT

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1977

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the National Academy of Sciences, or the program sponsors.

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PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of special interest and usefulness to transportation planners, administrators, and others seeking information on fuel efficiency and conservation in transportation. Detailed information is presented on energy efficiencies for both passenger and freight transportation modes.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information often is fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem frequently is not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems. Syntheses from this endeavor constitute an NCHRP report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems.

Conservation of energy used for transportation is of vital concern to the nation. This report of the Transportation Research Board details the efficiencies of various vehicles and modes for both passengers and freight under various conditions. Modes considered include highway, bus, rail, air, water, bicycle, and pipelines. The potential impacts of alternative energy-conservation options are evaluated, and research needs are identified.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

ACKNOWLEDGMENTS

This synthesis was completed by the Transportation Research Board under the supervision of Paul E. Irick, Assistant Director for Special Projects. The Principal Investigators responsible for conduct of the synthesis were Thomas L. Copas and Herbert A. Pennock, Special Projects Engineers. This synthesis was edited by Deborah K. Farmer.

Special appreciation is expressed to Myron Miller of Sharpsburg, Md., who was responsible for the collection of data and preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Alexander French, Chief, Highway Statistics Division, Office of Highway Planning, Federal Highway Administration; John Hemphill, Office of Transportation Research, Federal Energy Administration; Thomas H. May, Director, Bureau of Transportation Planning Statistics, Pennsylvania Department of Transportation; Robert Nutter, Systems Analyst, Office of Transportation Energy Policy, Office of the Secretary, U.S. Department of Transportation; Richard Shackson, Director, Environmental Research Office, Ford Motor Company.

Stephen E. Blake, Environmental Specialist, Transportation Research Board, and Paul V. Svercl, Highway Engineer, U.S. Department of Transportation, assisted the Special Projects Staff and the Topic Panel.

Information was provided by many agencies. Their cooperation and assistance was most helpful.

ENERGY EFFECTS, EFFICIENCIES, AND PROSPECTS FOR VARIOUS MODES OF TRANSPORTATION

SUMMARY

National concern recently has been focused on energy consumption and conservation. A major area for potential energy savings is transportation, which accounts for one-quarter of the total energy and one-half of the petroleum used in this country. Consumption of energy for transportation includes various modes of passenger travel and of freight movement. The energy use of each mode has many dimensions. *Comparisons of modes should be made on a common basis, and full consideration should be given to all aspects of the modal-system energy use*. Some of the factors that must be considered are load factor, circuity, empty backhauls, speed, nature of cargo, safety, costs, social acceptance, and all-weather characteristics.

The demand for passenger transportation is relatively price inelastic, because a large portion is considered essential travel. The cost or value of time, however, is an important element in a traveler's choice of mode. The value of time varies with trip purpose and income level but is usually high enough so that changes in fuel costs have only a small effect on transportation operating costs. Thus, neither fuel economy nor energy intensiveness is or will be the sole factor in choice of passenger transportation modes unless the price of energy becomes so large as to dominate all other costs.

Automobile travel comprises the predominant use of energy for passenger transportation. Reductions in automobile fuel consumption may be realized through modifications in design or changes in use. Current energy intensiveness of automobiles ranges from 2,310 to 7,400 Btu/passenger-mile (1.51 to 4.85 MJ/passenger-km), depending on trip purpose, vehicle fuel economy, and occupancy rate.

Bus efficiency ranges from 743 to 2,681 Btu/passenger-mile (0.49 to 1.76 MJ/passenger-km), depending on type of bus, type of trip, and occupancy rate. Only modest improvements can be expected in the fuel economy of buses.

Rail passenger service may become more efficient as service becomes concentrated in corridors (such as Boston-Washington). Substitution of electrified lines for diesel could save petroleum. Regenerative braking and lighter designs may also increase efficiency. Current energy consumption for rail passenger service varies from 1,646 to 3,533 Btu/passenger-mile (1.08 to 2.32 MJ/passenger-km), depending on type of service and occupancy rate. The greatest potential for increasing the efficiency of this mode lies in increasing load factors.

Air passenger service by certificated carriers averages about 7,800 Btu/passenger-mile (5.1 MJ/passenger-km). Specific intensity of a flight depends on plane type, stage length, and load factor. The greatest potential for increasing the efficiency of air passenger service also lies in increasing load factors.

Bicycles are the most efficient means of passenger transportation, requiring even less energy than walking (less than 100 Btu/passenger-mile—64 kJ/passenger-

km). The bicycle is still a very small part of passenger transportation, however, and its use is not likely to increase significantly.

Water passenger transportation is primarily recreational, and any reduction in its energy use would most likely come from reduced use or substitution of sails for engine power.

Freight transportation currently consumes about 28 percent of transportation energy; however, this may be greater in the future. When comparing efficiencies of various modes of freight transportation, it is not enough to compare ton-miles per gallon. Attention also should be given to such items as trip length; transport time; commodity value, perishability, and fragility; freight density; and manufacturing flow processes. *Comparisons should be made only if the data address the same markets and are related to the performance of the same transportation job.*

Data on truck fuel efficiency vary considerably. Intercity combination trucks have an average efficiency of about 2,700 Btu/ton-mile (2.0 MJ/t-km), and single-unit trucks average about 8,000 Btu/ton-mile (5.8 MJ/t-km).

Average rail-freight efficiency is about 675 Btu/ton-mile (0.49 MJ/t-km). Increased rail electrification should save petroleum, and future electric locomotives should also save energy.

Air freight is efficient when the belly capacity of scheduled passenger aircraft is used—about 3,100 Btu/ton-mile (2.2 MJ/t-km). An all-cargo plane is much more energy intensive—27,000 Btu/ton-mile (19.5 MJ/t-km).

Water freight primarily handles raw materials and bulk commodities. Water carriers are very energy efficient. Energy intensiveness of domestic carriers is estimated at about 650 Btu/ton-mile (0.47 MJ/t-km).

Data on the energy intensity of pipelines are lacking. Estimates based on limited data indicate energy efficiency of about 550 Btu/ton-mile (0.40 MJ/t-km) for all petroleum product pipelines, although values for large-diameter pipelines may be somewhat lower.

Opportunities for reducing transportation energy fall into five categories: (1) shift to more efficient modes, (2) increase load factors, (3) reduce demand, (4) increase energy conversion efficiency, and (5) improve use patterns.

Improving highway vehicle efficiency will be the most important option in the next decade for three reasons: the savings potential is greatest, efficiency gains will have little impact on service quality, and implementation can reduce total cost of transportation.

Load factor improvements are also important. Although inconveniences might make them unattractive for many users, such improvements could be implemented quickly with little or no capital costs and could add significantly to energy efficiency.

Operational improvements in use patterns and declines in growth rates will reduce energy consumption. Modal shifts offer theoretical savings, although they are not likely to be induced by fuel price increases.

Knowing what actions will conserve energy is not the same as making them happen. Transportation generally represents a small percentage of the total costs of goods and services, and energy is a small percentage of transportation costs; thus, the demand for transportation energy is price inelastic. Conservation measures for the private automobile are most critical, because automobiles use 55 percent of total transportation energy. To conserve energy, automobiles must not only be made more efficient, they must be used more effectively. Policies are needed to make conservation practices more attractive to individuals.

Research is needed to obtain more accurate data on fuel use, vehicle-miles traveled, automobile occupancy, and passenger-miles on public transit. Modal averages for energy consumption can be misleading when one is trying to determine the effects of modal shifts; more study is needed in this area. Most compelling is the need for research on implementation policies that will effect transportation energy conservation.

Conclusions of this synthesis include the following:

- Great care needs to be exercised in comparisons of the energy intensity of one mode with that of another. Emphasis should be on the mode's efficiency in performing the particular job or service.
- Producing and using more efficient modes of transportation do not necessarily mean using less energy.
- Energy conservation gains of more efficient automobiles may be offset by increased use unless an effort is made to promote more responsible use.
- The effects of technological improvements in fuel economy are 5 to 15 years away; early conservation depends on better use of existing technology.

CHAPTER ONE

INTRODUCTION

BACKGROUND AND SCOPE

National concern has been focused on energy consumption and conservation. One-quarter of the nation's energy use and one-half of its petroleum consumption are devoted to transportation. Thus, significant energy and petroleum savings can be realized through improved fuel efficiency and conservation in transportation. A large body of literature is available and has been examined in the preparation of this synthesis, which documents the efficiency of various transportation vehicles under various conditions and includes the specifics of circumstance, assumptions, and sources. The synthesis addresses the prospects of achieving such efficiencies for the various transportation modes evaluated.

In recent years a number of papers concerning the transportation energy sector and the energy efficiencies of the various transportation modes have been written. Many of these papers focus on specialized portions of the problem, such as urban passenger transportation or intercity air transportation. This report is a synthesis of the work of many others and presents an encompassing view of transportation's use of energy. The emphasis is on information regarding transportation energy use and conservation potential, not on the implementation policies necessary to achieve this greater conservation. Neither does this document address the need for energy conservation, because the case is already well stated in the Federal Energy Administration's "National Energy Outlook" (*1*).

TRANSPORTATION VS. OTHER ENERGY USERS

In 1973, one-fourth of the total gross energy consumption in the United States was expended in the transportation sector, primarily for automobile and aircraft trip-making. In the nontransportation sector, space heating and process steam accounted for 18 and 16 percent, respectively, of the total gross energy consumption in 1973. Figure 1 shows a breakdown of the U.S. gross energy end uses by various use categories. Figure 2 shows U.S. gross energy consumption by sector for the years 1960 to 1975. Table 1 gives U.S. energy consumption trends from 1850 to 1976. The rapid growth in petroleum use resulted mainly from automobile use; it can be observed from Figure 3 that in 1976 approximately 70 percent of transportation's use of energy was in the form of gasoline. Energy consumption and energy demand for various use categories have been such that if past trends were to continue without any abatement, total energy consumption would increase to approximately 123×10^{15} Btu (130×10^{18} J) by 1985. (A list of energy equivalents and energy-conversion factors is contained in Appendix A and Table A-1.)

COMPARATIVE ENERGY USE BY VARIOUS MODES

Figure 4 and Table 2 summarize total direct transportation energy (TDTE) consumption in 1972. Through calculation of an energy coefficient for each sector of the U.S. economy, it has become possible to apply input-output techniques to estimate the indirect energy costs associated with

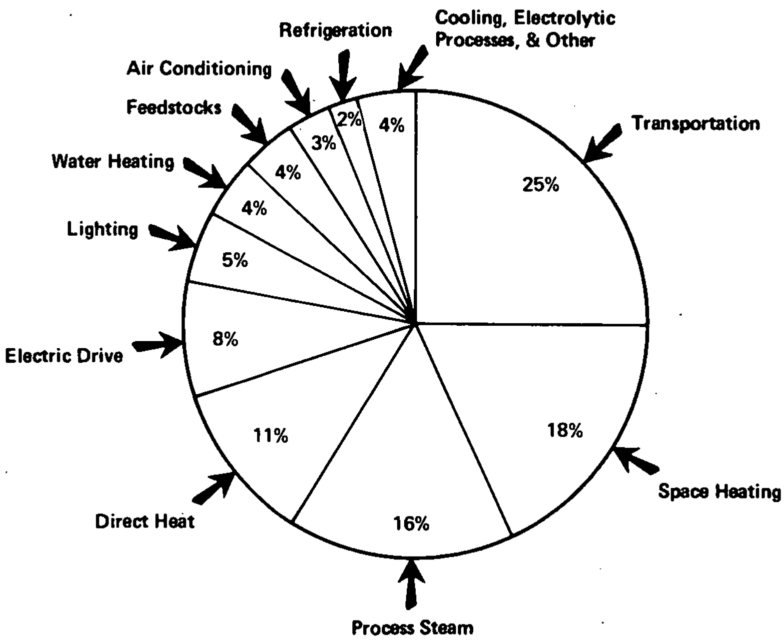


Figure 1. U.S. gross energy end uses, 1973 (total gross energy use: 74.7 × 10[15] Btu). (Source: U.S. Energy Prospects: An Engineering Viewpoint, *Natl. Academy of Engineering, 1974, p. 26.)*

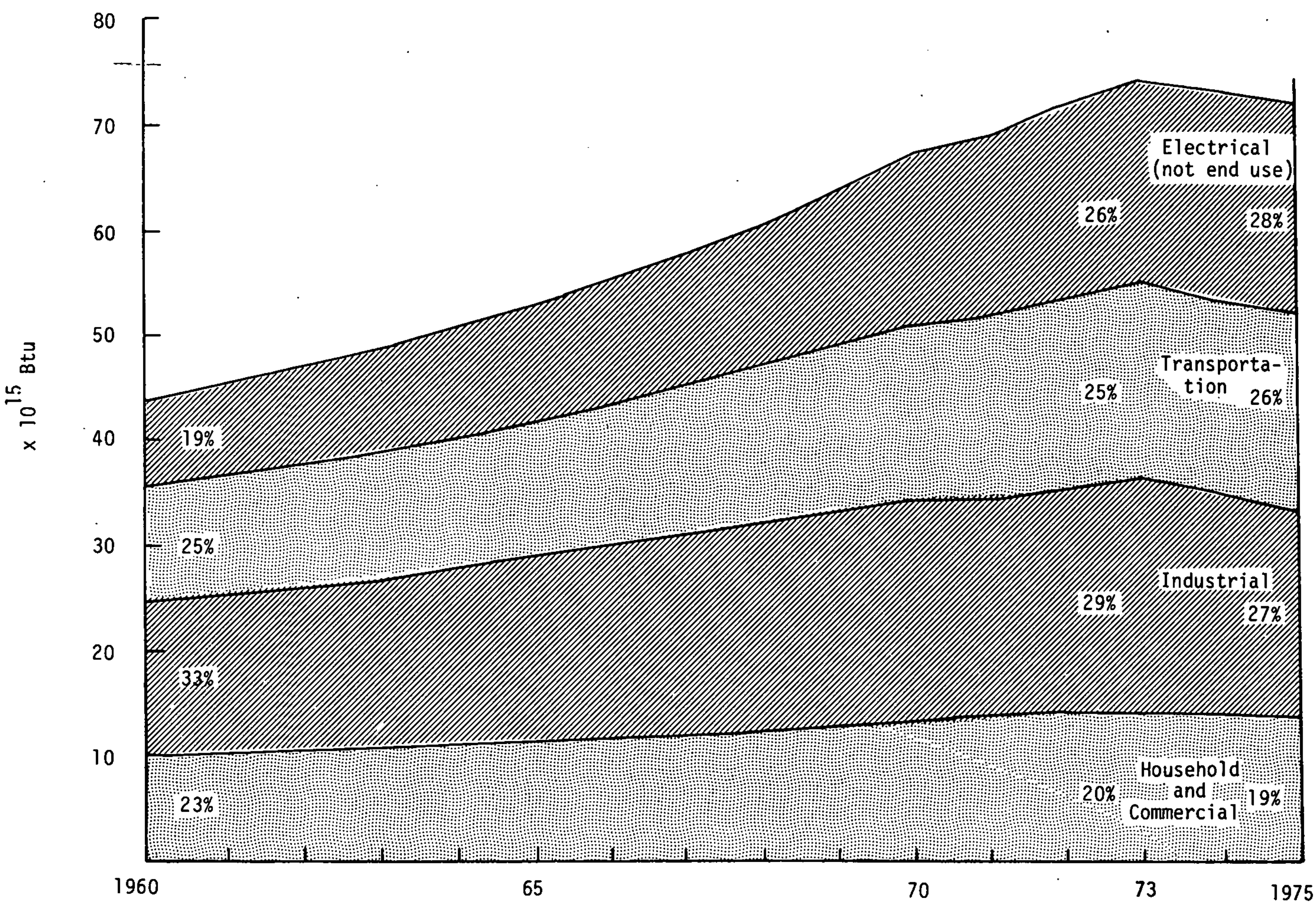


Figure 2. U.S. gross energy consumption, by sector, 1960–75. (Source: U.S. Bureau of Mines, 1976.)

various forms of economic activity (*3*). Figure 5 (based on 1963 and 1967 factors) shows that where indirect uses are included, transportation accounts for more than 40 percent of total energy consumption. These indirect energy flows are attributed chiefly to the following:

- Refining and distribution losses of transport fuels.
- Manufacture and maintenance of vehicles and equipment.
- Construction, operation, and maintenance of fixed transportation-related facilities, such as highways, airports, truck terminals, tracks, and ports.

Accordingly, a large share of the savings required in the total national conservation effort must come from the transportation sector, directly and indirectly, especially from the automobile, which represents the largest fuel consumer. In fact, the Energy Policy and Conservation Act of 1975 established mandatory average-fuel-economy standards applicable to each automobile manufacturer. The act required that the average fuel economy for passenger automobiles manufactured by any manufacturer in any model year after midyear 1977 shall not be less than the values given in Table 3. (The act contains some variations from the values in the table.)

Table 4 gives the energy and service trends from 1947 to 1975 and projections (made prior to the 1973 Arab oil embargo) of transportation industry activity for the period 1980 to 1990 using a 1972 base year.

Table 5, from Federal Highway Administration data (*6*), gives a detailed summary of U.S. highway fuel use yearly from 1919 to 1975.

The Department of Transportation report on energy statistics provides more detail (see Tables 6, 7, 8, and 9) on fuel consumption levels for the various transportation modes.

TABLE 1

U.S. ENERGY CONSUMPTION TRENDS, 1850–1976 (10^{15} BTU)[a] (*2*)

YEAR	COAL	PETROLEUM	NATURAL GAS	HYDRO-POWER	NUCLEAR	FUEL WOOD	TOTAL
1850	.2	-	-	-	-	2.1	2.3
1900	6.8	.2	.3	.3	-	2.0	9.6
1950	12.9	13.5	6.2	1.4	-	1.2	35.2
1960	10.1	20.1	12.7	1.7	-	-	44.6
1970	12.7	29.5	22.0	2.7	.2	-	67.1
1971	12.0	30.6	22.8	2.9	.4	-	68.7
1972	12.4	33.0	23.0	2.9	.6	-	71.9
1973	13.4	34.7	22.8	2.9	.9	-	74.7
1974[b]	13.1	33.4	21.7	3.3	1.2	-	72.9
1975[c]	12.8	32.7	19.9	3.2	1.8	-	70.6
1976[c]+	13.7	34.9	20.2	3.1	2.0	-	74.0

[a] 10^{15} Btu = 500,000 barrels petroleum per day for a year
= 40 million tons of bituminous coal
= 1 trillion cubic feet of natural gas
= 100 billion kWh (based on a 10,000-Btu/kWh heat rate)
= 1.055×10^{18} joules

[b] Data from Ref. *50*.

[c] Data from Ref. *57*.

+Estimated.

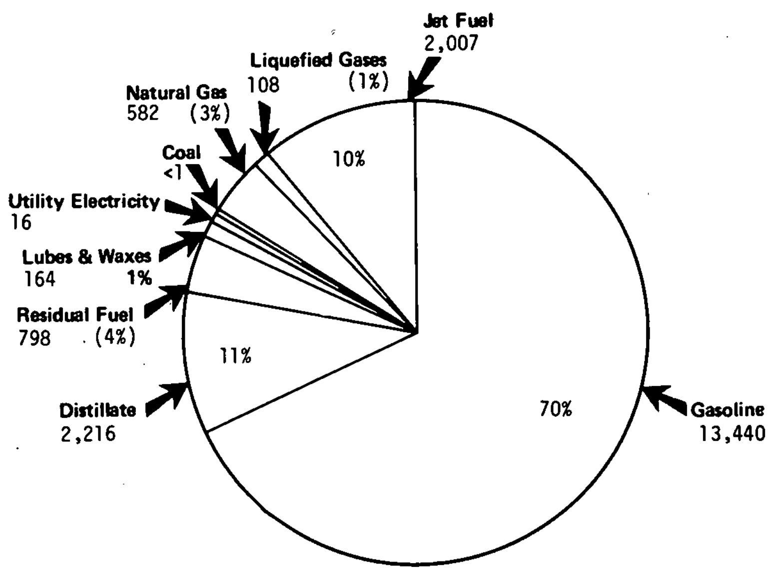


Figure 3. U.S. net transportation energy consumption, 1976 estimate 10^{12} Btu (total net energy consumption: $\times 10^{12}$ Btu) (57).

PROBLEM AREAS AND CONCERNS

The energy intensity of various modes of transportation has many dimensions. To avoid the improper comparison of data, when the energy intensity of one mode is compared with that of another, the comparison should be made on a common basis and full consideration should be given to all aspects of the modal system energy use. One must keep in mind that transportation vehicles must move not only themselves but also their contents. Thus, such operational considerations as load factor, circuity, empty backhauls, and speed are inherent in the energy intensity of any trip or shipment. In addition, the energy required to manufacture and maintain the modal infrastructure can be substantial.

Another fact not to be overlooked is that the nature of the cargo may dictate the choice of transportation mode. For example, very lightweight, expensive cargo generally is moved more readily by air and truck, and very heavy, dense, low-unit-cost cargo generally is moved more readily by rail or barge. The consideration of energy alone may not be the appropriate operational basis for making a decision on how to move cargo.

There are other factors that dictate why one mode is sometimes chosen over another mode that is theoretically superior in energy efficiency. The mode chosen may be more frequent, more convenient, faster, safer, superior in time requirements, more affordable, more socially acceptable, or better in terms of all-weather characteristics. In some cases, a mode may be chosen because no alternative is available.

TABLE 2

DIRECT TRANSPORTATION ENERGY AND RELATED CONSUMPTION BY MODE AND PURPOSE, 1972 (*4*)*

	Thousand Barrels Per Day			Quadrillion BTU's	Percent of Total Transportation Energy
	Gasoline	Distillate†	Other		
Highway					
Passenger Cars					
Private (Personal Use)	3,886.0	–	–	7.46	42.96
Commercial and Other	870.8	–	–	1.67	9.63
Total	**4,756.8‡**	–	–	**9.13**	**52.59**
Single Unit (Light Trucks)					
Private (Personal Use)	669.1			1.29	7.40
Commercial§	705.3	31.9	–	1.42	8.15
Government	32.9	.2	–	.06	.36
Total	**1,407.3**	**32.1**	–	**2.77**	**15.91**
Combination (Heavy) Trucks					
Commercial§	69.4	483.0	–	1.16	6.11
Government	.9	6.2	–	.01	.07
Total	**70.3**	**489.2**	–	**1.17**	**6.18**
Buses					
School	20.4	.4	–	.04	.23
Urban	2.0	18.8	1.6‖	.05	.25
Intercity	3.0	12.1	–	.03	.16
Total	**24.4**	**31.3**	–	**.12**	**.64**
Motorcycles	22.3	–	–	.04	.25
Total Highways	6,281.0	552.6	1.6		
	6,835.1			13.23	75.57
Airways					
Airlines					
Scheduled	–	670.0	–	1.39	7.41
Supplemental	–	6.0	–	.01	.07
Total	–	**676.0**	–	**1.40**	**7.48**
General Aviation	46.0	37.0	–	.17	.92
Military	–	288.0‡	–	.57	3.18
Factory and Miscellaneous	–	20.0	–	.04	.22
Total Airways	46.0	1,021.0	–		
	1,067.0			2.18	11.80
Railways	–	247.3	3.1**	.53	2.77
	–	.8††	–	–	.01
Total Railways	–	248.1	3.1		
		251.2		.53	2.78

TABLE 2 (continued)

	Thousand Barrels Per Day			Quadrillion	Percent of Total Transportation
	Gasoline	Distillate†	Other	BTU's/Year	Energy
Waterways					
Private and Commercial	44.8	65.9	–	.23	1.22
Commercial					
At Port	–	–	41.0	.09	.45
At Sea	–	–	196.0	.45	2.18
Total Waterways	44.8	65.9	237.7	–	–
	348.4			.77	3.85
Urban Public Transit (Nonhighway)††					
Rapid Transit	–	–	3.4	.01	.04
Surface Railway	–	–	.2	–	–
Trolley Coach	–	–	.2	–	–
Total UPT	–	–	3.9	.01	.04
Pipeline					
Total Pipeline	–	167.9‡‡	371.0§§	–	
			538.9	1.15	5.96
Total Transportation Energy	6,371.8	2,055.5	617.3		
	9,044.6			17.86	100.00
Miscellaneous					
Farm Equipment‖‖	134.0	144.0	–	.56	–
Construction Equipment	45.0	281.0	–	.69	–
Utility Engines##	22.0	–	–	.04	–
Snowmobiles	5.0	–	–	.01	–
Race Cars	.5	–	–	–	–
Total Miscellaneous	206.5	425.0	–		–
		631.5		1.30	
GRAND TOTAL	6,578.3	2,480.5	617.3		–
	9,676.1			19.16	

*Data may not agree with Bureau of Mines data as some volumes are estimated and some are based on Federal Highway Administration or tax data which could include changes in secondary inventories.

†Distillate as used includes the full range of middle distillate oils including diesel fuels, kerosine jet fuel, marine diesel and also naphtha jet fuel.

‡Due to the necessity of using data as described in footnote (*), this volume and the respective BTU value does not precisely agree with the values shown by the Patterns of Consumption/Energy Demand Task Group.

§Private business and for hire.

‖Propane.

#242,000 barrels per day naphtha jet fuel; 46,000 barrels per day kerosine jet fuel.

**Residual oil.

††Electricity converted to distillate equivalent.

‡‡Liquids pipeline fuels converted to distillate equivalent.

§§Natural gas pipeline fuels converted to distillate equivalent.

‖‖Fuel for motive purposes.

##Small horsepower engines, lawnmowers, tillers, etc.

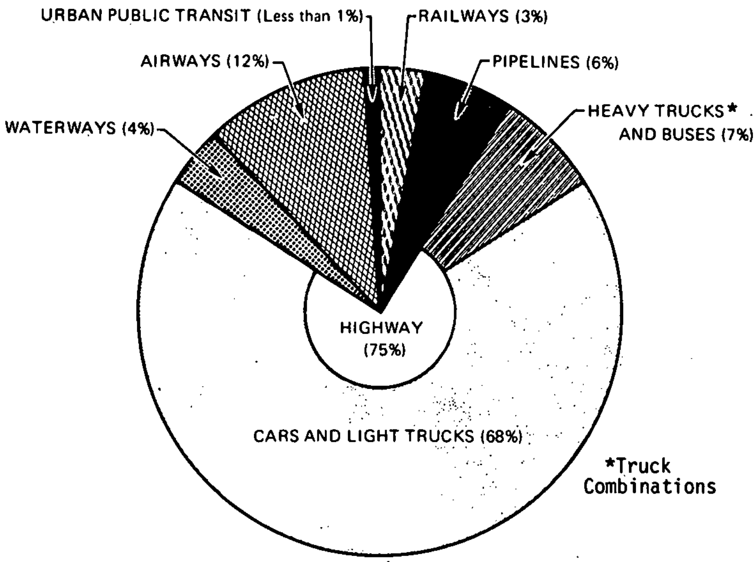
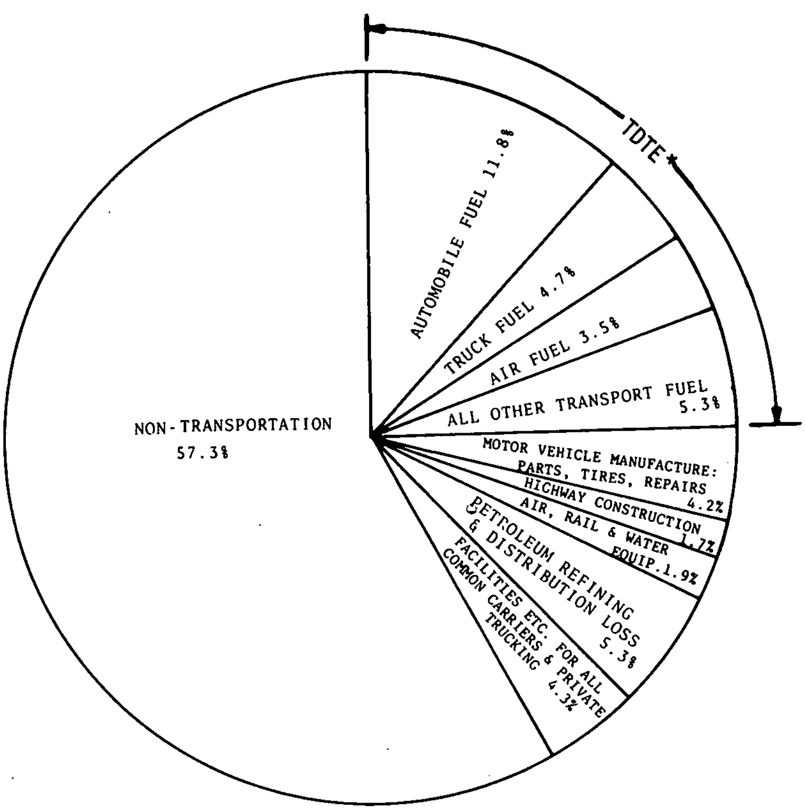


Figure 4. Components of direct transportation energy, 1972 (4).



*TDTE - Total Direct Transportation Energy

Figure 5. Distribution of total national energy consumption (based on 1967 input-output data). (Sources: (4); *total national energy consumption is given as 58.265 × 10*[15] *Btu by U.S. Dept. of Interior* (46); *direct energy consumption percentage is from the Rand Corp.* (47) *except that oil-pipeline energy was adjusted to 660 Btu/ton-mile. Indirect energy consumption was calculated from coefficients given in Ref.* (3) *by multiplying by industry sales from Ref.* (48) *or modal revenues from Ref.* (49).)

One must therefore be very careful in interpreting data presented on this subject. It is important to examine not only the basic energy efficiencies but also the operational factors and other considerations that apply.

TABLE 3

AVERAGE FUEL ECONOMY FOR PASSENGER AUTOMOBILES BY MODEL YEAR [a]

	Average Fuel Economy Standard	
Model Year	(miles/gallon)	(km/litre)
1978	18.0	7.7
1979	19.0	8.1
1980	20.0	8.5
1981-1984	b	b
1985 and thereafter	27.5	11.7

[a] As established by the Energy Policy and Conservation Act of 1975.

[b] Determined by the Secretary of Transportation. The Secretary has some leeway in determining the post-1980 standard but generally is required to set standards toward improving the 1985 goal. See Act for details.

TABLE 4

TRENDS AND PROJECTIONS OF TRANSPORTATION INDUSTRY ACTIVITY, 1947–1990 (FROM 1972 BASE) (5)

Transportation component	Unit of measure	1947	1958	1965	1970	1972	1973	1974	1975	PRE-EMBARGO PROJECTIONS 1980	1985	1990
GNP	Billions of 1958 constant dollars	310	447	614	723	791				1,090	1,300	1,550
	Billions of 1971 constant dollars	439	633	870	1,020	1,120				1,540	1,840	2,200
Population[1]	Thousands	145,000	175,000	194,000	205,000	209,000	209,700	211,200	212,800	224,000	236,000	247,000
Aviation:												
Domestic passenger	Billion passenger-miles	7.6	27.9	57.9	110	123	126	130	NA	207	280	372
International passenger	Billion passenger-miles	1.4	4.6	12.6	27.6	34.3	35.6	33.1		67.0	97.5	138
Domestic freight	Million ton-miles	116	702	2,010	3,410	3,690				8,500	14,300	24,100
International freight	Million ton-miles	NA	NA	NA	NA	NA				NA	NA	NA
Miscellaneous	Million ton-miles	NA	NA	NA	NA	NA				NA	NA	NA
General aviation:[2]												
Business aircraft	Million hours flown	1.97	5.70	5.52	7.08	7.63	8.6	9.1	NA	11.0	13.8	17.3
Personal aircraft	Million hours flown	2.62	2.37	4.02	6.81	8.40	7.5	8.4	NA	9.8	11.7	14.2
Government civilian aircraft	Million hours flown	NA	NA	.62	.89	1.06				1.4	1.9	2.4
Other aircraft	Million hours flown	11.21	3.58	4.63	8.97	9.62				12.0	14.1	16.6
Railroads:												
Passenger[3]	Billion passenger-miles	46.8	23.6	17.6	10.9	8.6	9.3	10.3	9.6	9.6	11.1	12.8
Freight	Million ton-miles	665,000	559,000	709,000	773,000	784,000	851,809	850,961	752,816	919,000	1,030,000	1,160,000
Other	Million ton-miles	NA	NA	NA	NA	NA				NA	NA	NA
Auto travel	Million VMT's[4]	303,000	555,000	732,000	973,000	1,080,000	1,016,861	990,721	1,028,121	1,350,000	1,510,000	1,680,000
Motorcycle							19,594	22,347	22,351			
Truck												
For hire:												
Intercity	Million ton-miles	45,100	96,300	154,000	220,000	258,000	272,500	287,000	301,500	374,000	444,000	527,000
Local	Million ton-miles	4,500	5,490	7,890	9,740	11,400	11,850	12,300	12,750	15,000	17,400	20,500
Miscellaneous	Million ton-miles	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Private:												
Intercity	Million ton-miles	19,600	81,600	111,000	130,000	134,000	138,750	143,500	148,250	172,000	205,000	244,000
	Million VMT's[4]	NA	NA	15,800	18,300	18,200	18,710	19,220	19,730	22,300	26,200	30,900
Local freight	Million ton-miles	22,600	36,400	63,800	59,700	58,100	61,030	63,960	66,890	81,500	96,800	114,000
	Million VMT's[4]	NA	NA	18,900	17,600	17,100	17,960	18,820	19,680	24,000	28,500	33,600
Nonfreight, private	Million VMT's[4]	NA	NA	78,300	86,200	100,000	105,500	111,000	116,500	144,000	171,000	205,000
Government trucking	Million VMT's[4]	2,930	4,930	8,580	10,800	11,800	12,490	13,180	13,870	17,300	20,800	25,200
Buses:												
Intercity[5]	Billion passenger-miles	24.8	20.8	23.8	25.3	25.6	26.4	27.6	25.6	30.4	33.9	38.0
Miscellaneous and freight		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
School	Million VMT's[4]	604	1,190	1,700	1,630	2,520	2,412	2,450	2,500			
Other	Million VMT's[4]	87	207	246	471					2,330	2,470	2,610
Urban transit:												
Transit	Million passengers	18,300	7,780	6,800	5,930	5,270	5,294	5,606	5,626	7,740	9,810	11,900
Taxicabs	Million passengers	NA	NA	NA	NA	NA	NA	NA		NA	NA	NA
Domestic water:												
Passenger	Million passenger-miles	NA	NA	NA	NA	NA				NA	NA	NA
Freight[6]	Million ton-miles	385,000	452,000	504,000	622,000	631,000				703,000	802,000	917,000
Miscellaneous		NA	NA	NA	NA	NA				NA	NA	NA
Commercial fishing		NA	NA	NA	NA	NA				NA	NA	NA
Private inboard		NA	NA	NA	NA	NA				NA	NA	NA
Private outboard		NA	NA	NA	NA	NA				NA	NA	NA
Overseas water:												
Passenger	Thousand passengers	650	1,220	1,650	1,730	1,750				1,550	1,300	1,060
Freight and miscellaneous		NA	NA	NA	NA	NA				NA	NA	NA
Pipeline:[7]												
Intercity	Million ton-miles	117,000	235,000	339,000	478,000	529,000				730,000	856,000	1,000,000
Miscellaneous		NA	NA	NA	NA	NA				NA	NA	NA
Transportation services NEC		NA	NA	NA	NA	NA				NA	NA	NA

[1]Includes armed forces abroad and excludes Puerto Rico.
[2]Excludes air taxi service.
[3]Includes all class I and class II rail travel.
[4]VMT indicates vehicle-miles traveled.
[5]Includes all class I, class II, and class III intercity bus travel.
[6]Includes an adjustment for circuitous water routings for coastwise traffic and excludes intraterritory traffic.
[7]Includes an adjustment for petroleum movements between storage tanks and ports of export.
Note: NA indicates not available.
Sources: Historical data based on various Federal Government reports and other estimates, adjusted for consistency; projections based on DOT input/output model. Data for 1973-75 supplied by FHWA.

TABLE 5

SUMMARY OF U.S. MOTOR FUEL USE FROM 1919–1975[1] (IN THOUSANDS OF GALLONS) (*6*)

YEAR	PRIVATE AND COMMERCIAL USE			PUBLIC USE (GASOLINE) 2/			SUMMARY OF TOTAL USE						LOSSES ALLOWED FOR EVAPORATION, HANDLING, ETC. (GASOLINE)	TOTAL QUANTITY CONSUMED IN UNITED STATES AND D.C.	YEAR
							HIGHWAY								
	HIGHWAY	NON-HIGHWAY	TOTAL	HIGHWAY (FEDERAL CIVILIAN, STATE, COUNTY, MUNICIPAL)	NON-HIGHWAY (STATE, COUNTY, MUNICIPAL)	TOTAL	GASOLINE	SPECIAL FUELS (PRIVATE AND COMMERCIAL)	TOTAL	GALLONS PER REGISTERED MOTOR VEHICLE	NON-HIGHWAY	TOTAL			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	
1919	2,605,200	75,030	2,680,230	66,800	-	66,800	-	-	2,672,000	353	75,030	2,747,030	-	2,747,030	1919
1920	3,264,023	102,164	3,366,187	81,977	-	81,977	-	-	3,346,000	362	102,164	3,448,164	-	3,448,164	1920
1921	3,840,954	129,824	3,970,778	94,046	-	94,046	-	-	3,935,000	375	129,824	4,064,824	-	4,064,824	1921
1922	4,727,721	173,035	4,900,756	113,279	-	113,279	-	-	4,841,000	394	173,035	5,014,035	-	5,014,035	1922
1923	5,938,814	235,177	6,173,991	139,186	-	139,186	-	-	6,078,000	402	235,177	6,313,177	-	6,313,177	1923
1924	7,328,318	312,186	7,640,504	168,682	-	168,682	-	-	7,497,000	426	312,186	7,809,186	-	7,809,186	1924
1925	8,556,558	394,890	8,951,448	192,517	-	192,517	-	-	8,749,075	436	394,890	9,143,965	-	9,143,965	1925
1926	9,848,668	488,210	10,336,878	215,283	-	215,283	-	-	10,063,951	453	488,210	10,552,161	-	10,552,161	1926
1927	11,093,864	605,570	11,699,434	237,462	-	237,462	-	-	11.331,326	486	605,570	11,936,896	-	11,936,896	1927
1928	12,106,219	728,822	12,835,041	255,241	-	255,241	-	-	12,361,460	501	728,822	13,090,282	-	13,090,282	1928
1929 3/	13,858,382	911,735	14,770,117	280,919	-	280,919	-	-	14,139,301	529	911,735	15,051,036	-	15,051,036	1929 3/
1930	14,454,164	1,023,796	15,477,960	299,747	-	299,747	-	-	14,753,911	552	1,023,796	15,777,707	-	15,777,707	1930
1931	15,149,145	1,164,599	16,313,744	307,517	-	307,517	-	-	15,456,662	592	1,164,599	16,621,261	90,438	16,711,699	1931
1932	14,012,600	1,088,189	15,100,789	326,551	-	326,551	-	-	14,339,151	588	1,088,189	15,427,340	89,377	15,516,717	1932
1933	13,998,958	1,019,753	15,018,711	349,194	-	349,194	-	-	14,348,152	594	1,019,753	15,367,905	114,839	15,482,744	1933
1934	15,033,999	1,086,697	16,120,696	380,897	21,212	402,109	-	-	15,414,896	610	1,107,909	16,522,805	202,780	16,725,585	1934
1935	15,919,281	1,209,663	17,128,944	425,416	35,933	461,349	-	-	16,344,697	616	1,245,596	17,590,293	216,899	17,807,192	1935
1936	17,640,917	1,359,528	19,000,445	458,221	40,995	499,216	-	-	18,099,138	635	1,400,523	19,499,661	237,944	19,737,605	1936
1937	18,973,618	1,549,101	20,522,719	481,836	41,919	523,755	-	-	19,455,454	647	1,591,020	21,046,474	259,253	21,305,727	1937
1938	19,110,356	1,592,164	20,702,520	501,287	49,036	550,323	-	-	19,611,643	658	1,641,200	21,252,843	325,636	21,578,479	1938
1939	20,170,516	1,741,289	21,911,805	543,836	53,347	597,183	-	-	20,714,352	668	1,794,636	22,508,988	344,649	22,853,637	1939
1940	21,417,818	1,906,481	23,324,299	583,538	60,868	644,406	-	-	22,001,356	678	1,967,349	23,968,705	365,809	24,334,514	1940
1941	23,637,867	2,074,864	25,712,731	554,530	162,180	716,710	-	-	24,192,397	693	2,237,044	26,429,441	290,677	26,720,118	1941
1942	19,472,813	2,358,100	21,830,913	467,074	140,938	608,012	-	-	19,939,887	604	2,499,038	22,438,925	253,572	22,692,497	1942
1943	15,668,249	2,527,713	18,195,962	336,001	110,810	446,811	-	-	16,004,250	518	2,638,523	18,642,773	228,649	18,871,422	1943
1944	16,089,547	2,747,614	18,837,161	340,121	114,765	454,886	-	-	16,429,668	539	2,862,379	19,292,047	231,505	19,523,552	1944
1945	18,797,970	2,777,567	21,575,537	350,998	120,192	471,190	-	-	19,148,968	617	2,897,759	22,046,727	257,028	22,303,755	1945
1946	25,269,041	3,112,859	28,381,900	379,957	114,689	494,646	-	-	25,648,998	746	3,227,548	28,876,546	324,919	29,201,465	1946
1947	27,714,492	3,315,333	31,029,825	501,213	149,463	650,676	-	-	28,215,705	746	3,464,796	31,680,501	355,385	32,035,886	1947
1948	29,908,912	3,706,859	33,615,771	551,729	161,647	713,376	-	-	30,460,641	741	3,868,506	34,329,147	377,812	34,706,959	1948
1949	31,857,123	3,840,177	35,697,300	581,102	168,844	749,946	32,010,871	427,354	32,438,225	726	4,009,021	36,447,246	395,217	36,842,463	1949
1950	35,042,559	3,999,121	39,041,680	619,164	178,545	797,709	35,124,800	536,923	35,661,723	725	4,177,666	39,839,389	449,001	40,288,390	1950
1951	37,489,152	4,160,307	41,649,459	649,625	184,704	834,329	37,430,684	708,093	38,138,777	735	4,345,011	42,483,788	477,367	42,961,155	1951
1952	39,910,334	4,258,266	44,168,600	686,385	194,540	880,925	39,760,208	836,511	40,596,719	762	4,452,806	45,049,525	488,568	45,538,093	1952
1953	42,020,542	4,444,642	46,465,184	725,339	204,548	929,887	41,805,845	940,036	42,745,881	760	4,649,190	47,395,071	508,756	47,903,827	1353
1954	43,579,378	4,530,857	48,110,235	787,085	222,596	1,009,681	43,319,266	1,047,197	44,366,463	758	4,753,453	49,119,916	516,731	49,636,647	1954
1955	46,914,652	4,602,738	51,517,390	817,082	231,783	1,048,865	46,527,057	1,204,677	47,731,734	761	4,834,521	52,566,255	551,175	53,117,430	1955
1956	49,366,531	4,690,961	54,057,492	849,071	244,387	1,093,458	48,805,145	1,410,457	50,215,602	771	4,935,348	55,150,950	561,263	55,712,213	1956
1957	50,953,894	4,827,338	55,781,232	912,183	262,621	1,174,804	50,229,696	1,636,381	51,866,077	773	5,089,959	56,956,036	488,740	57,444,776	1957
1958	52,445,059	4,892,266	57,337,325	975,006	278,860	1,253,866	51,563,249	1,856,816	53,420,065	782	5,171,126	58,591,191	497,160	59,088,351	1958
1959 4/	55,303,178	5,095,245	60,398,423	1,030,589	288,631	1,319,220	54,101,740	2,232,027	56,333,767	789	5,383,876	61,717,643	510,092	62,227,735	1959 4/
1960	56,781,322	5,030,556	61,811,878	1,098,586	301,779	1,400,365	55,428,618	2,451,290	57,879,908	784	5,332,335	63,212,243	504,030	63,716,273	1960
1961	58,155,216	4,911,483	63,066,699	1,150,890	317,273	1,468,163	56,607,240	2,698,866	59,306,106	781	5,228,756	64,534,862	512,751	65,047,613	1961
1962	60,520,185	5/ 4,074,765	64,594,950	1,176,922	329,776	1,506,698	58,749,049	2,948,058	61,697,107	779	5/ 4,404,541	66,101,648	535,224	66,636,872	1962
1963	63,273,938	3,906,321	67,180,259	1,242,494	337,723	1,580,217	61,274,435	3,241,997	64,516,432	780	4,244,044	68,760,476	550,738	69,311,214	1963
1964	66,617,501	3,839,022	70,456,523	1,283,908	357,043	1,640,951	64,268,645	3,632,764	67,901,409	787	4,196,065	72,097,474	569,019	72,666,493	1964
1965	69,775,616	3,837,460	73,613,076	1,328,814	370,723	1,699,537	66,978,519	4,125,911	71,104,430	787	4,208,183	75,312,613	584,370	75,896,983	1965
1966	73,279,282	3,928,268	77,207,550	1,385,210	386,304	1,771,514	69,973,025	4,691,467	74,664,492	795	4,314,572	78,979,064	614,256	79,593,320	1966
1967	76,269,265	3,778,767	80,048,032	1,461,403	401,582	1,862,985	72,680,934	5,049,734	77,730,668	802	4,180,349	81,911,017	677,718	82,588,735	1967
1968	81,424,728	3,787,743	85,212,471	1,524,713	419,111	1,943,824	77,258,786	5,690,655	82,949,441	822	4,206,854	87,156,295	721,368	87,877,663	1968
1969	86,537,161	3,670,244	90,207,405	1,597,941	434,999	2,032,940	81,805,024	6,330,078	88,135,102	839	4,105,243	92,240,345	754,445	92,994,790	1969
1970	90,729,670	3,593,165	94,322,835	1,599,386	409,688	2,009,074	85,598,364	6,730,692	92,329,056	852	4,002,853	96,331,909	784,688	97,116,597	1970
1971	95,880,745	3,491,505	99,372,250	1,677,841	421,865	2,099,706	89,984,705	7,573,881	97,558,586	863	3,913,370	101,471,956	837,908	102,309,864	1971
1972	103,310,056	3,380,790	106,690,846	1,752,122	443,238	2,195,360	96,542,738	8,519,440	105,062,178	884	3,824,028	108,886,206	879,822	109,766,028	1972
1973	108,648,096	3,433,954	112,082,050	1,824,785	461,797	2,286,582	100,636,236	9,836,645	110,472,881	879	3,895,751	114,368,632	948,841	115,317,473	1973
1974	104,515,540	3,163,342	107,678,882	1,785,225	459,173	2,244,398	96,504,516	9,796,249	106,300,765	818	3,622,515	109,923,280	894,479	110,817,759	1974
1975	107,101,402	3,161,183	110,262,585	1,882,945	481,126	2,364,071	99,353,593	9,630,754	108,984,347	820	3,642,309	112,626,656	922,127	113,548,793	1975

1/ For the purpose of this tabulation, "motor fuel" includes all gasoline used for non-military purposes, plus diesel and other special fuels used to operate vehicles on public highways. Military use, "tractor fuels," and exports are excluded. There is no duplication because of interstate shipment.

2/ Public highway use include Federal, State, country and municipal uses. Nonhighway use is State, county and municipal only.

3/ Includes data for all States and the District of Columbia beginning 1929.

4/ Includes Alaska and Hawaii beginning 1959.

5/ Excludes jet fuel beginning 1962.

TABLE 6

FUEL CONSUMPTION BY MODE OF TRANSPORT, 1964–1974 (7)

	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
Class I Railroads											
Locomotives											
Diesel Oil, gals x 10^6	3,624	3,736	3,920	3,883	3,917	3,919	3,804	3,819	3,999	4,141	4,112
Fuel Oil, gals x 10^6	85	77	65	47	42	33	-	-	-	-	-
Electricity, KWH x 10^6	931	933	922	832	750	610	578	534	608	346	467
Coal, tons	6,831	3,695	3,235	2,310	1,669	1,137	1,238	1,191	1,400	1,202	1,160
Motor Cars											
Diesel Oil, gals x 10^6	7	6	6	6	5	5	8	4	3	3	4
Electricity, KWH x 10^6	583	576	576	580	567	538	763	756	715	901	847
Gasoline, gals	4,585	-	-	-	-	-	-	-	-	-	-
Air											
Certificated Carriers											
Aviation Gasoline, gals x 10^6	589	519	398	268	128	33	15	12	13	11	n/a
Jet Fuel, gals x 10^6	3,830	4,650	5,670	7,523	8,891	10,113	10,085	10,140	10,302	10,671	9,554**
General Aviation											
Aviation Gasoline, gals x 10^6	262	292	375	396	495	522	551	508	584	n/a	n/a
Jet Fuel, gals x 10^6	41	81	106	138	n/a	168	208	226	245	n/a	n/a
Highway											
Gasoline, gals x 10^6											
Pass. cars + Taxis	47,567*	50,206	53,220	55,007	58,413	62,325	65,649	69,213	73,121	77,619	73,770
Motorcycles	-	69	92	103	111	123	135	301	342	392	447
Diesel + Gasoline, gals x 10^6											
Commercial Buses	622	645	637	646	655	657	644	631	561	520	525
School + other nonrevenue buses	242	249	259	264	277	290	300	316	320	327	333
Single-unit Trucks[1]	13,199	13,504	13,636	14,470	15,674	16,528	17,237	18,221	22,118	22,755	21,125
Combination Trucks	6,271	6,431	6,779	7,203	7,808	8,199	8,363	8,865	8,600	8,860	10,101
Water											
Vessels[2]											
Residual Fuel Oil, gals x 10^6	3,487	3,093	3,093	3,389	3,678	3,506	3,774	3,307	3,273	3,881 r	3,827
Distillate Fuel Oil, gals x 10^6	672	652	699	734	766	793	819	880	929	1,125	1,019
Gasoline, gals x 10^6	n/a	n/a	485	501	533	569	598	645	687	717	697
Transit											
Electricity, KWH x 10^6											
Rapid Transit	2,171	2,185	2,075	2,194	2,250	2,291	2,261	2,262	2,149	2,098	n/a
Surface Rail	222	218	226	180	179	173	157	153	146	140	n/a
Trolley	204	181	166	157	157	154	143	141	133	93	n/a
Gallons of Motor Fuel, gals x 10^6											
Gasoline	96	92	76	58	46	40	37	29	20 r	12 r	7
Diesel Oil	242	248	256	270	274	274	271	257	253 r	283 r	316
Propane	33	33	34	33	32	32	31	27	24	15	3
Pipelines (Gas & Oil)											
Natural Gas, Cu. Ft. x 10^6	433,204	500,024	535,353	575,752	590,965	630,962	722,166	742,592	766,156	728,177	668,792

1 Includes non-freight truck movements.
2 Vessel bunkering (including tankers). Includes purchases of fuel by all commercial vessels in U.S. ports.
* Includes Motorcycles.
** Includes Aviation Gasoline.
r Revised.
n/a Not available.

TABLE 7

HIGHWAY USE OF MOTOR FUEL, 1972–1975[1] *(6)*

		Passenger Vehicles							Cargo Vehicles			
		Personal passenger vehicles			Buses							
		Passenger cars	Motor-cycles	All personal passenger vehicles	Commercial	School	All buses	All passenger vehicles	Single-unit trucks	Combina-tions	All trucks	All motor vehicles
Number of vehicles registered (thousands)												
	1972	96,860.0	3,798.0	100,658.0	88.8	318.2	407.0	101,065.0	20,249.0	990.0	21,239.0	122,304.0
	1973	101,762.5	4,356.5	106,119.0	89.5	336.0	425.5	106,544.5	22,205.0	1,027.9	23,232.9	129,777.4
	1974	104,856.3	4,966.4	109,822.7	90.1	356.9	447.0	110,270.7	23,545.2	1,085.0	24,630.2	134,899.9
	1975	106,712.6	4,966.8	111,679.4	93.8	368.3	462.1		24,644.7	1,131.0	25,775.7	137,917.2
Average miles traveled per vehicle												
	1972	10,184	4,500	9,969	30,968	7,414	12,553	9,980	10,525	47,084	12,229	10,846
	1973	9,992	4,498	9,767	28,469	7,178	11,662	9,774	9,868	46,716	11,538	10,083
	1974	9,448	4,500	9,225	28,968	6,865	11,320	9,233	8,981	51,667	10,861	9,530
	1975	9,634	4,500	9,406	28,230	6,788	11,140	9,413	8,882	49,125	10,648	9,644
Fuel consumed (million gallons)												
	1972	73,121	342	73,463	561	320	881	74,344	22,118	8,600	30,718	105,062
	1973	77,619	392	78,011	520	327	847	78,858	22,755	8,860	31,615	110,473
	1974	73,770	447	74,217	525	333	858	75,075	21,125	10,101	31,226	106,301
	1975	76,010	447	76,457	553	342	895	77,352	21,868	9,764	31,632	108,984
Average fuel consumption per vehicle (gallons)												
	1972	775	90	730	6,318	1,006	2,165	736	1,092	8,687	1,446	859
	1973	763	90	736	5,810	973	1,991	741	1,025	8,620	1,361	851
	1974	704	90	676	5,827	933	1,919	681	897	9,310	1,268	788
	1975	712	90	685	5,896	929	1,937	690	887	8,633	1,227	790
Average miles traveled per gallon of fuel consumed												
	1972	13.49	50.00	13.67	4.39	7.37	5.80	13.57	9.63	5.42	8.46	12.07
	1973	13.10	50.00	13.29	4.90	7.37	5.86	13.21	9.63	5.42	8.45	11.85
	1974	13.43	50.00	13.65	4.97	7.36	5.90	13.56	10.01	5.55	8.57	12.09
	1975	13.53	50.00	13.74	4.79	7.31	5.75	13.65	10.01	5.69	8.68	12.20

[1]For the 50 states and District of Columbia.

TABLE 8

TREND OF ENERGY CONSUMPTION BY TRANSIT PASSENGER VEHICLES (*29*)

CALENDAR YEAR	ELECTRIC POWER CONSUMED (KILOWATT HOURS IN MILLIONS)				FOSSIL FUELS CONSUMED (GALLONS IN THOUSANDS)		
	LIGHT RAIL	HEAVY RAIL	TROLLEY COACH	TOTAL	GASOLINE	DIESEL	PROPANE
1940	4,050	1,977	307	6,334	(a)	(a)	0
1945	4,547	1,966	520	7,033	510,000	11,800	0
1950	2,410	2,000	841	5,251	430,000 (b)	98,600	(b)
1955	910	1,900	720	3,530	246,000	172,600	30,300
1956	700	1,960	680	3,340	219,400	183,500	30,300
1957	560	1,980	600	3,140	198,400	190,000	34,200
1958	485	2,073	535	3,093	181,700	192,700	35,100
1959	431	2,067	464	2,962	167,800	196,600	36,600
1960	393	2,098	417	2,908	153,600	208,100	38,300
1961	362	2,108	381	2,851	125,900	217,500	35,700
1962	325	2,115	346	2,786	108,400	229,000	36,100
1963	255	2,125	262	2,642	102,500	235,300	35,900
1964	222	2,171	204	2,597	95,900	242,200	33,400
1965	218	2,185	181	2,584	91,500	248,400	32,700
1966	226	2,075	166	2,467	76,000	256,000	33,600
1967	180	2,194	157	2,531	57,800	270,300	33,000
1968	179	2,250	157	2,586	45,700	274,200	32,200
1969	173	2,291	154	2,618	40,000	273,800	31,600
1970	157	2,261	143	2,561	37,200	270,600	31,000
1971	153	2,262	141	2,556	29,400	256,800	26,500
1972	146	2,149	133	2,428	19,647	253,250	24,400
1973	140	2,098	93	2,331	12,333	282,620	15,152
1974	(a)	(a)	(a)	2,630	7,457	316,360	3,142
P 1975	(a)	(a)	(a)	2,646	5,017	365,060	2,559

P = Preliminary

(a) Data not available.

(b) Propane included with gasoline.

TABLE 9

CONSUMPTION OF FUEL IN ALL SERVICES OF THE CERTIFICATED ROUTE AIR CARRIERS (IN THOUSANDS OF GALLONS)

Year	Total			Domestic Passenger/Cargo			International Passenger/Cargo			Air Cargo		
	Gasoline	Jet Fuel	Oil	Gasoline	Jet Fuel	Oil	Gasoline	Jet Fuel	Oil	Gasoline	Jet Fuel	Oil
1965	518,684	4,650,340	8,001	448,022	3,367,915	6,943	41,114	1,194,765	626	29,548	87,660	432
1966	397,558	5,669,485	6,202	331,869	3,993,205	5,152	31,258	1,529,713	548	34,431	146,567	502
1967	267,934	7,522,739	4,432	223,356	5,324,794	3,597	17,900	1,983,292	436	26,378	214,653	399
1968	127,873	8,980,578	2,999	113,234	6,454,803	2,474	8,840	2,267,156	402	5,799	258,619	123
1969	32,697	10,112,553	2,014	27,270	7,885,153	1,690	92	1,910,992	225	5,335	316,408	99
1970	14,479	10,084,693	1,435	13,839	7,782,536	1,144	---	2,013,883	249	640	288,274	42
1971	12,142	10,140,053	1,545	12,134	7,728,254	1;232	8	2,113,192	280	---	298,607	26
1972	12,923	10,302,068	1,412	12,054	7,886,394	1,105	869	2,099,232	289	---	316,442	18
1973	10,895	10,670,950	1,490	10,509	8,235,747	1,187	386	2,143,033	292	---	292,170	11
1974	6,789	9,545,655	1,349	6,689	7,415,856	1,095	100	1,864,354	231	---	265,445	23

Source: Bureau of Accounts and Statistics, CAB.

CHAPTER TWO

ENERGY EFFICIENCIES: PASSENGER TRANSPORTATION MODES

INTRODUCTION AND GENERAL DISCUSSION

In order to address the energy consumption rate and efficiency of various passenger transportation modes, quantitative measures must be defined and evaluated. Several measures appear to be useful. Energy is measured by British thermal units (Btu) or by gallons in each operational measure. The measures are Btu or gallons per vehicle-mile, Btu or gallons per seat-mile, and Btu or gallons per passenger-mile. Btu per vehicle-mile is the average fuel-consumption rate required to propel a vehicle through its daily duty cycle and power its accessories. As shown in Appendix A, there are 124,950 Btu/gal (35 MJ/litre) of gasoline. Btu per seat-mile provides indications of the efficiency of a transportation mode while it is performing the desired function, that of transporting people. Btu per passenger-mile is a measure of the efficiency of a transportation mode having an average passenger occupancy that represents either actual experience or, in the case of a new system, expected average occupancy.

Average occupancy is defined as the total annual passenger-miles divided by the total annual vehicle-miles. This measure is the best indication of the efficiency of existing transportation modes as they are currently performing. Many efforts have been directed toward increasing this average occupancy, or load factor (e.g., car pooling), and thereby improving the vehicle's efficiency in moving people.

Passenger transportation has some of the same characteristics that freight transportation does. The primary difference between the two is that in passenger transportation the commodity is known; namely, it is people. What varies in passenger transportation is the purpose and, therefore, the priority given to various attributes of transportation service. For example, a person in business may place a much higher priority on assurance of arrival at a particular time than on the dollar cost of travel. A vacationing individual may decide that time has a lower priority than other factors and be willing to go by a slower means if it will cost less. Frequently with passenger transportation, especially transportation within major cities, the passenger has a wide number of options from which to choose. In rural areas, the options for traveling may be only by automobile or bus. Increasingly, travel across the seas is becoming limited to aircraft travel, because oceangoing passenger vessels for international travel have been largely phased out. Similarly, for long-distance travel within the U.S., the passenger rail alternative is frequently not available.

In this chapter, the energy efficiencies for all the basic types of passenger transport are examined in terms of their over-all design, operating, and use characteristics. Special emphasis is given to the automobile, which dominates passenger travel, accounting for more than 90 percent of all passenger-miles. The dominance is greatest in local travel (trips of 30 miles—48 km—or less one way), in which automobiles (including taxicabs) account for approximately 97 percent of all passenger-miles. The proportion is lower in large cities, inasmuch as mass transit systems are usually available, but it still generally ranges between 80 and 90 percent. New York City is the one exception; more than half the travel there is on rail rapid transit or transit bus. Distributions of passenger-miles by trip purpose and by mode of local travel are given in Table 10 (*8*).

The automobile accounts for more than 85 percent of intercity passenger-miles (trips of more than 30 miles—48 km—one way). Airlines account for slightly more than 10 percent, and bus and rail the remainder. In 1972, rail accounted for less than 1 percent of total intercity passenger-miles. However, airlines become very important in trips in excess of 500 miles (800 km), accounting for more than 40 percent of passenger-miles (*8*). Data for intercity trips are given in Table 11 (*8*).

The importance of each mode of passenger travel in terms of fuel consumption is presented in Table 12. The predominance of the auto is evidenced by its large share of total fuel consumption.

The demand for passenger transportation is relatively price inelastic, because a large part of such transportation is considered an essential service. For example, commuting to work, making business trips, and taking family business trips account for about one-half of total passenger-miles. The other half is considered less essential, and consequently its demand is much more responsive to price changes. However, fuel costs represent only a part of the total cost of providing transportation (see Table 13).

The cost or value of time is an important element in the traveler's choice of mode and must be considered in the total cost of each transportation mode. The time cost is calculated as the sum of the travel, access, and waiting time, multiplied by the unit value of time. The value of time generally varies with trip purpose. The value of time used in Table 14 is the average hourly wage, wherein each trip purpose was assigned an assumed percentage of the average wage. Because of the importance of time in cost-benefit analysis, many studies on the value of time have been performed. Estimates of the value of time generally range between 33 and 100 percent of the wage rate. The value of time in air travel has been estimated at two and one-half times the average wage rate. There is general agreement on two propositions:

- The value of time increases with income level.
- The value of time varies according to trip purpose, with higher values being given to trips made for work and other business-related purposes.

Because existing studies lack any close agreement on the

TABLE 10

PASSENGER-MILES AND PERCENTAGE DISTRIBUTIONS BY PURPOSE (LOCAL TRIPS, 1972)* (MILLIONS) (*8*)

Mode:	Auto[a]		Bus Transit		Commuter Rail		Rail Rapid Transit		Total	
Purpose	Passenger-Miles	% of Total	Passenger-Miles	% of Total	Passenger-Miles	% of Total	Passenger-Miles	% of Total	Passenger-Miles	% of Total
Commuting	380037	30.4	9583	41.0	2955	71.7	7712	84.0	400287	31.2
%		94.9		2.4		0.7		1.9		100
Work-Related	53392	4.3	984	4.2	173	4.2	327	3.6	54876	4.3
%		97.3		1.8		0.3		0.6		100
Family Business	418880	33.6	10973	47.0	915	22.2	942	10.2	431710	33.6
%		97.0		2.5		0.2		0.2		100
Social and Recreation	396151	31.7	1815	7.8	78	1.9	199	2.2	398243	30.9
%		99.5		0.5		-		-		100
Total, All Trips Under 30 Miles	1248461	100.0	23355	100.0	4121	100.0	9180	100.0	1285117	100.0
%		97.1		1.8		0.3		0.7		100

[a]Auto trips 30 miles or less were assumed to represent local auto travel. Taxis are included. (Exclusive urban travel is normally considered approximately 20 miles.)
*Local travel - trips 30 miles or less in length.

Source: Auto--unpublished worksheets from the Nationwide Personal Transportation Study, Federal Highway Administration, U. S. Department of Transportation, adjusted to 1972 total; Bus Transit--1973-1974 Transit Fact Book, American Transit Association and An Analysis of Urban Area Travel by Time of Day, report to the Office of Planning, Federal Highway Administration, U. S. Department of Transportation; Commuter Rail--Commutation Traffic and Revenue of Individual Class I Railroads (ICC OS-B Reports) and unpublished worksheets from Tri-State Area Planning Commission Household Survey of Passenger Travel: 1963; Rapid Rail--1973-1974 Transit Fact Book and Tri-State Area Commission Planning Survey.

value of time, it is estimated for the different purposes in agreement with Reference (*8*), as given in Table 14.

Even large increases in fuel costs have a small effect on transportation operating costs for all modes except the auto. When time value is included, the effect of fuel-cost increases on total trip cost by auto is substantially reduced. As a consequence, travel demand in aggregate is relatively insensitive to oil price increases. In general, increases in fuel prices have a small effect on relative modal costs. For intercity travel, however, the increases are probably great enough to effect measurable increases in the shares for air, rail, and bus at the expense of the auto share. Breakdowns on the cost of operating an automobile are contained in Reference (*9*), and detailed travel patterns are contained in Reference (*10*).

A number of studies have estimated the price elasticity of demand for gasoline in this country. Values in the range of —0.06 to —0.83 for the short run have appeared in the literature, and estimates for the long run range from —0.07 to —0.92. The Federal Energy Administration, in compiling the "Project Independence" report, selected —0.21 to estimate the immediate impact of higher prices on gasoline consumption and —0.76 for the long-run elasticity (*8*).

A study of elasticities suggests that conservation occurred during the early years primarily because of reduced travel and in the later years primarily because of the purchase of more efficient automobiles.

Over the past two decades, the bulk of U.S. intercity travel has been by automobile and aircraft, the two low-fuel-economy modes. The choice is indicative of the convenience and speed of these modes as well as the former low price and abundance of petroleum fuel. Both air and auto travel are more expensive in dollars than other modes, but in neither air nor auto has fuel been the principal cost component.

There is some indication that most people have tended to write off the cost of owning a car against the daily urban work trip and have perceived only fuel and tolls as the cost for intercity trips. In such a situation, particularly for a multiple-occupant auto, the auto has been perceived as the

TABLE 11

PASSENGER-MILES AND PERCENTAGE DISTRIBUTIONS BY PURPOSE (INTERCITY TRIPS, 1972)* (MILLIONS) (*8*)

Purpose \ Mode		Auto		Intercity Bus		Rail		Air		Total	
		Passenger-Miles	% of Total	Passenger-Miles	% of Total	Passenger-Miles	% of Total	Passenger-Miles	% of Total	Passenger-Miles	% of Total
Visiting Friends or Relatives		177635	19.3	11034	43.1	2282	51.2	32808	27.5	223759	20.9
	%		79.4		4.9		1.0		14.7		100
Business and Conventions		222381	24.1	3507	13.7	963	21.6	52255	43.8	279106	26.0
	%		79.7		1.3		0.3		18.7		100
Outdoor Recreation		81103	8.8	3072	12.0	134	3.0	2386	2.0	86695	8.1
	%		93.5		3.5		0.2		2.8		100
Sightseeing and Entertainment		292630	31.6	4019	15.7	651	14.6	16702	14.0	314002	29.3
	%		93.2		1.3		0.2		5.3		100
Other		149122	16.2	3968	15.5	428	9.6	15152	12.2	168670	15.7
	%		88.4		2.4		0.3		9.0		100
Total, All Trips Over 30 Miles		922871	100.0	25600	100.0	4458	100.0	119303	100.0	1072232	100.0
	%		86.0		2.4		0.4		11.1		100

* Intercity trips - trips more than 30 miles.

Source: Passenger-miles for auto were based upon unpublished worksheets from the National Personal Transportation Study, adjusted forward to 1972, and re-assigned to the above five purposes. Auto trips over 30 miles in length were assumed to represent intercity auto travel. Sources for total passenger-miles for other modes were as follows: Intercity bus--Bus Facts 1972; Intercity (Non-Commutation) Rail--ICC, Transport Statistics, 1972, Part I; Air--CAB, Air Carrier Traffic Statistics, December 1973. Percentage distributions by purpose were taken from the 1972 National Travel Survey (except for auto).

cheapest intercity mode. Some travelers are willing to pay a premium price for time-saving in the form of the convenience of the auto and the speed of the airplane. On a long trip, however, the average auto occupancy is approximately three persons, so auto travel is even cheaper than bus travel for three people. The time and price elasticities of travelers appear to be such that many people would still opt for air travel even if fuel prices were to rise significantly.

Fuel economy in terms of passenger-miles per gallon or its potential in the form of seat-miles per gallon is in fact an incomplete cost-benefit measure. Not all trips have the same value, and not all travel speeds have the same value. As fuel and travel costs rise, some trips will be abandoned when the value of the trip no longer justifies the expense of the first-choice mode or the time consumed by the alternative that provides better fuel economy. The choice will be made differently by different people according to their varying needs and resources.

Fuel economy (or energy intensiveness) has not been and will not be the sole choice factor in transportation unless the price of energy increases to the point where it dominates all other costs. Between 1945 and 1973, the real price of fuel decreased with respect to other costs. What has been happening recently, however, is that the price of fuel has been rising not only in dollars but also in significance relative to other factors that determine travel patterns: time, convenience, comfort, labor, and so on. Thus, fuel economy is expected to carry increasing weight in the years ahead if fuel prices increase sufficiently to remain a significant consideration.

Any transition, by necessity, would be slow because of the massive investments in present equipment, the large new investment needed for upgrading transportation systems, and the many long-term commitments to present patterns. Fuel-economy measures are useful in the planning process in two principal ways: as estimators of fuel requirements in existing or developing transportation patterns and as clues to the areas likely to yield the most benefit from research and development and from external incentives to change travel patterns.

In any event, it is important that a proper perspective be maintained and that the planner keep in mind: (a) that

TABLE 12

PASSENGER-MILES AND FUEL CONSUMPTION FOR PASSENGER MODES, 1972 (*8*)

Passenger Mode	Passenger-miles (10^6)	Fuel Consumption: Gasoline (10^6 gal)	Diesel (10^6 gal)	Jet Fuel (10^6 gal)	Aviation Gasoline (10^6 gal)	Liquified Petroleum Gas (10^6 gal)	Electricity (10^6 kWh)
LOCAL*							
Auto ***	1,248,461	53246					
Bus Transit	23,355	26	247			24	
Rail Rapid Transit	9,180						2428
Commuter Rail	4,121		78				435
INTERCITY**							
Auto	922,871	19396					
Air (Domestic)	119,303			7954			
Rail	4,458		84				471
Intercity Bus	25,600	31	186				
OTHER							
General Aviation				283	418		
International Air				1784			
Personal Use of Trucks		7158				174	
Motorcycles		342					
School and Other Bus		367					

*Local travel - trips 30 miles or less in length.
**Intercity travel - trips more than 30 miles in length.
***Auto fuel consumption totals 72,742 x 10^6 gallons compared to 73,121 x 10^6 gallons, from FHWA Table VM-1, and shown elsewhere in this report.

fuel economy estimates can be based on fragmentary or biased data; (b) that estimates in passenger-mile units are strongly influenced by the way a mode is merchandized and used and that such estimates can give a poor representation of the technology's potential; (c) that the technological potential for fuel economy is often unreachable in practice; (d) that train and bus as surface mass-transportation modes in their speed regimes have the best potential for fuel economy; (e) that autos, track-levitated vehicles, and aircraft have roughly the same potential for fuel economy in three widely differing speed regimes; (f) that convenience, speed, safety, cost, and comfort—factors not included in fuel-economy measures—are important in determining the value of a transportation system; and (g) that, as a result, a mode with less technical potential may have greater service utility and fuel efficiency in actual use at the time and place.

The Boeing Company analyzed energy comparisons of intercity passenger transportation (*11*). Their analysis, summarized in Figure 6, concluded that intercity buses are

TABLE 13

FUEL COST AS PERCENTAGE OF TOTAL OPERATING COST (*8*)

Mode	Fuel Costs as Percentage of Total Operating Cost (or Fare)	Fuel Costs as Percentage of Total Operating Cost (or Fare) Plus Travel Time Costs[1]
Auto[2]		
Local	45.9	18.2
Intercity	48.4	26.3
Rail Transit	8.0	1.9
Bus Transit	1.7	0.3
Intercity Rail	7.2	3.9
Air	12.0	9.8
Intercity Bus	2.5	1.0

[1]Based on time value in local commuting at a trip length of 6 to 10 miles (10 to 16 km) and intercity business trips of 200 to 299 miles (320 to 466 km).
[2]Excludes fixed depreciation and insurance rates.

more fuel efficient than all other modes at all ranges. Contrary to what might have been thought, intercity trains (in the spring of 1974) were not the most fuel-efficient mode. This is partly because of the comparatively old equipment used in passenger train operations. Recently ordered Amtrak equipment has the potential to improve this picture. Except for some short-range services, automobiles and airplanes are comparable to trains in fuel efficiency. At long distances, automobiles have a fuel efficiency advantage over airplanes. Automobile occupancy is a major factor in the range trend. The assumed 60 percent load factor for public modes gives intercity buses and trains (for the spring of 1974) an advantage over aircraft and automobiles. Bus fuel-use efficiency is greater than that of other modes because the bus is more efficient in terms of weight and floor area per seat, which results in a lower-rated horsepower per seat. These advantages are sufficient to easily overcome the well-known steel-wheel-on-rail rolling-friction advantage that trains enjoy. Lightweight, high-capacity trains designed for low speeds offer the potential of energy efficiency comparable with that enjoyed by some buses.

The Boeing study drew additional conclusions regarding modal fuel use versus range, as follows:

- Airplane fuel use improves with range because of the decreasing impact of terminal-area maneuvers.

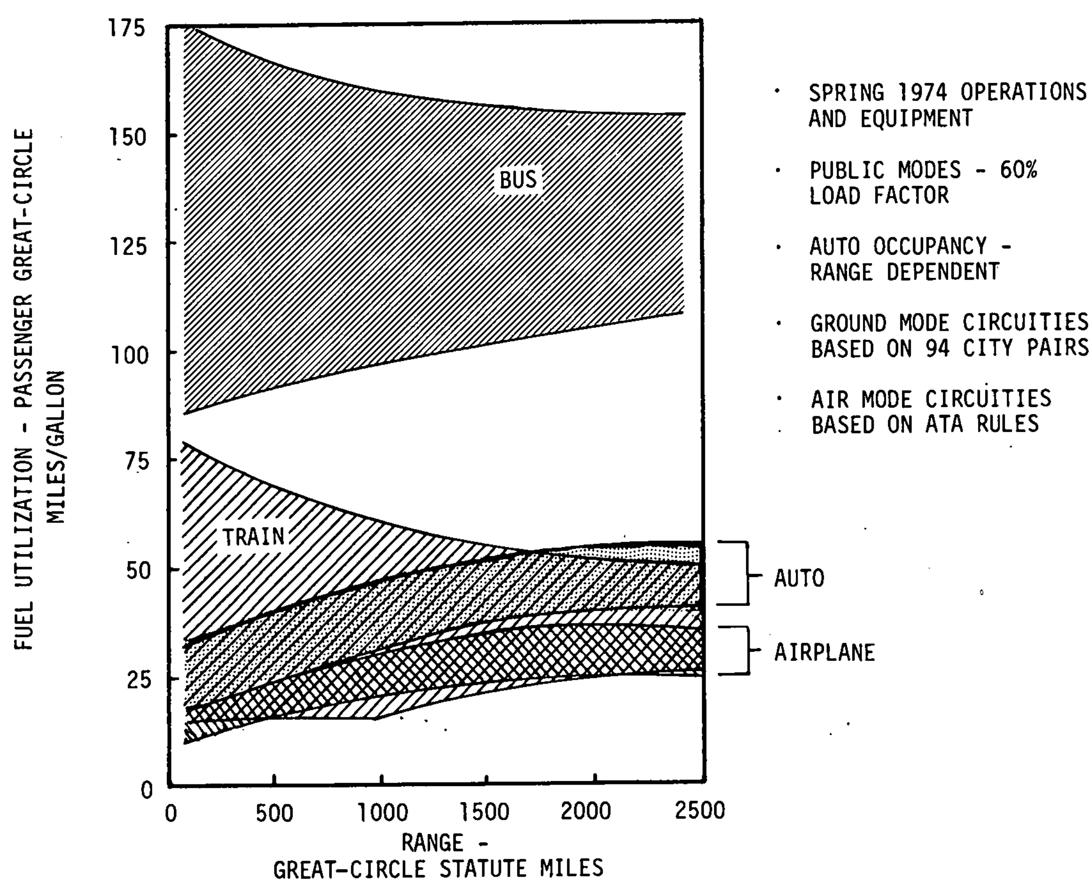


Figure 6. Fuel use versus range (great-circle statute miles) (11).

• Automobile fuel use improves with range because of higher occupancy levels and the reduced impact of city driving. These two trends together mask the fact that automobiles, like other modes, have higher circuity (ratio of the travel distance to the great-circle distance) at short distances than at long distances.

• For trains, fuel use at short distances reflects system circuity trends combined with the wide range of in-service equipment and seating density. At longer distances, fuel use reflects the use of full-service equipment (diners, club cars, sleepers, etc.) combined with circuity.

• Bus range trends are dominated by the system's circuities.

• Automobile fuel-consumption levels may be somewhat optimistic because of data deficiencies for such items as driver habits, mechanical condition, and geographic penalties.

• Bus and automobile performances are representative of typical intercity equipment, although some equipment on some routes may exceed these boundaries.

Many values are used in the literature to report on the energy efficiency of passenger transportation modes. As an aid to the reader, Table 15 has been prepared to summarize some of the highlights of this information in a form that facilitates general comparisons of the magnitudes involved. The balance of this chapter presents specific data on different modes of passenger transportation.

TABLE 14

HOURLY VALUE OF TIME BY TRIP PURPOSE, 1973 * (*8*)

Trip Purpose	% of Wage	Dollars
Urban Commuting (including Intercity: Business and Conventions)	60	2.59
Business-Related	100	4.32
Family Business Affairs	40	1.73
Social and Recreation Visits to Friends and Relatives, Outdoor Recreation, Sightseeing and Entertainment	25	1.08

*Average hourly wage of $4.32. These values may not adequately address special travel requirements, degree of urgency, or emergencies.

AUTOMOBILE

Data on automobile service and energy consumption for 1972 are given in Table 16. Because of the automobile's very large consumption of fuel and potential for fuel savings, improving the efficiency of new motor vehicles has been the subject of considerable study during the past few years. The results of one major study, carried out by the Department of Transportation and the Environmental Protection Agency, are summarized in "Potential for Motor Vehicle Fuel Economy Improvement: Report to the U.S. Congress" (*23*). Following are the study's major findings for automobiles.

• By a variety of means and with little further price increase, fuel economy in the new model fleet of 1980 can be improved 20 percent over that of 1974 automobiles. The full range of potential improvements, which is from 40 to 60 percent, is shown in Figure 7.

• Obtaining fuel economy improvements while simultaneously achieving such interrelated objectives as low emissions and occupant safety will involve competition for capital, expertise, and other resources. The effects, some of which may require compensating action, include the following:

(a) The price of new automobiles will rise because of fuel economy improvements. For example, a 40 percent improvement over 1974 will increase the price as much as 10 percent. Savings in operating and maintenance costs, however, will more than offset this price increase for the vehicle owner.

(b) A sustained or increased shift to the more fuel economical small cars, without a concurrent upgrading of their crashworthiness or increased use of effective passenger restraints, will result in a rise in the serious injury and death rate on the highways. Limited evidence indicates that crashworthiness of the smaller car can be upgraded without serious weight penalties.

(c) Achievement of the statutory emission standards for hydrocarbons and carbon monoxide, with substantial fuel economy improvement, is feasible in the new model fleet of 1980. For the oxides-of-nitrogen emission standard, the issue of level and cost achievable by 1980 concurrent with substantial improvement in fuel economy is unresolved.

(d) Dramatic savings in petroleum requirements can result from fuel economy improvements. The savings in petroleum may not be fully realized, because the resulting gain in operational economy may induce additional vehicle travel and increased sale of larger (although improved) cars.

The detailed conclusions of the study are presented in Appendix B; they contain much insight into the trade-offs between vehicle cost, emissions, safety, and fuel economy as well as a discussion of testing, enforcement, and cost benefit. Clearly, the price to be paid for increased fuel economy must be evaluated against many other related factors (*24*). Some trade-offs must be made among safety, emission, efficiency, and cost factors.

The Jet Propulsion Laboratory of the California Institute

TABLE 15

ENERGY EFFICIENCY FOR PASSENGER TRANSPORTATION MODES

Mode	Passenger-Miles Per Gallon	Seat-Miles Per Gallon	Btu per Passenger-Mile	Load Factor Assumed	Source	Remarks
Auto	22	57	5,578	1.9	TSC (12)	Urban (1972)
	43	83	2,902	2.6	TSC (12)	Intercity (1972)
	30	68	4,208	2.2	TSC (12)	Combined (1972)
	15	54	8,100	1.4	Hirst (13)	Urban (1970)
	37	77	3,400	2.4	Hirst (13)	Intercity (1970)
	23	61	5,400	1.9	Hirst (13)	Combined (1970)
	25				Mooz (14)	
		64			Rice (15)	
	18-28			Incr. with dist.	Boeing (11)	
Small						
Work and related business	21.67	70 *	5,768	1.6	FHWA (54)	
Shop and family business	41.39	63	3,020	2.3	FHWA (54)	
Social and recreation	74.93	94	1,668	2.8	FHWA (54)	
Subtotal	47.74	76	2,618	2.2	FHWA (54)	
Standard						
Work and related business	15.68	59	7,972	1.6	FHWA (54)	
Shop and family business	20.70	54	6,039	2.3	FHWA (54)	
Social and recreation	42.15	90	2,966	2.8	FHWA (54)	
Subtotal	24.51	67	5,100	2.2	FHWA (54)	
Total	29.70	69	4,209	2.2	FHWA (54)	
Bus	90-162			60%	Boeing (11)	Intercity Bus
	51		2,681		TSC (12)	Urban Transit(1972)
	168		743		TSC (12)	School (1972)
	116	247	1,170	47%	TSC (12)	Intercity (1972)
	112		1,210		TSC (12)	Combined (1972)
			3,700	<20%	Hirst (13)	Urban (1970)
			1,600		Hirst (13)	Intercity (1970)
			1,100		Hirst (13)	School (1970)
	116	276	1,192	42%	DOT/NASA (17)	Intercity (1972)
	48	180	2,891	24%	DOT/NASA (17)	Urban (1972)
	125		1,100		Rice (15)	Intercity(mid-1960's)
	83				Rice (18)	Intercity(1966-70)
Rail	84		1,646		TSC (12)	Transit (1972)
	55		2,493		TSC (12)	Commuter (1972)
	39		3,533		TSC (12)	Intercity (1972)
	64		2,146		TSC (12)	Combined (1972)
		210			Mitre (16)	
	80		1,700		Rice (15)	(mid-1960's)
	32	128	4,300	25%	Mitre (16)	Urban (1970)
	51	138	2,730	37%	Mitre (16)	Intercity (1970)
	48	130	2,900	37%	Hirst (13)	Intercity (1970)
	14-64			60%	Boeing (11)	
Air	16		7,766		TSC (12)	Domestic (1972)
	15.2	29		52.7%	FEA (8)	Domestic (1972)
	19	34		56.4%	FEA (8)	International (1972)
	14		9,700		Rice (15)	(mid-1960's)
			8,400	49%	Hirst (13)	(1970)
	15				Rice (18)	(1966-70) short haul
	20				Rice (18)	(1966-70) long haul
	18-28			60%	Boeing (11)	700 statute-mile range
Misc.				PM/VM		
Bicycle			1,300		Hirst (19)	Total energy use
			97		EPA (20)	10 MPH
			200		Rice (15)	5 MPH
Walking			500		EPA (20)	2.5 MPH
			300		Rice (18)	2.5 MPH
Taxi**	8.0		15,600	0.7	DOT (51)	
Dial-A-Bus	15.6			3.0	HRB (21)	Peak hour
Van-Pool	81	108	1,540	9.0	3-M Co.(59)	Peak hour
BART	88			40	BART (22)	Peak hour

*Small cars are assumed to average 3.5 passenger-seats and other cars 6.0 passenger-seats.
**The driver is assumed not to be a passenger.

of Technology concluded that, quite apart from any major change in the automobile's basic power plant, fairly large reductions in national fuel consumption (with some improvement in pollutant emissions) can be realized through modifications in design of the rest of the automobile and/or changes in its use (*25*). Changes in use are discussed in Chapter Four. Design modifications that provide better fuel economy through weight reduction and other measures supplement any future gains in new engine technology.

Fuel consumption significantly lower than that of today's automobiles can be obtained with the same engines by implementing the following vehicle changes:

1. Weight reduction through decreased exterior size and the use of construction materials that reduce weight.
2. Transmission improvements.
3. Moderately reduced acceleration capability.
4. Lower aerodynamic drag.
5. Optimized accessories and accessory drives.

Table 17 summarizes the percentage of weight reduction, relative to typical 1974/1975 model autos, that can be achieved in the various classes. (Note that percentage improvements are not additive algebraically.) Table 18 gives estimates of the corresponding percentage of reduction in fuel consumption attainable from those weight reductions and other changes. Fuel consumption can be reduced 14 to 35 percent over the range of automobile classes by using intermediate technology (i.e., technology

TABLE 16

AUTOMOBILE SERVICE AND ENERGY CONSUMPTION BY TOTAL FLEET, 1972

	LOCAL[a]	INTERCITY[b]	TOTAL
Direct fuel consumed			
thousand bbl/day	3,473	1,265	4,738
million gal/year[c]	53,246	19,396	72,642 (73,121)[e]
trillion Btu/year	6,656	2,424	9,080
percentage of TDTE	36.3	13.2	49.5
Services rendered			
million vehicle-miles/year[d]	639,111	355,943	995,054 (986,407)[e]
average occupancy[d]	1.9534	2.6	2.2
million passenger-miles/year[d]	1,248,461	922,871	2,171,331 (2,170,095)[f]
Average efficiency			
Btu/passenger-mile	5,331	2,627	4,182
passenger-miles/gal	23	48	30

[a] Local travel - trips of 30 miles or less in length.
[b] Intercity travel - trips of more than 30 miles in length.
[c] Fuel data from Ref. *8*.
[d] Travel occupancy data from Ref. *8*.
[e] Table VM-1, Highway Statistics, 1972 *(6)*.
[f] Table 6, Ref. *27*.

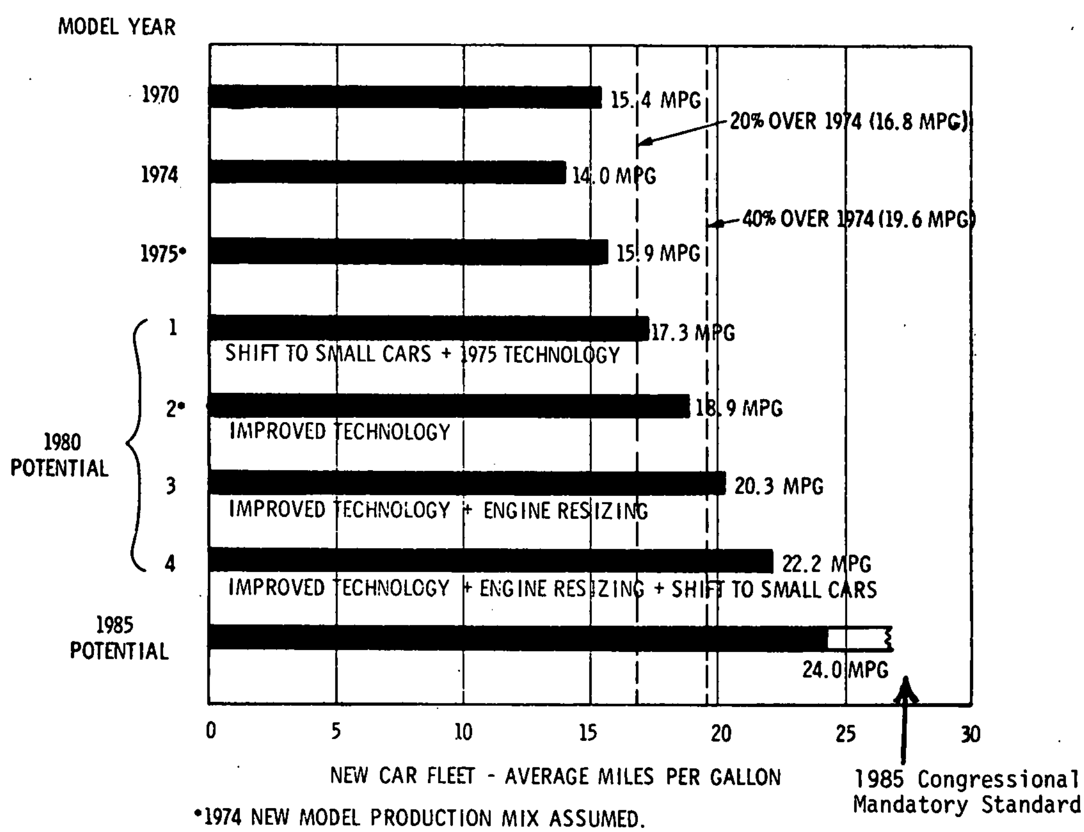


Figure 7. Potential for automobile fuel-economy improvement (23).

TABLE 17

PRACTICABLE WEIGHT SAVINGS THROUGH VEHICLE IMPROVEMENTS (PERCENT) (*25*)

Source of weight savings	Small (Imports)	Subcompact (Imports 20%)	Subcompact (U.S. 80%)	Subcompact Average	Compact (All U.S.)	Large (All U.S.)
1. Exterior size reduction	5	5	10	9	10	15
2. Materials: HSLA[a] and plastics	3	3	3	3	4	5
3. Design details	0	0	2	2	2	3
4. V-6 engine	-	-	-	-	4	-
Intermediate over-all effect	8			13	19	22
5. Materials: aluminum (additional to item 2)	6	7	7	7	7	7
6. Front-wheel drive	2	3	5	4	5	5
Longer-term over-all effect	15			26	28	31

[a]High-strength, low-alloy steels.

that is achievable entirely with present methods and materials and that could be completely implemented by 1981).

Table 19 gives energy intensiveness and the breakdowns of fuel consumption and travel (percent of trips, vehicle-miles, and passenger-miles) according to trip purpose. The energy intensiveness and percentage of fuel consumed are based on the fuel economies assumed for each trip purpose. For example, for vacation trips, the average fuel economy was assumed to be 18.0 mpg (7.7 km/litre), whereas on the low side, the short, around-town shopping trips were assigned a fuel economy of 11.5 mpg (4.9 km/litre). The assumed fuel consumption values were chosen to yield a value for all trips of 13.6 mpg (5.8 km/litre), consistent with the 1970 national average for the automobile.

The least efficient (most energy intensive) use of the automobile is in commuting (to-and-from-work category), primarily because of the low load factor (1.4 occupants per auto). Social and recreational trips, with nearly double the load factor of to-and-from-work trips, constitute the most efficient use of the automobile (yet they may be curtailed more easily than work trips). For vacation trips, the average occupancy of 3.3 persons per auto makes the automobile less energy intensive than intercity rail and half as energy efficient as intercity buses operating at approximately a 50 percent load factor.

TABLE 18

COMPOSITE FUEL-CONSUMPTION REDUCTIONS FROM VEHICLE IMPROVEMENTS (PERCENT) (*25*)

Source of reduction	Small	Subcompact	Compact	Large
1. "Intermediate" weight reduction	6	10	15	18
2. 4-speed automatic transmission with lockup	3	6	7	8
3. Reduced acceleration[a]	2	2	5	10
4. Lower aerodynamic drag	3	3	3	2
5. Improved accessories and drive	1	1	2	3
Over-all effect of intermediate improvements	14	20	29	35
6. Longer-term weight reduction (replaces item 1)	12	21	23	25
7. Continuously variable transmission (CVT) replaces item 2)	10	13	14	15
Over-all effect of longer-term improvements	26	35	40	45

[a]Assumes an increase in 0-60 mph acceleration time ranging from 1 second for the Small car class to 3 seconds for the Large car class.

BUS

Data on bus service and energy consumption for 1972 are given in Table 20. Modest improvements in bus engine and drive-train components can be expected to increase fuel economy by 1980 (*26*). In the case of transit and intercity

TABLE 19

AUTOMOBILE USE AND EFFICIENCY BY TRIP PURPOSE, 1970 (*16*)

TRIP PURPOSE	AVERAGE TRIP LENGTH (ONE WAY)	AVERAGE OCCUPANCY	ASSUMED FUEL CONSUMPTION	% TRIPS	% VEHICLE-MILES	% PASS-MILES	% FUEL CONSUMED	ENERGY INTENSIVENESS	
Earning a Living									
• to & from work	9.4 miles	1.4 pass/veh.	13.0 mpg	32.3	34.1	24.0	35.6	7400 Btu/Pass mi	16.9 pass mi/gal
• related business	16.0	1.6	16.0	4.4	8.0	6.4	6.9	5370	23.3
	10.2	1.4	13.4	36.7	42.1	30.4	42.5	6970	17.9
Family business									
• medical & dental	8.3	2.1	13.5	1.8	1.6	1.8	1.6	4430	28.2
• shopping	4.4	2.0	11.5	15.4	7.6	8.0	9.0	5600	22.3
• other	6.5	1.9	12.5	14.2	10.4	10.4	11.3	5400	23.1
	5.5	2.0	12.1	31.4	19.6	20.2	21.9	5390	23.2
Educational/Civic/Religious	4.7	2.5	11.5	9.4	5.0	6.6	6.0	4530	27.6
Social/Recreational									
• vacations	165.1	3.3	18.0	0.1	2.5	4.1	1.9	2310	54.1
• visits to friends & relatives	12.0	2.3	15.0	9.0	12.2	14.2	11.0	3860	32.4
• pleasure rides	19.6	2.7	16.0	1.4	3.1	4.2	2.7	3200	39.1
• other	11.4	2.6	15.0	12.0	15.5	20.3	14.0	3440	36.3
	13.1	2.5	15.3	22.5	33.3	42.8	29.6	3450	35.9
All Trips	8.9	1.9	13.6	100.0	100.0	100.0	100.0	4980	25.1

Data source for trip length, occupancy, % trips, and % vehicle-miles: Nationwide Personal Transportation Study, Federal Highway Administration.

buses, which are already dieselized, the fuel economy gain of the 1980 vehicles is likely to be limited to an improvement of approximately 20 percent over the 1972 averages of 4.4 mpg (1.9 km/litre) for transit and 6.2 mpg (2.6 km/litre) for intercity. Through dieselization, school buses, which are predominantly gasoline-powered, could experience gains of approximately 30 percent over their 1972 average of 7.4 mpg (3.1 km/litre).

Table 21 details the service and fuel uses by class of bus for 1973. It is of interest to note that there are more than 10 times as many school buses as there are intercity buses and that each school bus travels, on the average, only one-seventh as many miles per year. Also, bus fuel consumption varies from 4.6 to 7.4 mpg (2.0 to 3.1 km/litre), making high occupancy an essential factor for efficient operation.

RAIL

Rail passenger service and energy consumption for 1972 are given in Table 22. To the extent that future intercity rail passenger service becomes relatively more concentrated in corridors such as Boston-Washington, energy efficiency may increase because corridor trains typically carry much less "deadweight" (sleeping cars, dining cars, baggage cars, etc.) than long-haul conventional trains. Furthermore, high-density corridors are prime candidates for electrification,

TABLE 20

BUS SERVICE AND ENERGY CONSUMPTION, 1972 (*12*)

	LOCAL**		INTERCITY***	TOTAL
	Transit 1/	School		
Direct fuel consumed				
thousand bbl/day	22	21	14	57
million gal/year	344	320*	217	881*
trillion Btu/year 2/	47	39	30	116
percentage of TDTE	0.25	0.21	0.16	0.63
Service rendered				
million vehicle-miles/year	1,470	2,359*	1,280	5,109*
million passenger-miles/year 3/	17,640	52,824	25,600	96,069
Average efficiency				
Btu/passenger-mile	2,681	743	1,170	1,210
passenger-miles/gal	51	168	116	112

1/ Includes airport and sightseeing buses.

2/ Conversion factors are 136,000 Btu/gal for diesel-powered transit and intercity and 125,000 Btu/gal for gasoline-powered school and other non-revenue buses.

3/ Load factor assumed for intercity buses is approximately 47 percent.

*Table VM-1, Highway Statistics, 1972 (*6*).

**Local travel - trips of 30 miles or less in length.

thereby saving petroleum through substitution of other forms of energy.

For new-technology trains operating in corridors where the new traffic will support them, the efficiency is much better than that for the 1972 intercity average. Under typical operating conditions, the electrified Washington-New York Metroliner has an energy consumption of 440 Btu/seat-mile (288 kJ/seat-km), which at a 70 percent load factor is 643 Btu/passenger-mile (422 kJ/passenger-km), or 215 passenger-miles/gal (91 passenger-km/litre) (*12*). After adjustment for generating efficiency (33 percent) and distribution efficiency (91 percent), this is equivalent to 2,141 Btu/passenger-mile (1.4 MJ/passenger-km), or 64 passenger-miles/gal (27 passenger-km/litre). The Metroliner design is, in fact, somewhat heavy; new, improved state-of-the-art passenger trains could have an energy consumption as low as 360 Btu/seat-mile (electric) (240 kJ/seat-km). Regenerative braking could further reduce energy consumption 25 to 40 percent by 1990. Thus, during the 1990s, primary energy consumption per passenger-mile for corridor trains may be in the vicinity of 1,000 Btu (660 kJ/passenger-km), or 138 passenger-miles/gal (59 passenger-km/litre) (*12*).

On the other hand, there is a desire for greatly increased speed in rail service. Because the energy consumed in overcoming aerodynamic drag increases as the second power of velocity, it is possible that a significant portion of this saving may be lost.

Depending on how the trade-off between efficiency and speed is resolved, future passenger rail service may show efficiency gains large enough to save about 0.2 percent of total direct transportation energy (TDTE) by 1990. Furthermore, an increasing fraction of energy for rail passenger service will be supplied by coal or nuclear prime movers, possibly sufficient to reduce petroleum consumption in 1990 by the equivalent of another 0.1 percent of TDTE.

TABLE 21

BUS FUEL CONSUMPTION, 1973

	LOCAL		INTERCITY	TOTAL
	Transit	School & Other Non-revenue		
Total Buses	48,286	323,000 (336,000) *	30,367	401,653 (425,500) *
Fuel consumed (millions of gals/year)	295	328 (327) *	191	814 (847) *
% of fuel consumed on total fuel used by all automotive sources	0.14	0.3	0.35	0.79
Average miles/year traveled	28,500	7,500 (7,178) *	52,700	13,443 (11,662) *
Average miles per gallon	4.6	7.4 (7.37)*	6.0	6.6 (5.86)*

* Table VM-1, Highway Statistics 1973 (*6*).
Data Source: Ref. *26*.

TABLE 22

RAIL PASSENGER SERVICE AND ENERGY CONSUMPTION, 1972 * (*12*)

	TRANSIT	COMMUTER	INTERCITY	TOTAL
Direct fuel consumed				
thousand bbl/day	N/A	N/A	N/A	8
million gal/year				125
trillion Btu/year (includes kWh)	25	11	15[1]	51
percentage of TDTE	0.14	0.06	0.08	0.27
Service rendered				
million vehicle-miles/year	N/A	N/A	N/A	N/A
million passenger-miles/year	15,344	4,228	4,164	23,925
Average efficiency				
Btu/passenger-mile	1,646	2,493	3,533	2,146
passenger-miles/gal	84	55	39	64

[1] Adjusted to remove 20 percent of 1972 passenger-train energy charged to mail and express.

* Sources: Transit fuel consumption, Reference *27*. Other fuel figures, Reference *28*. Transit passenger-miles calculated from passenger data in Reference *29* by means of the passenger-mile factor of Reference *30*. Other passenger-miles from reference *27*.

AIR

Pollard, Hiatt, and Rubin summarized the data on air service and energy consumption for domestic air passenger service by certificated carriers in 1972 as given in Table 23 (*12*).

The Council on Environmental Quality analyzed the average fuel efficiency of air transportation in great detail as given in Table 24 (*8*). Because fuel costs represent approximately 23 percent of total operating costs, airlines are expected to implement strategies to increase fuel efficiency, given an increase in fuel prices. Two basic methods are available: increases in passenger load factors and changes in operational procedures. These are discussed in Chapter Four.

Airplane energy intensity depends on both airplane type and stage length. This fact is shown dramatically in Figure 8 (*32*). Energy intensity decreases rapidly as stage length increases. The reason for this improved fuel use with increasing range is that nonproductive flying (takeoff, climb, landing, and terminal maneuvering) becomes less significant. Fuel use is also sensitive to airplane configuration. The large, wide-bodied, high-bypass-ratio-engine airplanes tend to be more efficient than the smaller, standard-bodied, low-bypass-ratio-engine airplanes. Most of the long-range airplanes have peak fuel use at stage-length ranges of 2,000 to 3,000 miles (3 200 to 4 800 km). At payloads of less than 200 passengers, the smaller airplanes are more fuel efficient because they operate at higher load factors.

The greatest potential for increasing the fuel efficiency of commercial aircraft lies in increasing passenger load factors. Fuel consumption in jet aircraft is relatively insensitive to increasing weight; the Boeing 727-100's fuel consumption, for example, increases only about 0.3 percent per additional 1,000 lb (450 kg) at normal loaded weights. Thus, the additional fuel required for higher payloads is

TABLE 23

AIR PASSENGER SERVICE AND ENERGY CONSUMPTION, 1972 (*12*)

Direct fuel consumed[1]	
thousand bbl/day	490
million gal/year	7,536
trillion Btu/year	946
percentage of TDTE	5.2
Service rendered[2]	
million passenger-miles/year	121,820
Average efficiency	
Btu/passenger-mile	7,766
passenger-miles/gal	16

[1]Passenger-service fuel consumption was computed to be total passenger/cargo aircraft fuel use (Reference *31*) minus marginal fuel use for the weight of belly cargo.

[2]From CAB, Air Carrier Traffic Statistics, December 1972.

quite small, and improved fuel efficiency is almost directly proportional to increased load factor.

Passenger load factors have declined almost steadily for 20 years. In 1951, the passenger load factor for the major domestic carriers was 70 percent; for the past several years it has been near 50 percent (*33*). This decline was due to several factors, the more important of which were the advent of jet aircraft, with their lower break-even load factor; the excess capacity caused by optimistic projections of demand growth; the addition of wide-bodied aircraft; and the regulatory policies on service levels and competition.

Load factors rose sharply in response to the fuel shortage. Figures for March 1974, the height of the fuel shortage, show that the combined load factor for domestic trunks and local-service carriers was 58.7 percent, compared with 49.7 percent for March 1973 (*34*). This rapid increase indicates a potential for substantial improvement in load factor. If a 60 percent average load factor for domestic service were achieved, fuel requirements would be about 16 percent less than those for a 50 percent load factor. If a 70 percent load factor (which is considered to be a practical upper limit) were achieved, aircraft fuel consumption would be approximately 28 percent less than it is with a 50 percent load factor.

Data on fuel consumption for general aviation are scarce. For the period from FY 1972 to 1976 inclusive, fuel consumption of domestic air carriers showed little change,

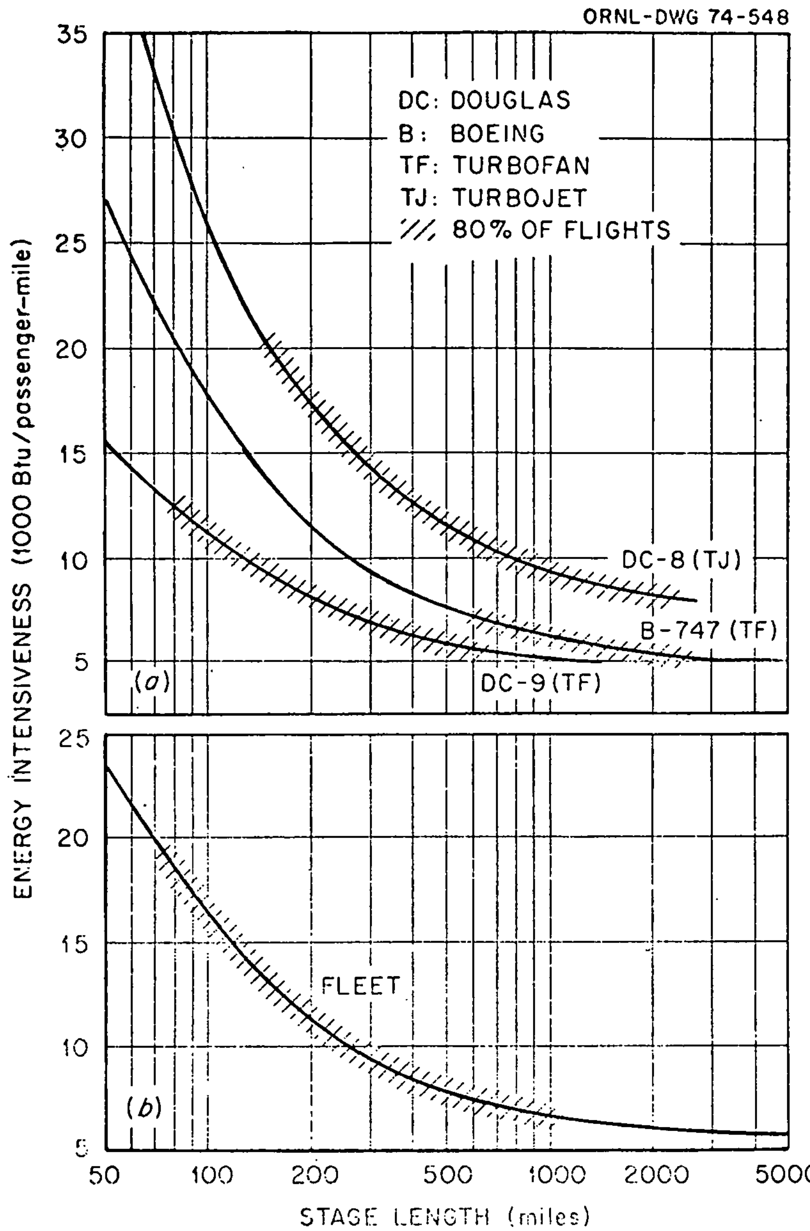


Figure 8. Energy intensiveness (EI) as a function of stage length (32).

whereas the FAA estimates that general aviation use of jet fuel has doubled and use of aviation gas has increased by about 25 percent (*58*). General aviation uses about 7 percent of all jet fuel and 96 percent of the aviation gas, for a total of about 12 percent of the fuel consumed in domestic civil aviation.

BICYCLE

The bicycle is a remarkable transportation invention requiring even less energy per unit-distance than walking. Hirst has estimated that the total energy used for bicycling (food, bicycle manufacture and sale, repairs and maintenance, tires, and bikeway construction) amounts to about 1,300 Btu/mile (850 kJ/km) (*19*). Included in this estimate is 790 Btu/mile (520 kJ/km) for food; this may be larger than that required for the bicycle trip alone.

TABLE 24

FUEL-EFFICIENCY DATA BY AIRCRAFT EQUIPMENT GROUPS, 1972[a] (DOMESTIC AND INTERNATIONAL) (*8*)

EQUIPMENT GROUP (Passenger/Cargo Aircraft)	Passenger-Miles per Gallon	BTU per Overall Ton-Mile	Fuel Consumption	Passenger-Miles	Passenger-Miles Per Available Seat-Mile	Average Stage Length
			Thousand Gallon	Million	Load Factor %	Miles
DOMESTIC[b]						
4FW (B-747)[c]	18.8	56,505	632,719	11,930	45.8	1962
3FW (L-1011, DC-10)	18.8	58,680	271,119	5,100	45.4	1079
4FR (B-707b, DC-8)	14.5	79,209	1,934,594	28,088	51.3	993
3FR (B-727)	15.1	79,011	2,591,723	39,240	55.1	525
2FR (B-737, DC-9)	16.3	73,990	937,731	15,315	59.3	320
4JR (B-707, DC-8)	11.2	104,751	792,178	8,888	51.9	836
4 Turboprop	9.3	139,801	12,085	113	43.1	207
TOTAL	15.2 (15.0)[d]	76,817	7,172,149	108,674	52.7	--
INTERNATIONAL						
4FW (B-747)	24.0	43,469	759,038	18,202	54.7	2434
3FW (L-1011, DC-10)	24.9	48,992	19,267	479	67.3	1558
4FR (B-707b, DC-8)	16.2	56,138	1,044,040	16,904	57.4	1486
3FR (B-727)	16.4	76,036	161,083	2,636	62.2	473
2FR (B-737, DC-9)	14.9	97,391	7,782	115	30.8	278
4JR (B-707, DC-8)	13.9	77,853	108,022	1,503	60.4	1586
TOTAL	19.0	56,732	2,099,232	39,842	56.4	--

[a] *Data for each aircraft equipment group were obtained from the 1972 Aircraft Operating Cost and Performance Report published by the Civil Aeronautics Board.*

[b] *Domestic travel data are for the domestic trunks only, excluding the local service component. The domestic trunk provides 92 percent of domestic passenger-miles. Fuel efficiency was later adjusted to account for the much lower fuel efficiency of local service travel.*

[c] *The aviation 4FW refers to a 4-engine, turbofan, wide-bodied aircraft. In the other similar notations, the J refers to turbojet and the R to a regular-bodied aircraft.*

[d] *Passenger-miles per gallon adjusted to include local service transport based on historical efficiency performance relative to the domestic trunk and market share.*

TABLE 25

BICYCLE USE IN U.S. (MILLIONS)

Year	U. S.-Manufactured and Imported Bicycles	Bicycles in Use*	Estimated Users
1960	3.8	23.5	35.2
1965	5.7	32.9	49.3
1970	6.9	50.0	75.3
1971	8.9	53.1	79.6
1972	13.9	61.2	91.9
1973	15.3	70.0 +	100.0 +
1974	14.1	75.0 +	100.0 +
1975	7.3	75.0 +	100.0 +

* Number of bicycles in use is estimated.

Source: Bicycle Manufacturers Assn. of America.

In terms of vehicle efficiency, a bicyclist moving at 10 mph (16 km/h) uses only 97 Btu/passenger-mile (64 kJ/passenger-km), whereas a pedestrian walking at 2.5 mph (4 km/h) uses 500 Btu/passenger-mile (330 kJ/passenger-km) (*20*). The bicycle is efficient, both structurally and mechanically. A person's energy consumption with the aid of the bicycle is about one-fifth that consumed in walking. Therefore, apart from increasing speed by a factor of three or four, the cyclist's efficiency rating improves to number one among moving creatures and machines (*35*).

Greater recognition of the potential role of the bicycle resulted in an increase in bicycle users from 35.2 million in 1960 to 91.9 million in 1972 (i.e., one bicycle rider for every two persons between the ages of 7 and 69). In 1973, 15.3 million bicycles were sold (see Table 25). Despite this growth, the bicycle is still a very small part of the transportation picture. Clearly, the bicycle can not be ignored in any study of alternative urban transportation modes.

WATER

Less than 0.5 percent of TDTE is devoted to water recreational activities. Intercity common carriers (mainly ferries) consume even less energy; service performed by them is estimated at 4,300 million passenger-miles/yr (6.9×10^9 passenger-km/yr) (*12*). Technology transferred from the automotive industry may result in some improvement in the efficiency of marine power plants; however, this effect is not likely to amount to more than 0.1 percent of TDTE (equivalent to a 20 percent reduction in fuel consumption per boat-mile) in any year. More significant savings in marine passenger transport could come from reduced use of pleasure boats, the substitution of sail for engine power, or both. Under any conditions of fuel shortage sufficiently severe to result in general gasoline supply restrictions, pleasure boating would probably decline severely, perhaps to 0.2 or 0.3 percent of TDTE. The same percentages would apply in future years, if one assumes that demand for pleasure boating would grow at about the same rate as the demand for other transportation modes.

Thus, although there are some domestic-intercity and international water passenger-transportation operations, plus a fast-growing trend in private recreational boating, freight traffic is by far the dominant user of water transportation. Measures of fuel efficiency are available for the freight traffic category only (see Chapter Three).

CHAPTER THREE

ENERGY EFFICIENCIES: FREIGHT TRANSPORTATION MODES

INTRODUCTION AND GENERAL DISCUSSION

This chapter compares energy efficiencies for basic types of freight transportation modes in terms of their design, operating, and use characteristics.

At present, freight transportation consumes approximately 28 percent of the energy supply (*5*). It is expected to consume a larger portion in the future, so it is important that policies and plans be adopted to minimize transportation energy requirements and still maintain required freight transport. These plans and policies should be based on a careful appraisal of the energy efficiencies of alternative freight transport modes, in terms of both specific and general use.

It is important to caution the reader that some comparisons of freight transportation energy efficiency are misleading. In many cases in the literature, the relative efficiency of different types of transportation is determined simply by comparing the number of ton-miles hauled per gallon of fuel. It can be shown that this is quite misleading and is an oversimplification of a complex problem. Little or no attention is given to the shipment and commodity characteristics of the freight being carried by the various modes. This practice can give the impression that modes compete in identical markets and that any ton of freight is the same for any commodity. In reality, the modes serve a large number of different markets that have wide-ranging freight-commodity characteristics and transportation requirements. Although intense competition exists among some modes in some markets, all modes do not compete in all markets. Indeed, in many respects the modes are complementary; for example, air and rail depend on the flexibility of trucks in the local distribution and collection of commodities. The speed capabilities of air transportation have added an important and marketable commodity, and rail transport of truck trailers has added another element.

One facet to be considered in choice of mode is that energy efficiency is not and can not be the sole criterion for mode selection. Mode selection varies with the specifics of each transportation requirement: trip length; market size; transport time; and commodity value, perishability, and fragility. It is important to understand the relationship between energy consumption and commodity characteristics (e.g., freight density) when comparing one mode of transportation with another. Consideration also must be given to the role that transportation is assigned when the manufacturing flow process is used in lieu of maintaining large inventories of stocks and parts.

Many other relationships need to be explored, particularly the one between energy conservation and the value of transportation. Conservation policies must take this trade-off into proper account to avoid superficially derived practices for conserving energy. It would be fruitless to conserve energy by not providing needed transportation services; our national transportation requirements must be met—but with intelligent expenditure of our finite energy supplies. This demands that the energy needed to perform given services be compared on an objective and honest basis.

For example, if the number of specific kinds of freight that can be moved between specific points at a given time is known, the amount of fuel required can be calculated for each mode. In other words, if it is known that 50,000 tons (45 000 t) of coal are to be transported from a mine to a generating plant at a given time, and if the terrain to be traversed is known, the amount of fuel that would be required to move it by each mode of transportation (railroad, truck, water, pipeline, or even conveyor belt) could be determined with some degree of precision.

Also, if it is known that 50,000 tons (45 000 t) of merchandise of a different kind and characteristic are to be moved from 500 known points of origin to 500 known points of destination in a given period of time, it would be possible to compute the fuel requirements by mode of transport. In either case, the number of ton-miles per gallon of fuel could be determined; however, these data would be largely irrelevant for comparison purposes, because the job being performed is different. For example, determining ton-miles per gallon of fuel required to move fresh fruit by the most efficient mode may be improper and misleading.

Normally, the types of traffic being handled by each mode of transport reflect the economic efficiency of each mode, including its energy efficiency. For the most part, pipelines move bulk liquids in heavy volume between fixed points. Water carriers move long-haul bulk commodities in large shipments between points on navigable waterways. Railroads move heavy, dense commodities in large volume in medium-to-large shipments between points on their lines. Air carriers move high volumes of small shipments of a priority nature. Trucks move virtually everything that is transported in the local and urban areas as well as moving intercity freight that is transported in small lots or that demands prompt delivery or special handling. Trucks also participate in the movement of all intercity freight transported by other modes originating and/or terminating at points not directly served by those modes.

A comparison of the amount of petroleum consumed by a number of transportation modes can demonstrate variances in their energy efficiencies. Consideration needs to be given to the fact that up to half of the travel by some trucks, rail cars, and barges takes place when the vehicles are empty. Also, consideration of typical situations and conditions of operation reveals that at times alternatives to apparently inefficient situations may actually require additional petroleum to accomplish the transportation task. A paper by French includes a revealing set of examples of truck operations to show how variable the energy efficiency of trucking operations can be in typical trucking situations (*36*). Results varied from 30 to 103 ton-miles/gal (11.6 to 39.7 t-km/litre), depending on varying operational factors in the four hypothetical examples of intercity trucking operations evaluated. The procedures considered are shown in Figure 9.

The four examples are based entirely on assumed weight as the measure of truck capacity. With typical semi-trailer-van dimensions and with allowances for loading clearances, a shipping density of more than 15 lb/ft^3 (240 kg/m^3) is necessary to achieve the assumed 30-ton (27-t) payload. Furniture, appliances, toys, and most general merchandise packed for retail sale are well below this density. Beverages, machine parts, some produce, and liquids such as paint are much heavier. Thus, the truck operator who can assemble loads of mixed commodities can more nearly achieve an optimum density that approaches both the weight and volumetric capacity of the vehicles. This may also reduce the total number of truck trips required to transport large amounts of freight. Tons shipped is therefore an effective measure of comparative fuel efficiency only when shipping densities are similar. For fuel efficiency comparisons, ton-miles-per-gallon values are useful when commodities of similar densities are involved; however, load size, vehicle type or mode, and distance may vary.

Transportation modes are subject to different system and equipment constraints, operational procedures, and data reporting methods. An understanding of these differences is basic to an objective assessment in comparing modal fuel use.

Gross modal efficiency is usually specified as the ratio of system revenue ton-miles to system fuel consumption. The method is fundamentally invalid for modal comparisons because, as stated earlier, different modal systems address different markets. Also, the quality of the source data varies so widely that the results are controversial. The first difficulty is that of distance bookkeeping. Aircraft data give distance credit only for great-circle miles. Statistics for aircraft fuel consumption involve actual miles flown, which usually exceed great-circle distances. Clearly, this bookkeeping system is different from those used by the ground modes, which are credited with either the actual travel distance or the rate-making distance. Both measures exceed the great-circle distance on most trips, resulting in an overstatement of the transportation service provided.

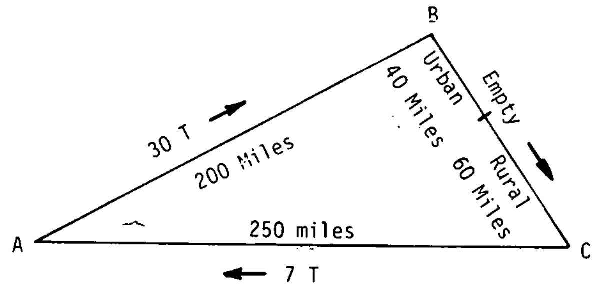
Trains, for example, are subject to wide variations in cruise speed, terrain, track curvatures, and local track quality, all of which impose speed constraints. For many trains, actual fuel efficiency is less than 50 percent of the idealized fuel efficiency.

The assumption of straight track or road ignores the geographical and system constraints that contribute to circuity or additional route-miles traveled from origin to destination. Particularly misleading are comparisons that use idealized analysis for one mode and operational data for another mode.

The reader is to be cautioned in the proper use of data on energy efficiency. These data are useful when the constraints under which they should be used are both stated and understood.

Comparisons of data on mode efficiency should be made only if the data address the same markets and are related to the performance of the same transportation job. Such a comparison is, then, a measure of each mode's efficiency in performing a particular transport task as well as its efficiency relative to other modes in performing the same task. Values reported in the literature for the efficiency of each mode of intercity freight transport are contained in Table 26, which gives the data in ton-miles per gallon and Btu per ton-mile for truck, trailer-on-flatcar and container-on-frame-car, railway, waterway, airplane, and pipeline. The energy efficiency values have been gathered from a number of the references consulted for this synthesis. The energy intensities for the individual transport modes are presented in the balance of this chapter.

Example I



I. Full Load Out, Long Dead Head for Partial Return Load

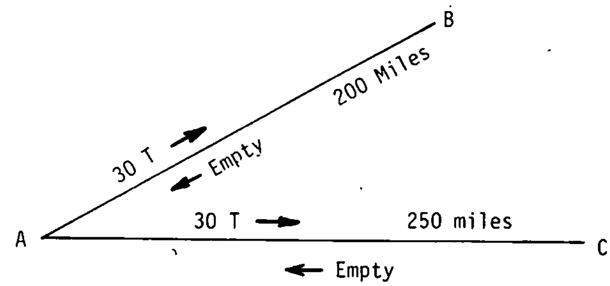
A-B Loaded 30T 200 miles @ 3.5 m.p.g. = 57.14 gallons
C-A Loaded 7T 250 miles @ 4.8 m.p.g. = 52.08 gallons
37T 109.22 gallons

Ten-Miles 30T x 200 miles = 6,000 ton-miles
7T x 250 miles = 1,750 ton-miles
7,750 ton-miles

B-U Empty 60 miles @ 6 m.p.g. = 10.00 gallons
U-C Empty 40 miles @ 3 m.p.g. (urban stop & go) = 13.33 gallons
TOTAL 132.55 gallons

Ten-Miles/Gallon = 7,750 ÷ 132.55 = 58.47 ton-miles/gallon
Tons Shipped per Gallon = 37T ÷ 132.55 gallons = 0.2791
Empty mileage 100 miles ÷ 550 = 18.18 percent

Example II



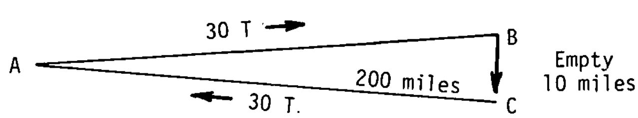
II: Full Leads Out and Empty Backhaul

A-B Loaded 30T 200 miles @ 3.5 m.p.g. = 57.14 gallons
C-A Loaded 30T 250 miles @ 3.5 m.p.g. = 71.42 gallons
60 450 128.56 gallons

Ton-Miles 30T x 450 miles = 13,500 ton-miles
A-C Empty 250 miles
B-A Empty 200 miles
450 miles @ 6 m.p.g. = 75.00 gallons
TOTAL 203.56 gallons

Ton-Miles/Gallon = 13,500T ÷ 203.56 gallons =
66.32 ton-miles/gallon
Tons Shipped per Gallon = 60T ÷ 203.56 gallons = 0.2947
Empty mileage 450 miles ÷ 900 miles = 50.00 percent

Example III

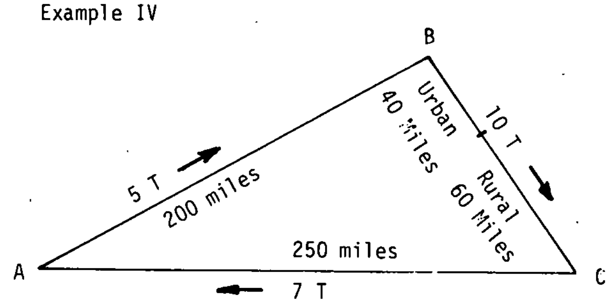


III: Full Loads Out and Full Backhaul

A-B and C-A Loaded 30T 400 miles @ 3.5 m.p.g. = 114.28 gallons
Ten-Miles 30T x 400 miles = 12,000 ton-miles
B-C Empty 10 miles @ 6 m.p.g. = 1.67 gallons
115.95 gallons

Ton-Miles/Gallon = 12,000 ton-miles/115.95 gallons =
103.49 ton-miles/gallon
Tons Shipped per Gallon = 60T ÷ 115.95 gallons = 0.5175
Empty mileage 10 miles ÷ 410 miles = 2.49 percent

Example IV



IV: Partial Loads on All Links

A-B Loaded 5T 200 miles @ 5.0 m.p.g. = 40.00 gallons
B-U Loaded 10T 60 miles @ 4.6 m.p.g. = 13.04 gallons
U-C Loaded 10T 40 miles @ 2.6 m.p.g.
(urban stop and go) = 20.00 gallons
C-A Loaded 7T 250 miles @ 4.8 m.p.g. = 52.08 gallons
125.12

Ton-Miles 5T x 200 miles = 1,000
10T x 100 miles = 1,000
7T x 250 miles = 1,750
3,750 ton-miles

Ton-Miles/Gallon = 3,750 ton-miles ÷ 125.12 gallons =
29.97 ton-miles/gallon
Tons Shipped per Gallon = 22T ÷ 125.12 gallons = 0.1758
Empty mileage = Zero = 0.00 percent

Figure 9. Four hypothetical examples of intercity truck operations analyzed for fuel consumption (36).

TABLE 26

ENERGY EFFICIENCY FOR INTERCITY FREIGHT TRANSPORT MODES

MODE	TON-MILES PER GALLON	BRITISH THERMAL UNIT PER TON-MILE	SOURCE	REMARKS
Heavy-Duty Truck (Combinations)	59	2300	Rice *(15)*	Based upon mid-1960 data.
	57	2400	Mooz *(37)*	Based upon 1967 data.
	49	2800	Hirst *(13)*	Based upon late 1960's data.
	123 – 67	1110 – 2023	DOT/NASA *(17)*	Engineering estimate (optimistic).
	51	2679	TSC *(12)*	Based upon 1972 highway statistics.
	41	3440	Mitre *(16)*	
	85	1600	DOT/EPA *(26)*	Based upon year 1972 ATA data.
	29 – 103	4690 – 1320	French *(36)*	Four-case study to illustrate operational factor impact.
TOFC/COFC (Trailer-on-Flat-Car/ Container-on-Frame-Car)	Estimate 9% fuel savings	-	FRA *(52)*	Discussed intermodal fuel saving potential.
	Estimate small savings	-	Morlok *(53)*	Compares with highway and rail.
Railway	203	680	Rice *(15)*	
	184	750	Mooz *(37)*	
	212	650	Smith *(38)*	Modification of Mooz *(37)* to eliminate data errors.
	206	670	Hirst *(13)*	
	418-251	330-550	DOT/NASA *(17)*	Engineering estimate (optimistic).
	204	676	TSC *(12)*	
	204	675	Mitre *(16)*	
	197	700	FEA *(8)*	Show efficiency decreasing from 650 in 1965 to 700 in 1972.
Waterway	259	540	Rice *(15)*	
	280	500	Mooz *(37)*	
	214	655	Smith *(38)*	Modification of Mooz *(37)* to eliminate data errors.
	206	680	Hirst *(13)*	
	275	509	TSC *(12)*	
	187	750	Mitre *(16)*	
Airplane	3.4	37,000	Rice *(15)*	
	2.0	63,000	Mooz *(37)*	
	3.0	42,000	Hirst *(13)*	
	16-8.5	7700-14,700	DOT/NASA *(17)*	Enginering estimate (optimistic).
	40.5	3100 (lower hold)	TSC *(12)*	Air freight carried in lower hold of passenger planes.
	4.7	27,000	TSC *(12)*	
	3.3	37,500	Mitre *(16)*	
Pipeline	302	450	Rice *(15)*	Oil pipeline.
	73.5	1,850	Mooz *(37)*	Oil pipeline.
	302	450	Hirst *(13)*	Oil pipeline (assumes 20" pipe diameter).
	206	660	TSC *(12)*	Oil pipeline.
	52	2,637	TSC *(12)*	Gas pipeline.
	324	420	Mitre *(16)*	Oil pipeline.
	267	509	Rice *(39)*	Update of earlier work (1974).

Source data usually give efficiency estimates in Btu's per ton-mile. Ton-miles per gallon were calculated using the following conversion factors to provide a uniform pattern throughout the table:

Truck (Diesel Oil)	136,000 Btu/gal
Railway (Diesel Oil)	138,000 Btu/gal
Waterway (Bunker Oil)	140,000 Btu/gal
Airplane (Jet Fuel)	125,580 Btu/gal
Pipeline (Diesel Oil)	136,800 Btu/gal

HIGHWAY

The "Study of Potential for Motor Vehicle Fuel Economy Improvement: Truck and Bus Panel Report" is the most comprehensive reference dealing with truck transport efficiency (*26*). Table 27 and Figure 10 summarize the data on truck fuel consumption. "A Summary of Opportunities to Conserve Transportation Energy" likewise provides data on truck service and energy consumption (*12*). These data are reproduced in part in Table 28.

As demonstrated in Table 26, the literature is replete with varying estimates of truck transport fuel efficiency, which are usually derived by use of different assumptions, information, or methods.

The assumptions are particularly important, because the fuel efficiency of truck transport depends on many factors, including equipment type, mechanical condition, speed limit, driving technique, terrain, winds, cargo load, and trip distance. The Boeing Company developed a model of truck fuel economy that was found to be consistent with operational fuel economies of a major trucking company (see Fig. 10) (*40*). Plots of trip distance versus fuel economy, payload versus fuel economy, route circuity, and package density versus fuel economy were made in the same study and are shown in Figures 11, 12, 13, and 14.

Most trucks used in intercity freight shipments are combinations (tractor-trailer configurations), and an increasing number are diesel-powered (*8*). FHWA data for 1972, 1973, and 1974 indicate that combination trucks had an average fuel economy of 5.4 miles/gal (2.3 km/litre) (*6*). Combination trucks carried loads on approximately 70 percent of their trips, and these loads averaged 13 to 14 tons (11.8 to 12.7 t) (*55*). Thus, the fuel intensiveness for combination trucks was 49 to 53 ton-miles/gal (19 to 20 t-km/litre), or 2,800 to 2,600 Btu/ton-mile (2.0 to 1.9 MJ/t-km).

Data covering operations of single-unit trucks show that their average fuel economy was 10 miles/gal (4 km/litre) (*6*). Approximately 50 to 55 percent carry loads, and these loads average about 3 tons (27 t) (*55*). Thus, the fuel intensiveness for single-unit trucks is 15 to 16.5 ton-miles/gal (5.8 to 6.4 t-km/litre), or 8,300 to 7,600 Btu/ton-mile (6 to 5.5 MJ/t-km). These single-unit trucks carry only about 11 percent of the ton-miles on main rural roads.

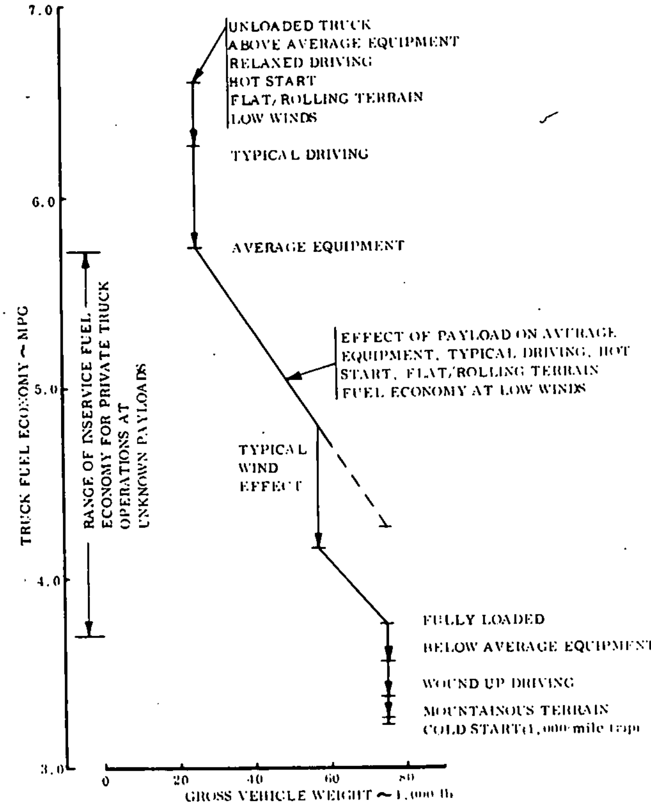


Figure 10. Truck fuel-economy model (55-mph posted speed limits) (40).

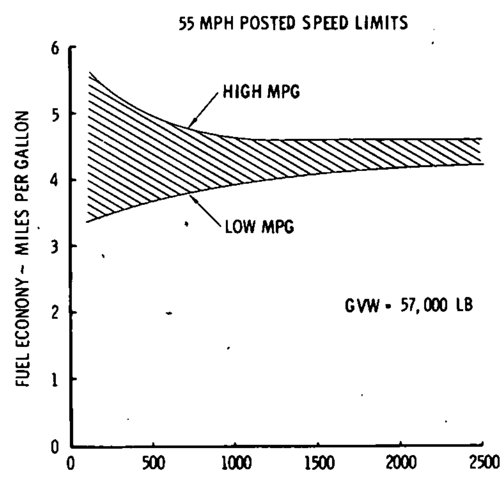


Figure 11. Intercity-truck fuel economy versus trip distance (40).

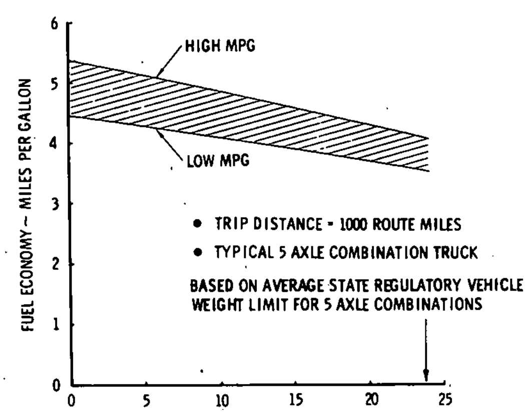


Figure 12. Effect of payload on intercity-truck fuel economy (40).

TABLE 27

TRUCK FUEL CONSUMPTION *(26)*

Industry Duty Class	Medium Duty			Light Heavy Duty		Heavy Duty			
Category - Weight Class	III	IV	V	VI		VII		VIII	
Gross Vehicle Weight (pounds)	10,001 to 14,000	14,001 to 16,000	16,001 to 19,500	19,501 to 26,000		26,001 to 33,000		over 33,000	
Most popular models	Van, Multi-stop, Stake			Van, Dump, Stake		Dump, Van		Truck-tractor trailer combination	
Principal uses	Pick-up and delivery, agriculture, motor homes			Whsle, retail, beverage delivery, dump, agric.		Dump truck, ready-mix concrete, garbage, fuel delivery			
Principal current fuel	Gas	Gas	Gas	Gas	Diesel	Gas	Diesel	Gas	Diesel
New registrations 1973 calendar year* (1) by weight class	47,607	2,216	18,185	213,569	4,270	27,000(7)	14,000	15,000	127,000
by duty class		68,008		217,839		41,000		142,000	
Total trucks (2) by weight class	227,000	224,000	1,144,000	2,070,000	73,000	324,000	100,000	434,000	700,000
by duty class		1,595,000		2,143,000		424,000		1,134,000	
Fuel consumed by new 1973 trucks (3) (million gals/year) by weight class	84	5	58	736	17	137	124	131	2,000
by duty class		147		753		261		2,131	
Fuel consumed by total in-service fleet (4) (million gals/year) by weight class	217	253	1,647	3,340	240	773	807	2,344	8,627
by duty class		2,117		3,580		1,580		10,971	
% of total fuel consumed (5) by weight class	0.2%	0.2%	1.5%	3.1%	0.2%	0.7%	0.7%	2.2%	8.0%
by duty class		1.9%		3.3%		1.4%		10.2%	
Miles traveled per year for new trucks (6) by weight class	15,000	17,000	19,000	20,000	28,000	27,000	53,000	43,000	90,000
% of total trucks for each duty class by primary use (6)						Gas		Diesel	
local-urban		88%		88%	74%	76%		35%	
short range		9%		10%	23%	20%		33%	
long range		3%		2%	3%	4%		32%	
Average miles per year for each duty class by driving mode (6) local-urban**		8,900		8,700	15,400	12,700		22,500	
short range		20,800		20,400	28,400	26,800		53,000	
long range		16,000		29,500	53,000	42,900		90,000	
weighted average		10,400		10,500	20,000	16,600		54,000	
Average fuel economy by weight class and driving mode (MPG) (6) local-urban	8.3	6.8	5.8	5.7	6.8	5.3	6.0	4.9	5.7
short range	8.6	7.1	6.1	5.7	7.0	5.3	6.0	4.9	5.7
long range	8.6	7.1	6.1	6.0	7.0	5.3	6.0	4.9	5.7
weighted average	8.5	7.0	6.0	5.8	6.9	5.3	6.0	4.9	5.7
Vehicle ton-miles per gallon by duty class and driving mode (6) local-urban	16.6	15.6	17.4	39.9	47.6				
short range	17.2	16.3	18.3	39.9	49.0				
long range	17.2	16.3	18.3	42.0	49.0				
weighted average	17.0	16.1	18.0	40.6	48.3	58.7	66	73.5	85.5

* Calendar Year from 1/1/73 to 12/31/73.

** Local-urban - Pickup and delivery service within the city.
Short range - Under 200 mile round trip-return to base each night.
Long range - Over 200 mile - Line haul across country.

Sources:
(1) 1973 Registration - Wards Automotive Yearbook 1974.
(2) Total in service - American Trucking Association data for 1972 updated to 1973 by a factor of 1.025 plus 1973 motor truck facts, Motor Vehicle Manufacturers Assn.
(3) Fuel consumed 1973 model - Estimate based upon average mileage per year and fuel consumption data of typical vehicles. Road user and property taxes on selected vehicles 1973, U. S. Department of Transportation, ATA data.
(4) Fuel consumed, all years - ATA data for 1972 updated to 1973 by a factor of 1.025, road user and property taxes on selected vehicles 1973, U. S. DOT and ADL estimates.
(5) % of total fuel for all automotive sources - Estimate based upon 1972 ATA data, and 1972 highway statistics (DOT).
(6) Mileage per vehicle per year, Average fuel consumed per vehicle, miles/gallon, ton-miles per gallon - ATA data, 1972.
(7) 1973 Registration - Estimate based on Wards Automotive Yearbook 1974 and 1973 Motor Truck Facts.

TABLE 28

TRUCK SERVICE AND ENERGY CONSUMPTION

		LIGHT TRUCKS (2 axle < 10,000 lb)			HEAVY-DUTY SINGLE-UNIT TRUCKS (6 tires, 10,000-33,000 lb)			ALL SINGLE-UNIT TRUCKS			COMBINATION TRUCKS (33,000 LB)			ALL TRUCKS		
		URBAN	INTER-CITY	TOTAL	URBAN	INTER-CITY	TOTAL	URBAN	INTER-CITY	TOTAL	URBAN	INTER-CITY	TOTAL	URBAN	INTER-CITY	TOTAL
Direct Fuel Consumed:																
Thousand bbl/day	1972	368	458	826	272	338	610	640	796	1,436	162	399	561	802	1,195	1,997
	1974															
Million gal/year	1972	5,648	7,026	12,764	4,168	5,186	9,354	9,816	12,212	22,118	2,488	6,112	8,600	12,304	18,324	30,718
	1974			12,191			8,934			21,125			10,101			31,226
Trillion Btu/year	1972	706	878	1,533	521	686	1,170	1,227	1,564	2,703	339	831	1,170	1,566	2,395	3,783
	1974															
Percentage of TDTE	1972	3.80	4.73	8.54	2.81	3.49	6.30	6.61	8.23	14.84	1.68	4.12	5.80	8.29	12.35	20.64
	1974															
Service Rendered:																
Million VMT/year	1972	66,425	82,645	149,070	28,541	35,511	64,052	94,967	118,155	213,122	13,485	33,128	46,613	108,452	151,283	259,735
	1974	80,047	81,133	161,180	24,182	26,007	50,189	104,229	107,231	211,460	10,110	45,949	56,059	114,339	153,180	267,519
Million ton-miles/year	1972	20,465	21,190	41,655	53,071	82,718	135,789	73,536	103,908	177,444	107,023	323,874	430,897	180,559	427,782	608,341
	1974	30,011	22,042	52,053	47,794	62,104	109,898	77,805	84,146	161,951	80,137	432,403	522,540	157,942	526,549	684,491

Data Source: FHWA Office of Hwy. Statistics.

Light trucks are used primarily for personal transportation and services, so simply dividing their total energy consumption by total freight carried would yield a distorted measure of efficiency. For those trucks used strictly as cargo vehicles, efficiency is estimated at 7106 Btu/ton-mile by the FHWA Office of Highway Statistics.

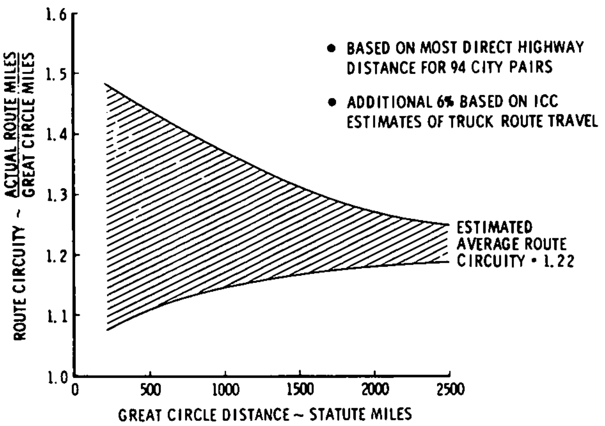


Figure 13. Truck route circuity (40).

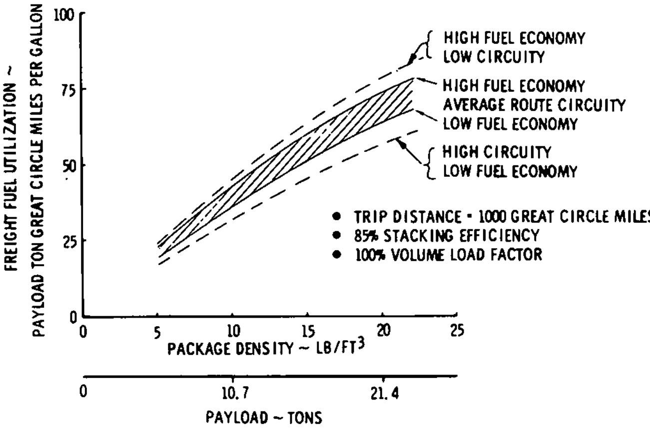


Figure 14. Effect of package density on intercity-truck freight fuel use (40).

RAIL

The railroads are the largest transporter of domestic intercity freight in the U.S. in terms of ton-miles. In 1975, Class I railroads carried 753 thousand million revenue ton-miles of freight (1.10×10^{12} revenue t-km), comprising an estimated 37 percent of total intercity freight shipments (*56*). Although the rail system is capable of carrying freight of widely varying characteristics, it currently specializes in the transport of primary commodities, with mining, agricultural, and forestry products accounting for 43 percent of total carloads in 1975 (*56*).

Locomotives currently in service are predominantly diesel-electric, consuming fuel in the middle-distillate range. In 1975, Class I railroads owned 28,524 locomotive units; 28,289 were diesel-electric, 224 were electric, and 11 were steam (*56*).

The new diesel-electrics have power ratings as high as 6,000 hp (4.5 MW), with developments in technology providing superior performance in terms of reduced maintenance and increased tractive force. The average horsepower per locomotive has increased regularly since the introduction of the new generation of equipment in 1961; thus, increases in traffic have been obtained with fewer units.

Despite the efficiencies of more modern equipment, fuel efficiencies in rail freight have decreased slightly since 1965 (see Table 29) (*8*). Class I railroads consumed 650 Btu/revenue ton-mile (470 kJ/revenue t-km) in 1965, but they consumed 700 Btu/revenue ton-mile (510 kJ/revenue t-km) in 1972. It appears that this was caused primarily by a deterioration of car use over the seven years. Nonloaded car-miles in 1972 comprised 43.5 percent of total rail freight car-miles, compared with 39 percent in 1965 (*8*).

It is important to note that fuel expenses for rail freight represented only about 4.4 percent of fully distributed costs attributable to freight in 1972 (*8*) and are therefore less of a driving force for increased fuel conservation than they are with most other modes.

Average rail-freight efficiency has been calculated at 676 Btu/ton-mile (490 kJ/t-km) on the basis of the data in Table 30 (*12*), which also gives data on rail service and energy consumption. Figure 15 summarizes average rail-cargo loads; Figure 16 shows average route-haul distance. Both measures are useful in a consideration of rail freight service.

Dramatic improvements in rail energy efficiency occurred during the postwar years through dieselization. That technology is now mature, so only very minor additional gains are possible, mainly through turbo-charging more locomotives. However, significant petroleum savings can eventually be achieved through rail electrification—perhaps as high as 2 percent of TDTE. It is widely believed that even if the economic case for electrification does not demand immediate implementation, long-term trends in fuel prices (i.e., higher rates of increase for liquid fuels than for electricity) may ultimately result in the construction of catenaries over the high-density lines in the U.S. High-density lines constitute 10 to 25 percent of the track mileage but are responsible for 80 percent or more of rail ton-mileage. Because of the enormous construction costs involved, electrification will necessarily be a slow process.

The electric locomotives currently in use exhibit about the same over-all efficiency as the diesel-electrics, hence they offer no energy savings but do offer petroleum savings. Electric locomotives that should begin to enter the fleet in the 1980s are expected to incorporate regenerative braking, which will yield an over-all energy saving of 25 to 40 percent. Assuming that electrification is justifiable on lines carrying 80 percent of the ton-mileage and that implementation is 50 percent complete by 1990, the petroleum savings could amount to about 150,000 bbl/day (24×10^6 litre) and the energy savings could equal as much as 0.6 percent of 1990 TDTE (*12*).

Besides these technology changes, it is also possible that the rail-traffic mix may shift more toward bulk commodities hauled in unit trains. These trains operate as efficiently as 300 Btu/ton-mile (220 kJ/t-km). An increasing market share for them could provide further improvement in the over-all rating of rail efficiency.

TABLE 29

FREIGHT FUEL EFFICIENCY OF CLASS I RAILROADS (*8*)

Year	Revenue Ton-Miles[a] (Billions)	Line Haul[b]		Switching[b]		Electricity[b] (Millions of KWHs)	BTUs per Revenue Ton-Mile	BTUs[c] per Gross Ton-Mile
		Diesel Oil (Millions of Gallons)	Residual Oil (Millions of Gallons)	Diesel Oil (Millions of Gallons)	Residual Oil (Millions of Gallons)			
1972	778.1	3527.8	--	375.2	--	468	700	280
1971	739.7	3282.6	--	375.8	--	371	690	280
[illegible]	764.8	3180.8	--	363.9	--	417	650	270
[illegible]	767.8	3256.1	32.3	357.4	--	430	660	280
[illegible]	719.5	3030.7	46.4	354.3	--	551	660	280
[illegible]	697.9	2828.4	76.8	341.9	--	603	650	280

[a] *Source: Association of American Railroads, Yearbook of Railroad Facts: 1973 Edition.*

[b] *Source: Interstate Commerce Commission, Transport Statistics in the United States, Part I - Railroads, Table 17 (data for 1972 as yet unpublished).*

[c] *Derived from data above and Transport Statistics, Table 162.*

AIR FREIGHT

Domestic certificated and supplemental air carriers have experienced rapid growth in the transportation of freight. For all U.S. carriers, ton-miles of total cargo, including freight, express cargo, and mail, have increased in recent years. Although domestic air-cargo ton-miles represented less than 0.2 percent of total intercity freight in 1972, airlines have become an important long-haul transporter of low-weight, high-value products; their extremely high rates per ton-mile relative to other modes have been counterbalanced by the speed and quality of service (*8*). In addition, international air-cargo services provide the only substitute for international water transportation of transoceanic shipments.

Certain characteristics of the air transportation industry facilitate the development of freight service. Where demand provides large tonnage for transportation between points and offers the potential for two-way traffic, cargo can be shipped in aircraft expressly designed for freight service. In addition, where freight volume is low or irregular, large belly capacities of current aircraft allow partial loads of freight on airplanes in passenger service. In 1972, 58.7 percent of total scheduled domestic shipments of the trunk carriers was shipped in this way, whereas only 47.9 percent was transported in passenger craft in 1967 (*8*). The capability of air carriers to use craft already committed to flight provides opportunities for highly efficient use of otherwise unused capacity. (Intercity buses have also employed this technique for package delivery. In addition, Amtrak offers this service between some cities.)

Technical innovation in commercial aircraft has been rapid since World War II; piston aircraft using aviation gasoline was supplanted first by larger turboprop aircraft and then by jets. Current aircraft are capable of cruising speeds in excess of 500 mph (800 km/h), with capacities reaching as high as 50 tons (45 t) in passenger configura-

TABLE 30

RAIL FREIGHT SERVICE AND ENERGY CONSUMPTION, 1972 (*12*)

Direct fuel consumed	
thousand bbl/day	252
million gal/year	3,874
trillion Btu/year	539
percentage of TDTE	2.93
Service rendered	
vehicle-miles/year	N/A
ton-miles/year	785,000 (million)
Average efficiency	
Btu/ton-mile	676
ton-miles/gal	204

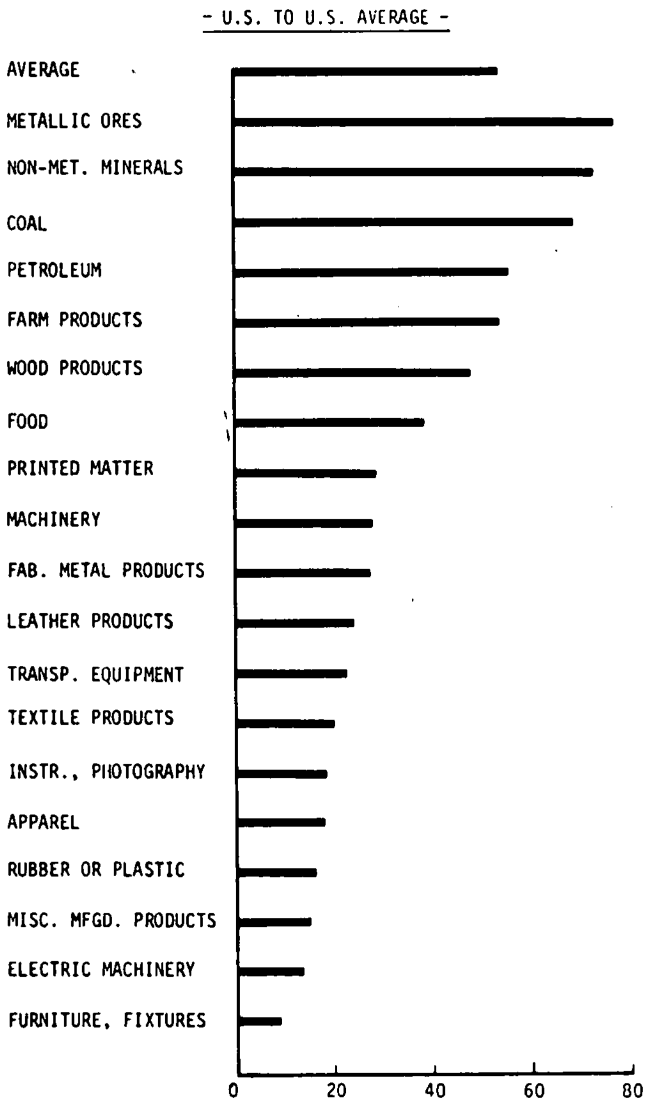


Figure 15. Average rail-cargo loads (40).

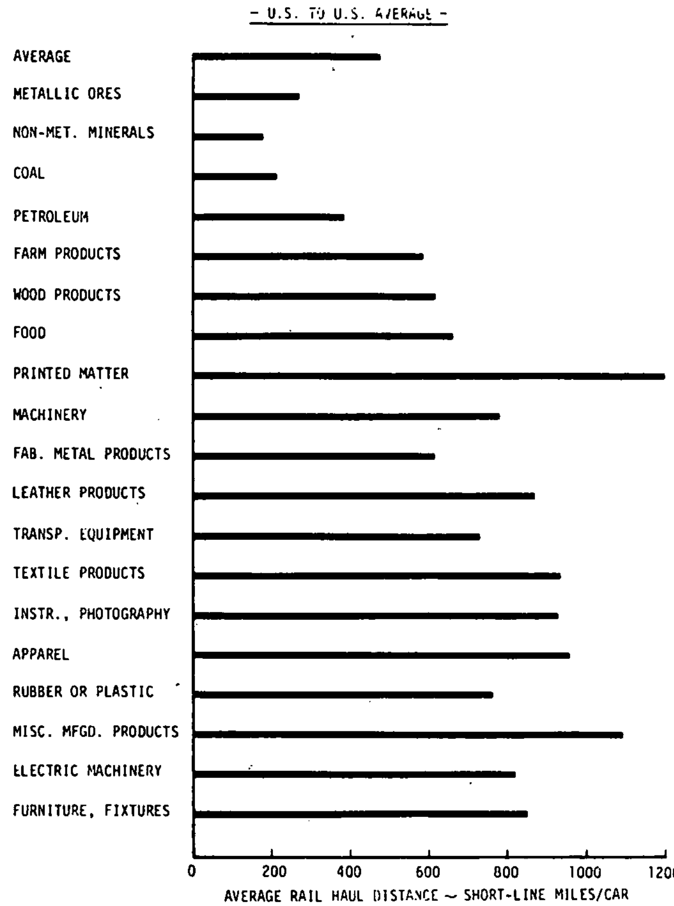


Figure 16. Average route-haul distance (40).

tion. Modern aircraft use kerosine-based jet fuel at a high rate; the Boeing 747 burns more than 3,300 gal/block h (12 500 litre/block h) in normal operation, with craft currently predominating in freight service ranging from 1,300 to 2,000 gal/block h (4 900 to 7 500 litre/block h) (*8*). (A block hour is the time from removal of the wheel blocks of an aircraft before departure to placement of the wheel blocks after arrival.)

The large energy consumption necessary to lift and propel an aircraft makes transportation by air freight highly energy intensive when compared to other modes. In fact, it is estimated that energy consumption (Btu/revenue ton-mile) in 1972 for all freight in domestic air-freight service was 29,600 (21 MJ/revenue t-km), as compared to 3,080 (2.2 MJ/revenue t-km) for intercity trucks, 700 (500 kJ/revenue t-km) for trains, and 500 (360 kJ/revenue t-km) for domestic water transportation (*8*). A summary of average fuel intensiveness of air transport by type of plane in freight service in 1972 is given in Table 31.

The relative fuel intensiveness of freight carried on passenger aircraft is shown in Figure 17 (*40*). The "Project Independence" report concluded that previous studies vastly overstated the fuel intensiveness of air freight by failing to make adequate provision for the weight of equipment such as seats, bulkheads, and air compressors, all of which are solely attributable to passenger service (*8*). (Hirst of the Oak Ridge National Laboratory computed fuel intensiveness for air freight at 42,000 Btu/ton-mile—30 MJ/t-km, and Mooz of the Rand Corporation found a value of 63,000 Btu/ton-mile—45 MJ/t-km.) Estimates of fuel intensiveness of air freight in passenger craft on the basis of payload alone agree with previous work. However, noting differences in aircraft capacity between passenger and cargo cabin configurations and allocating these weights to passenger service yield estimates of freight fuel intensiveness consistent with those found in freighter service. Because aircraft capacity is determined by such factors as weight of empty planes, airport altitude, runway length, and engine thrust capability, allocating total load weight in this manner would be expected to yield more precise results. Figure 18 shows the effect of package density on the efficiency of transport in air freighters (*40*).

Fuel consumption per ton-mile is high, and the share of total airline costs attributable to fuel is also high, estimated to be 17.5 percent of fully distributed cost for domestic all-

TABLE 31

FUEL PERFORMANCE OF FREIGHT AIRCRAFT IN DOMESTIC AND INTERNATIONAL SERVICE, 1972 (*8*).

DOMESTIC

Type of Aircraft	Engine		Capacity (Tons)	Revenue Tons Per Plane Mile	Load Factor (Percent)	Stage Length (Miles)	Average Airborne Speed	Ton-Miles Per Gallon	BTUs Per Ton-Mile
	Type	Number							
DC-8-50F	Fanjet	4	38.1	18.8	49.4	1,337	478	4.41	30,600
DC-8-63F	Fanjet	4	48.9	28.1	56.9	1,297	479	5.70	23,700
B-707-300C	Fanjet	4	41.8	19.8	46.5	1,066	473	4.38	30,800
B-727-100C/QC	Fanjet	3	19.2	12.0	62.8	816	467	3.62	37,300

INTERNATIONAL

Type of Aircraft	Revenue Tons Per Plane Mile	Load Factor (Percent)	Stage Length (Miles)	Average Airborne Speed	Ton-Miles Per Gallon	BTUs Per Revenue Ton-Mile
DC-8-50F	24.6	65.5	1,899	487	5.17	26,100
DC-8-63F	30.9	68.6	1,624	492	6.53	20,700
B-707-300C	20.3	51.8	1,468	491	4.80	28,100
B-727-100C/QC	12.4	62.1	836	459	6.56	20,600

Source: Civil Aeronautics Board, Aircraft Operating Cost and Performance Report for Calendar Years 1971 and 1972 (Washington, D.C., August 1973) Part 1.

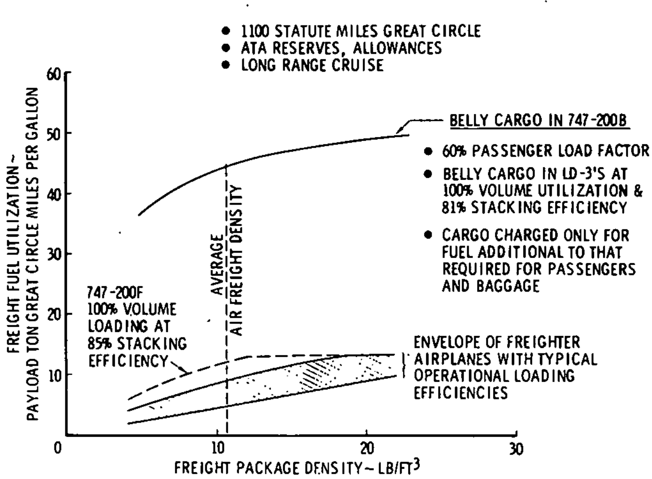


Figure 17. Fuel use of freighter airplanes compared to belly cargo in 747-200B passenger airplane (40).

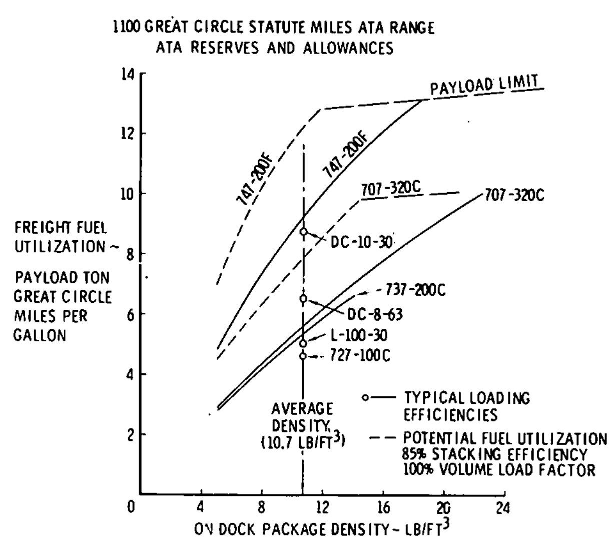


Figure 18. Effect of package density on air freighters (40).

cargo airlines and 18.9 percent of international all-cargo line operations (*8*). Because terminal and promotional expenses of passenger-cargo lines are not adequately reported to the Civil Aeronautics Board for purposes of cost allocation to freight service, these estimates are the best ones available for application to all freight operations and are probably representative of the sector cost structure as a whole.

Table 32 gives 1972 service and consumption data for scheduled air freight services (*12*).

TABLE 32

AIR FREIGHT SERVICE AND ENERGY CONSUMPTION, 1972[1] (*12*)

	Air Freighter	Lower Hold	Total
Direct fuel consumed			
thousand bbl/day	24	3	26
million gal/year	364	39	402
trillion Btu/year	46	5	51
percentage of TDTE	0.2%	--	0.3%
Services rendered			
million ton-miles/year	1,691	1,561	3,252
Average efficiency			
Btu/ton-mile	27,000	3,100	15,527
ton-miles/gal	4.6	40.5	8.1

1 Ton-mile data are from Reference *33*. Ton-miles include all freight, express, and mail on scheduled flights. The ton-mile split between freighters and passenger/cargo lower holds is from Reference *41*. Fuel data are based on ton-miles and estimated average fuel consumption. Freighter fuel efficiency is from Reference *13*; lower-hold fuel efficiency is from Reference *42*.

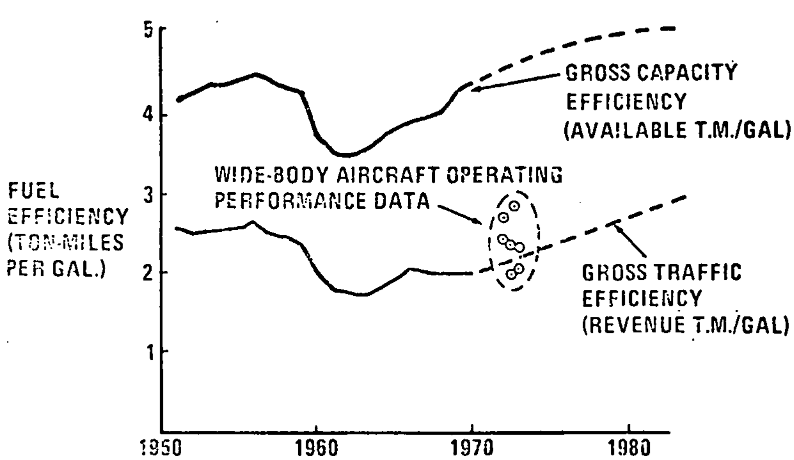


Figure 19. Fuel efficiency of certified route carrier operations (airline) (16).

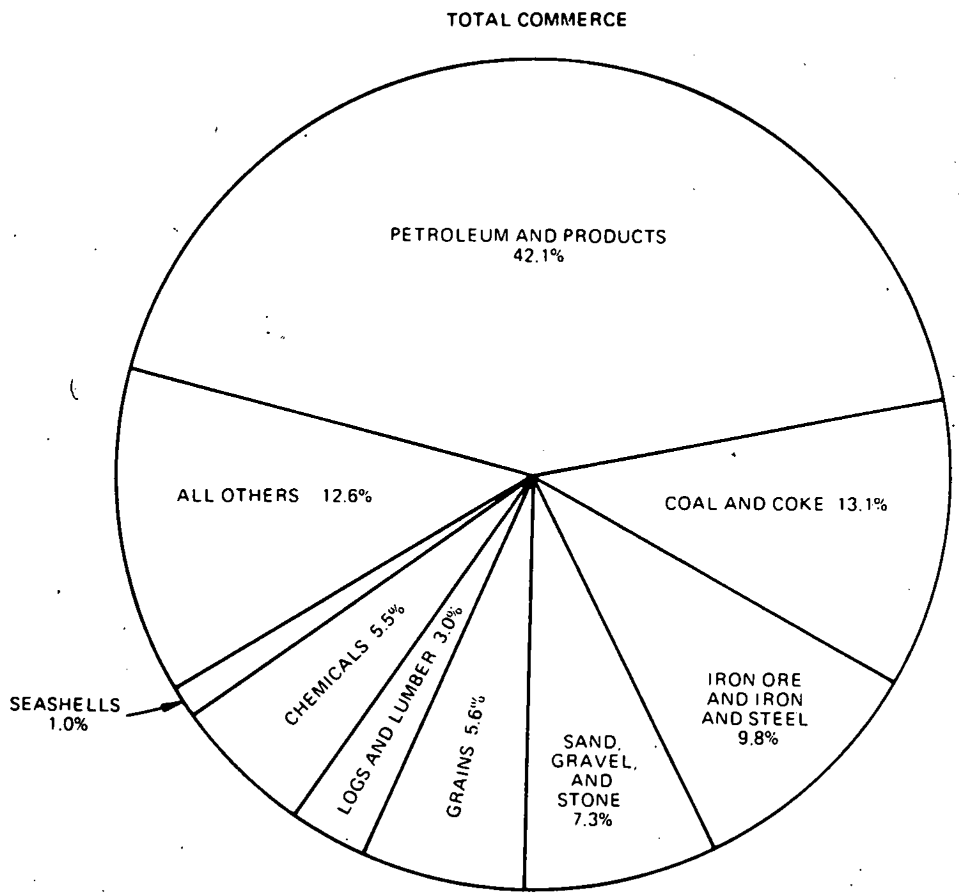
Figure 19 (*16*) shows the recent trend of fuel efficiency for certified route carriers where the present gross traffic efficiency is approximately 3 revenue ton-miles/gal (1.2 revenue t-km/litre) and the gross capacity efficiency is approximately 5 available ton-miles/gal (1.9 t-km/litre). As long as there is a surplus capacity in the lower hold of scheduled passenger aircraft, an increase in use of the lower hold has a small conservation potential. Increasing passenger payload and eliminating excess capacity will reduce lower-hold freight.

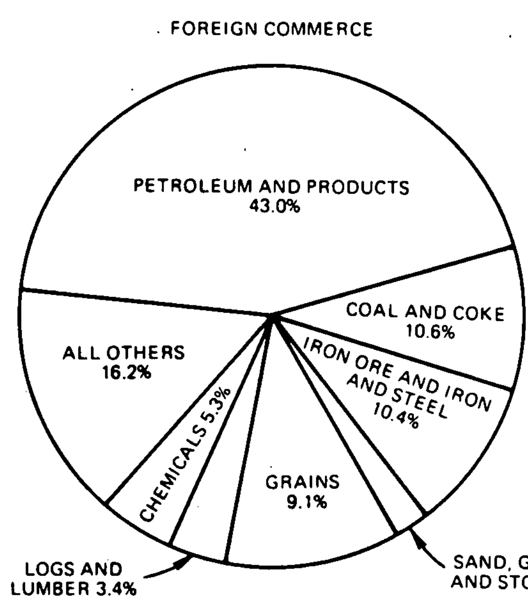
WATER FREIGHT

Domestic carriers are subject to classification by type of carrier, regulatory status, and type of waterway traversed. In 1972, approximately 8 percent of total domestic ton-miles of water freight was hauled by carriers regulated by the Interstate Commerce Commission (ICC), 51 percent was carried by for-hire carriers not subject to ICC regulations, and 41 percent was transported by private carriers (*8*). Divisions of operation for domestic water carriers include inland waterways, coastwise, and Great Lakes movements.

The domestic water sector experienced moderate growth from 1963 to 1972; total ton-miles of revenue freight increased by 25 percent, to 631.1×10^9 ton-miles (9.2×10^{11} t-km). Coastwise and intercoastal shipments accounted for more than half the total, and internal barge traffic increased 6.5 percent per year from 1963 to 1972 and represented 29 percent of domestic water ton-miles by 1972 (*8*). Historically, water carriers have specialized in the transportation of raw materials and refined bulk commodities, including farm products, chemicals, minerals, and petroleum products (see Fig. 20 and Table 33). Although the charges for water transportation are among the lowest charges for all modes, the carriers are the slowest. Railroads are currently the chief competition of the domestic water carriers, combining greater speed in shipment with higher fares. Pipelines are competitive in the shipment of petroleum products and have made inroads into the transport of other commodities.

Operations in the international sector include all activities of U.S. flag carriers and of U.S. import activities of foreign flag carriers. As in the case of international air carriers, a lack of necessary data hampers measuring and projecting the traffic and fuel use of oceangoing vessels. Data are not available on either revenue freight ton-miles or total fuel used for bunkering inbound vessels. Data are available concerning domestic bunkering of vessels in international commerce, but these include fuel used by foreign flag carriers transporting U.S. exports—operations outside the definition of this sector but relevant in determining domestic demands. Significant portions of this vessel fuel are imported and placed into "bonded" stocks for use in foreign commerce. The Maritime Administration estimates that currently more than 90 percent of total fuel loaded in oceangoing vessels on the Atlantic coast is of this variety, 50 percent loaded along the Gulf Coast is bonded, and Pacific-coast fuel stocks are almost entirely domestic in origin. Demands for bunker fuel by overseas carriers are thus significantly influenced by the relative prices of foreign





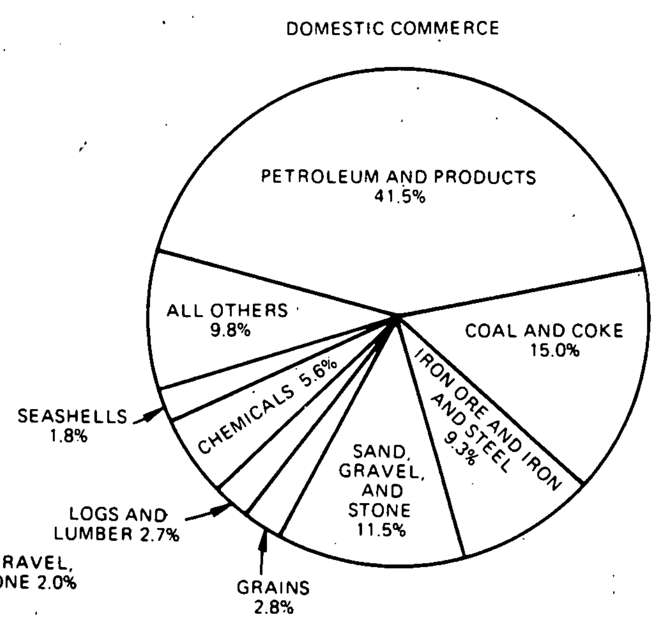


Figure 20. Principal commodities carried by water, calendar year 1974 (7).

TABLE 33

MOVEMENT OF PETROLEUM IN U.S. WATERBORNE TRADE, 1948–1974 (THOUSANDS OF SHORT TONS) (*7*)

	Domestic Trade									All Waterborne Trade, Foreign and Domestic			
	Coastwise[2]		Local, Intraport,[3] and Intraterritory		Lakewise and Internal		Total Domestic						
Year	Crude Oil and Products	All Other Domestic Trade	Crude Oil and Products	All Other Domestic Trade	Crude Oil and Products	All Other Domestic Trade	Crude Oil and Products	All Other Domestic Trade	All Domestic Trade	Crude Oil and Products	All Other Foreign and Domestic Trade	Total Trade	Petroleum as a Per Cent of Total Trade
1974	182,838	50,520	61,473	30,779	163,138	493,951	407,448	575,222	982,670	736,204	1,010,584	1,746,788	42.1
1973	184,727	52,068	63,713	33,793	172,765	487,093	421,206	572,952	994,158	757,987	1,003,565	1,761,552	43.0
1972	192,443	50,217	59,124	33,025	175,037	476,966	426,603	560,209	986,812	680,571	936,222	1,616,793	42.1
1971	197,284	45,632	52,986	30,523	166,522	453,651	416,792	529,806	946,598	635,949	876,635	1,512,584	42.0
1970	192,552	45,889	48,286	34,819	161,830	476,379	402,668	548,059	950,727	604,243	927,454	1,531,697	39.4
1969	171,985	44,723	49,030	39,872	157,847	463,942	378,863	548,537	927,399	567,396	881,316	1,448,712	39.2
1968	168,250	46,000	47,503	44,846	145,249	436,041	361,003	526,887	887,889	534,949	860,890	1,395,839	38.3
1967	167,012	47,635	45,778	58,020	137,511	414,678	350,301	520,333	870,634	505,064	831,542	1,336,606	37.8
1966	158,752	49,622	42,707	57,755	131,417	422,472	332,877	529,848	862,725	488,397	845,719	1,334,116	36.6
1965	155,183	46,325	41,296	63,055	127,192	396,118	323,671	505,498	829,169	473,459	799,437	1,272,896	37.2
1964	161,568	44,120	37,712	63,448	122,525	386,796	321,805	494,364	816,169	461,417	776,677	1,238,094	37.2
1963	172,835	41,018	40,375	60,236	122,402	351;242	335,612	452,496	788,108	470,307	703,460	1,173,767	40.1
1962	173,035	42,426	39,194	64,345	117,501	334,305	329,730	441,076	770,805	458,714	670,690	1,129,404	40.6
1961	169,798	37,102	38,361	56,671	114,538	316,355	322,697	410,128	732,825	443,934	618,221	1,062,155	41.8
1960	167,986	41,211	39,848	65,362	110,462	335,704	318,296	442,277	760,573	439,987	659,863	1,099,850	40.0
1959	164,120	41,389	39,641	68,093	105,634	307,855	309,395	417,337	726,732	429,500	622,902	1.052,402	40.8
1958	154,858	39,192	41,778	66,479	102,003	291,355	298,639	397,026	695,665	414,035	590,480	1,004,515	41.2
1957	153,689	42,730	41,487	71,741	104,625	358,590	299,801	473,061	772,862	419,341	712,061	1,131,402	37.1
1956	158,745	47,165	41,952	74,637	97,606	346,118	298,303	467,920	766,223	405,960	686,953	1,092,913	37.1
1955	153,163	42,554	40,825	73,989	90,676	343,826	284,664	460,369	745,033	377,971	638,165	1,016,136	37.2
1954	148,564	38,676	36,692	67,438	83,752	278,673	269,008	384,787	653,795	350,327	517,312	867,639	40.4
1953	148,325	40,433	34,101	69,714	91,828	321,751	274,254	431,898	706,152	359,534	564,014	923,548	38.9
1952	143,364	40,856	38,498	66,924	93,980	276,302	275,842	384,082	659,924	357,548	529,702	887,250	40.3
1951	145,868	40,805	37,652	75,793	84,218	307,650	267,738	424,248	691,986	340,889	583,093	923,982	36.9
1950	141,269	41,275	35,380	72,765	76,434	284,236	253,083	398,276	651,359	316,206	504,378	820,584	38.5
1949	127,367	34,064	33,316	69,322	69,965	241,329	230,648	344,715	575,363	283,460	457,261	740,721	38.3
1948	134,312	39,769	36,633	77,326	66,718	275,470	237,663	392,565	630,228	284,175	509,025	793,200	35.8

[1] Includes inland waterways.
[2] Atlantic, Gulf, and Pacific Coasts. Includes traffic between Great Lakes ports and seacoast ports.
[3] Includes traffic within a single channel of a port and traffic between the several channels of a port. Includes such traffic within Great Lakes ports.

Source: Department of the Army, Corps of Engineers, *Waterborne Commerce of the United States* Part 5, 1974, pp. 3, 7, 8, 12, 13, 15, 16 and earlier editions for prior years.

and domestic oil. Because of the relative lack of substitute modes for international transport, overseas carriers transport wide ranges of commodities and manufactured goods. Containerization of cargo has provided the opportunity to make international shipments truly intermodal.

The water transportation sectors use equipment varying in size from small tugs for the local shipment of barges to oil tankers with capacities in excess of 200,000 deadweight tons (1.8×10^5 t). Equipment varies markedly by type of waterway, available depth, and draft available at ports. Similarly, fuel use and efficiency vary with type of equipment. Certain vessels in Great Lakes service use coal for fuel. Inland towboats use middle-distillate diesel fuels, and oceangoing craft use diesel or residual fuel oil or mixtures of the two.

Unfortunately, available data do not allow reliable estimation of fuel use by type of waterway. However, measures of fuel intensiveness of domestic water transport may be estimated for the entire sector through use of U.S. Corps of Engineers ton-mile data (*43*) combined with data on domestic water fuel use. Fuel intensiveness of domestic carriers is estimated at 500 Btu/ton-mile (360 kJ/t-km) for 1972 (*8*). Studies by Mooz (*37*) and Hirst (*13*) estimated fuel intensiveness at 500 and 680 Btu/ton-mile (360 and 490 kJ/t-km), respectively.

Smith (*38*) analyzed these studies by Mooz and Hirst and concluded that using a total of 515×10^9 ton-miles (7.5×10^{11} t-km) and 337×10^{12} Btu (350 PJ) produces a revised 1967 efficiency factor of 655 Btu/ton-mile (470 kJ/t-km) for waterway transport. The revised computation eliminates earlier duplications in ton-mile statistical data compilations.

Analysis of the share of fuel cost in total cost has revealed significant differences among carriers operating on different types of waterways. A sampling of ICC report forms for a selected group of regulated carriers in 1972 yielded estimates of the ratio of fuel cost to total cost ranging from 6.3 percent in coastwise movement to 11.4 percent on the Great Lakes (*8*). A staff member of American Waterways Operators estimated fuel cost to be as high as 15 percent of total cost for the inland carriers as a whole, although the estimate derived from ICC data was 9 percent. Weighting estimates of relative fuel cost by waterway type on the basis of total tonnage shipped yields an aggregated estimate of 9.5 percent for domestic water carriers (*8*).

Tables 34 and 35 give the estimated fuel consumption of U.S. foreign and domestic waterborne commerce for vessel operations and tug and barge operations, respectively (*4*).

TABLE 34

U.S. FOREIGN AND DOMESTIC WATERBORNE COMMERCE ESTIMATED FUEL CONSUMPTION, VESSEL OPERATIONS *(4)*

Parameters Affecting Consumption	1973	Anticipated Normal Operations 1974	1975	1976	1977	1978
U.S. Waterways						
Billion Ton Miles	439	452	470	488	591	690
Fuel Efficiency (1,000 Ton Miles Per Barrel)*	8.78	9.22	9.68	10.16	13.42	15.73
Residual Fuel Oil Consumption (Million Barrels)						
At Port (30%)	15.0	14.7	14.6	14.4	13.2	13.2
At Sea (70%)	35.0	34.4	34.0	33.6	30.8	30.7
Total Consumption	50.0	49.1	48.6	48.0	44.0	43.9
International Waters						
Imports and Exports (Million Short Tons)	741	767	857	970	1,123	1,170
Fuel Efficiency (Short Tons Per Barrel)†	19.7	20.7	21.7	22.7	23.9	25.1
Residual Fuel Oil Consumption (Million Barrels)						
Total Consumption (All At Sea)	37.6	37.1	39.5	42.7	47.0	46.6
Total Fuel Consumption in Both U.S. and International Waters (Million Barrels)						
At Port	15.0	14.7	14.6	14.4	13.2	13.2
At Sea	72.6	71.5	73.5	76.3	77.8	77.3
Total Consumption	87.6	86.2	88.1	90.7	91.0	90.5

* Estimated to rise 5 percent per year, adjusted upward for North Slope volumes beginning in 1977.

† Estimated to rise 5 percent per year through entire period.

TABLE 35

U.S. FOREIGN AND DOMESTIC WATERBORNE COMMERCE ESTIMATED FUEL CONSUMPTION, TUG AND BARGE OPERATIONS *(4)*

Parameters Affecting Consumption	1973	Anticipated Normal Operations 1974	1975	1976	1977	1978
Billion Ton Miles	286	308	334	362	394	426
Propulsion Efficiency (1,000 Ton Miles Per Horsepower of Units in Service)*	63.37	65.59	67.88	70.26	72.72	75.26
Tow and Tug Capacity in Use (Million Horsepower)	4.508	4.699	4.913	5.149	5.411	5.655
Annual Round Trip (Hours Under Tow Per Unit)†	4,030	4,190	4,358	4,534	4,716	4,904
Billion Annual Horsepower Hours of Propulsion	18.17	19.69	21.41	23.35	25.52	27.73
Fuel Efficiency (Pounds of Diesel Fuel Per Horsepower Hour)‡	.421	.440	.436	.432	.427	.423
Annual Diesel Fuel Consumption (Million Barrels)	25.2	28.5	30.7	33.2	35.8	38.6

* Estimated to rise at 3.5 percent per year throughout.

† Estimated to rise at 4 percent per year due to improved utilization and longer trips.

‡ Calculated to decline 1 percent annually from 1975 through 1978 due to increased proportion of larger horsepower tugs.

PIPELINES

The pipelines considered in this section are petroleum pipelines. Products carried include crude petroleum and light products (e.g., gasoline and jet fuel). Crude and heavier petroleum products are too viscous to transport by pipeline without supplemental heating, especially in areas where low temperatures increase the viscosity of these products. Operations are conducted in gathering lines, trunk lines, and distribution lines. A relatively few carriers dominate pipeline activities. In 1972, the three largest companies transported 142×10^9 trunk ton-miles (2.1×10^{11} trunk t-km), or 38 percent of the 379×10^9 trunk ton-miles (5.5×10^{11} trunk t-km) of regulated carriers (*8*). The total of pipeline ton-miles is estimated at 529×10^9 (7.7×10^{11} t-km) for regulated and nonregulated carriers, including shipments between storage tanks and exports (*8*). It is thought that most of the intrastate carriers transport crude petroleum. Table 36 gives data on total pipeline service (including natural gas) and energy consumption for 1972 as estimated by Pollard, Hiatt, and Rubin (*12*).

Direct data on fuel consumption and energy intensiveness of petroleum pipelines are not published in any comprehensive manner. The "Project Independence" report attempted to develop estimates of the quantities and types of fuels actually consumed by pipelines (*8*). In addition, this report investigated the share of energy costs in total costs.

Major factors influencing the energy intensiveness of pipelines include the viscosity of the fluid, the diameter of the pipe, and the speed at which the product is pumped. These factors have been analyzed in engineering calculations by Hirst; the results are given in Table 37 (*13*). The estimates in this table reflect an assumed 29.5 percent conversion efficiency to electricity and an 85 percent efficiency of the motor-pump set. In addition, these estimates constitute a wide range, indicating that each of the factors makes a large difference in the potential efficiency of pipelines.

Few measurements of the actual fuel intensiveness of petroleum pipelines have been published. In one estimate, Mooz (*37*) calculated pipeline energy use at 1,200 to 2,600 Btu/ton-mile (0.87 to 1.9 MJ/t-km); however, this work relied heavily on an estimate of a California utility that was pumping residual oil through a small-diameter pipe and on rough cross-checks from ICC data on transportation expense. By contrast, Hirst chose an estimate of 450 Btu/ton-mile (330 kJ/t-km) (*13*).

To provide more accurate measures of pipeline fuel consumption, Jack Faucett Associates contacted a number of large pipeline companies. Some companies provided estimates of physical quantities, some provided only breakdowns of costs, and others declined to provide the data—usually because of the expense of obtaining them from the individual pumping operations. Table 38 gives the responding companies' data on energy intensiveness (*8*). Also included are data for two companies that replied to earlier Jack Faucett Associates inquiries (*45*).

The principal fuels used by responding companies were electricity and natural gas, the former accounting for about 85 to 90 percent of fuel expenditures. (There are some indications that the present percentage is slightly higher because of recent shifts by some companies to greater use of electric power.) The average fuel intensiveness for responding companies (including fuel used in the electric generation process) was approximately 433 Btu/ton-mile (310 kJ/t-km). This figure, however, would appear to understate intensiveness for the industry as a whole, because only the large companies that tend to use relatively large-diameter pipes were surveyed. Estimated fuel intensiveness for all pipeline operations (including unregulated companies) is at the somewhat higher level of 550 Btu/ton-mile (400 kJ/t-km). Both estimates, however, are in reasonable agreement with that employed by Hirst (*13*).

Besides covering estimates of fuel intensiveness on a physical basis, Jack Faucett Associates also collected data from company ICC report forms, which allow accurate estimation of fuel costs as a share of total inputs.

Oil pipelines are relatively efficient carriers and can be improved only through increases in their effective diameters ("looping"). Such increases will take place only gradually and only if product flows increase significantly. Gas pipelines rank rather poorly on a Btu-per-ton-mile scale; how-

TABLE 36

PIPELINE SERVICE AND ENERGY CONSUMPTION, 1972 * (*12*)

	OIL	NATURAL GAS	TOTAL
Direct fuel consumed			
thousand bbl/day	N/A	N/A	N/A
million gal/year			
trillion Btu/year	317	791	1,093
percent of TDTE	1.64	4.30	5.94
Service rendered			
vehicle-miles/year	N/A	N/A	N/A
million ton-miles/year	480,000	300,000[1]	757,000
Average efficiency			
Btu/ton-mile	660	2,637	1,528

[1] Conversion to ton-miles/year assumes the average distance from source to market to be the same as for oil.

*Sources: Oil ton-miles, Reference *27*; pumping energy estimate from engineering-handbook formulas. Gas pipeline volume and pumping energy, Reference *44*.

TABLE 37

PIPELINE ENERGY INTENSIVENESS (*13*)

Pipeline Diameter (in.)	Kinematic Viscosity 0.000010 ft^2/sec^a Velocity (ft/sec) 3	6	9	Kinematic Viscosity 0.000075 ft^2/sec^b Velocity (ft/sec) 3	6	9	Kinematic Viscosity 0.00050 ft^2/sec^c Velocity (ft/sec) 3	6	9
8	180	590	1330	290	960	1850	460	1500	2870
20	60	220	450	90	310	660	140	490	980
32	30	130	260	50	170	360	80	270	540

[a] *Kerosine at 80°F.*

[b] *California crude oil at 80°F.*

[c] *Light engine oil at 80°F.*

ever, their high energy consumption results directly from the low density of gaseous products. Significant changes in efficiency are not anticipated, although decline of gas supplies may reduce absolute energy consumption quite substantially during the 1980s.

COAL-SLURRY PIPELINES

At least 273 miles (439 km) of coal-slurry pipeline transporting over 4×10^6 tons (3.6×10^6 t) of coal per year are currently in operation in the U.S. This method of transportation might be considered feasible on a large scale, but it is technologically immature. However, slurry pipelines are receiving serious consideration as a means of transporting the huge quantities of coal that could be extracted from the western coal fields as their development accelerates. A slurry pipeline is considered an alternative to (a) transport by unit train and (b) construction of synthetic natural gas plants at the mine sites and transport of the resulting gas by pipeline to existing load center.

It is estimated that the energy required for a slurry pipeline capable of transporting 30×10^6 tons (2.7×10^{10} t) per year would be approximately the same as that required by rail transport. In any case, it is close enough that using one mode instead of the other will not have a significant impact on energy consumed in transporting the coal. In all likelihood, the determination of which mode to use will be based on factors other than energy consumption, such as environmental impact of pipeline placement, water conservation, and easement rights through railroad property.

OTHER PIPELINES

Pipelines are also used for water distribution, sewer collection, irrigation, gas distribution, and steam distribution. No data are readily available on the energy requirements for these uses.

TABLE 38

ENERGY INTENSIVENESS OF SELECTED PETROLEUM PIPELINE COMPANIES (*8*)

Company		BTUs per Ton-Mile[a]	Principal Fuel
1:	1970	424.8	Electricity (87%)
	1971	424.8	Electricity (87%)
	1972	414.6	Electricity (90%)
	1973	414.6	Electricity (91.3%)
2:	1971	520.9	Electricity (100%)
	1972	358.4	Electricity (100%)
3:	1972	432.5	Electricity (76.3%)
	1973	445.7	Electricity (75.8%)
4:	1970	546.9	Electricity (87.5%)
5:	1971	1018.6	Electricity (75.6%)
	1972	1067.9	Electricity (72.6%)
Estimated Weighted Average 1972 Responding Companies		432.91	88%
Estimate for All Companies		550	75-80%

[a]*Adjusted to exclude fuel used on non-trunk operations since ton-miles were available only for trunk line movements. The BTU's are on a production basis and represent the BTU inputs to the utility plant when electricity is the form of energy use (i.e., 11,566 BTU/KWH).*

CHAPTER FOUR

POTENTIAL IMPACT OF ENERGY CONSERVATION OPTIONS

A useful structure for organizing alternatives for reducing transportation energy consumption is shown in Figure 21 (*16*). The alternatives are conveniently organized into these five general categories:

1. Shift traffic to more efficient modes.
2. Increase load factor.
3. Reduce demand.
4. Increase energy conversion efficiency.
5. Improve use patterns.

Conservation initiatives falling within each of these five categories are summarized in Table 39 (*12*) and Table 40 (*4*). The latter includes comments on implementation methods and incentives.

Of the five categories, increasing the energy conversion efficiency of highway vehicles will be the most important option in the 1980s, for the following reasons:

- The savings potential of improving vehicle efficiency is much larger than that of any of the other approaches,

TABLE 39

SUMMARY OF OPPORTUNITIES TO CONSERVE TRANSPORTATION ENERGY (*12*)

OPTION	FUEL SAVINGS AS % OF TOTAL DIRECT TRANSPORT ENERGY 1980	FUEL SAVINGS AS % OF TOTAL DIRECT TRANSPORT ENERGY 1990	FUEL SAVINGS IN THOUSANDS OF BBL PER DAY 1980	FUEL SAVINGS IN THOUSANDS OF BBL PER DAY 1990	FUEL SAVINGS PER UNIT OF SERVICE (PM, TM OR VM) % at full implementation	FUEL SAVINGS PER UNIT OF SERVICE Btu	INCREMENTAL COSTS (+) OR SAVINGS (-) CAPITAL INVESTMENT Billion $	CAPITAL INVESTMENT % Change	TOTAL USER COST Cents/Unit of Service	TOTAL USER COST % Change	YEARS TO OBTAIN MAXIMUM BENEFITS	TRAVEL TIME (% Change)	EMISSIONS IMPLICATIONS	SAFETY IMPLICATIONS	LIKELIHOOD OF ACHIEVEMENT
PASSENGER CARS															
VEHICLE EFFICIENCY															
Future Cars															
Modest off-the-shelf improvements (scenario A)[3]	8.2	15.0	848	1689	21	1968/vm	+ 0.05	+ 0.2	- 0.9	- 6	15	none	neutral	neutral	high
Advanced technology (scenario B)	8.7	24.4	894	2740	34	3168/vm	+ 3.7	+ 12	- 1.5	- 11	25	none	neutral	neutral	medium to high
Maximum "off-the-shelf" (scenario C)	10.9	21.7	1121	2440	31	2829/vm	+ 0.9	+ 3	- 1.0	- 7	15	none	neutral	neutral	high
Advanced technology & shift to small cars (scenario D)	13.1	32	1350	3601	46	4227/vm	+ 5.0	+ 17	- 3.0	- 21	25	none	neutral	negative	medium to high
Existing Fleet															
Radial tires (pre-1975 cars only)	0.5	0	47	0	3	270/vm	+ 0.6	+ 20	- 0.1	- 0.7	5	none	neutral	neutral	high
Other retrofits	0.5	0	47	0	3	270/vm	N/A[4]	N/A	0	0	5	none	neutral	neutral	low
LOAD FACTOR															
Carpools (work trips only) at 47% participation	1.9	1.5	200	174	14	780/pm	negative	N/A	(2 to 4)	-(15 to 35)	1	+10 to 40	-14%[11]	neutral	medium
Carpools (work trips only) at 70% participation	4.9	3.8	500	436	29	1617/pm	negative	N/A	(2 to 4)	-(15 to 35)	1	+10 to 40	-30%[11]	neutral	low
OPERATIONAL IMPROVEMENTS															
Speed limits 55 mph	1.2	0.9	121	105	8	588/vm	negligible	N/A	-0.5/vm	-3	1	+ 18	minor benefit	significant benefit	high
Better maintenance	0.7	0.6	75	65	1.5	140/vm	~1	N/A	+0.2/vm	+1.4	5	none	significant benefit	none	low
Driving habits	2.4	1.9	250	215	5	463/vm	negligible[2]	N/A	-0.4/vm	-2.3	5	negligible	minor benefits	minor benefits	medium
Urban traffic flow	0.4	0.7	98	84	3	318/vm	>1	N/A	-0.2/vm	-1	10	minor benefits	minor benefits	minor benefits	high
SERVICE REDUCTION															
Short-run (emergency)					*As dictated by circumstance*										
Long-run savings from 2.6% annual growth in VMT vs. 4.8% historic rate	7.9	18.9	819	2130	N/A	N/A	N/A	N/A	N/A	N/A	>20	N/A	major benefit	major benefit	high
BUSES															
VEHICLE EFFICIENCY	.07	.13	7	15	20	121/pm	negligible	N/A	negligible	N/A	10	none	none	none	high
AIR PASSENGER															
LOAD FACTOR IMPROVEMENT[5]	2.3	3.7	231	415	28	2174/pm	negative	N/A	0	0	4	0	Proportional to fuel savings	none	high
OPERATIONAL IMPROVEMENTS															
Cruise speed reduction	0.2	0.4	25	44	3	233/pm	0	0	0	0	0	2	"	"	high

N/A = not available (or not applicable).

1. Total direct transportation energy projections were based on the growth rate projected for the "$11/bbl conservation case" of the "Project Independence" report (8), which anticipates implementation of some of the measures described in Ref. (12).
2. Transportation fuel consumption in bbl/day is projected at 8.9 million bbl/day in 1980 and 9.4 million bbl/day in 1990, consistent with the above and assuming 5.8 million Btu/bbl with 95% of TOTE from liquid fuels in 1980 and 92% in 1990.
3. See Ref. (12) for scenario definitions.
4. However, retrofitting entire fleet with fuel-economy meters alone would cost several billion dollars.
5. Assuming change is from 50% load factor to 70% load factor.
6. Will require changes to air traffic control procedures and equipment.
7. Preliminary FAA study indicates that the value of the fuel savings would defray capital and operating costs of tow vehicles.

TABLE 39 (continued)

OPTION	FUEL SAVINGS AS % TOTAL DIRECT TRANSPORT ENERGY 1980	1990	FUEL SAVINGS IN THOUSANDS OF BBL PER DAY 1980	1990	FUEL SAVINGS PER UNIT OF SERVICE (PM, TM OR VM)(1990) % at full implementation	Btu	INCREMENTAL COSTS (+) OR SAVINGS (-) CAPITAL INVESTMENT Billion $	% Change	TOTAL USER COST Cents/Unit of Service	% Change	YEARS TO OBTAIN MAXIMUM BENEFITS	TRAVEL TIME (% Change)	EMISSIONS IMPLICATIONS	SAFETY IMPLICATIONS	LIKELIHOOD OF ACHIEVEMENT
AIR PASSENGER (cont'd)															
Altitude Increase[6]	0.1	0.2	11	19	1.3	101/pm	0	0	0	0	2	0	Proportional to fuel savings	none	medium
Ground Engine Use Reduction	0.1	0.1	7	12	0.8	62/pm	0	N/A	0	0	0	0	"	"	high
Ground Towing	0.2	0.4	22	40	2.7	210/pm	N/A[7]	N/A	0	0	N/A[8]	0	"	"	medium
RAIL PASSENGER	0	0.2	0	30	57	2000	N/A	N/A	N/A	N/A	15	none	minor benefit	none	high
WATER PASSENGER															
VEHICLE EFFICIENCY	0.1	0.1	9	11	N/A	N/A	N/A	N/A	N/A	N/A	15	none	none	none	high
SERVICE REDUCTION	0.2	0.2	11	23	N/A	N/A	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A	low
DOMESTIC FREIGHT TRUCK															
VEHICLE EFFICIENCY	3.3	8.7	306	888	23[9]	N/A	1	10%	negative	N/A	15	none	neutral	neutral	High
LOAD FACTOR	1.8	2.1	178	221	N/A	N/A	negative	N/A	negative	N/A	5	N/A	minor benefit	minor benefit	Medium
SPEED LIMITS	0.5	0.6	46	66	2.3	N/A	N/A	N/A	+0.4/tm	+4%	1	+9	minor benefit	significant benefit	High
AIR															
INCREASED USE OF P/C LOWER HOLDS	0.1	0.2	9	26	89	23,900/tm	none	N/A	negative	N/A	N/A	N/A	minor benefit	neutral	High
RAIL															
ELECTRIFICATION	none	0.6[10]	9	150[10]	none	none	up to 15	20	N/A	N/A	20[8]	none	N/A	neutral	Medium
WATER															
OPERATIONAL	0.3	0.3	25	29	15	76/tm	negative	N/A	N/A	N/A	5	N/A	negligible	N/A	High
PIPELINE					No significant Opportunities for Conservation										
MODE SHIFTS															
URBAN AUTO TO:															
Urban Bus	0.7	0.8	74	86	43	1358/pm	6	600	N/A	N/A	15	+200	minor benefit	minor benefit	Low
Urban Rail					limited to a few large cities										
Bicycle	0.5	0.7	50	80	100	3820/pm	0	0	-6.7	-100	10	-50 to +50	minor	unknown[14]	Medium
INTERCITY AUTO TO:															
Intercity Bus	0.2	0.2	17	20	29	489/pm	6.8	500	+1.4	+ 56	15	+10 to 50	"	minor benefit	Low
Intercity Rail	—	0.01%	—	1.4	40	659/pm	N/A	N/A	N/A	N/A	15	none	minor	minor	Medium
					No significant Opportunities for Conservation[12]										
SHORT-HAUL AIR TO:															
Intercity auto	0.2	0.4	19	40	77	6107/pm	0	0	- 15.5	- 86	5	+0 to 50	minor benefit		MEDIUM
Intercity Bus	0.2	0.4	24	43	85	6596/pm	0.8	60	- 14.1	- 78	15	+0 to 60	neutral	minor benefit	MEDIUM
Intercity Rail[12]	0.2	0.3	16	28	55	4266/pm	N/A	N/A	- 13.2	- 73	?	+0 to 40	N/A	minor benefit	MEDIUM
AIR FREIGHT TO:															
Intercity Truck					No significant Opportunities for Conservation[13]										
TRUCK FREIGHT TO:															
Rail	0.4	1.4	34	141	65%	1244/tm	N/A	N/A	- 2	- 30	15	+25 to 100	minor benefit	minor benefit	HIGH
INDIRECT CONSUMPTION															
REFINING LOSS					Multiply direct savings by 1.2										
VEHICLE LIFE EXTENSION	0	1[15]	0	100	N/A	N/A	unknown		N/A	N/A	N/A	none	none	none	Med
MODE SHIFTS					Not quantified, but probably significant										

8. Tow vehicles are not now available.
9. Average for all classes.
10. Rail electrification does not necessarily save energy but does substitute coal or nuclear power for oil. Percentage savings are greater for bbl/day than for TDTE.
11. Applies to pollutants emitted by commuter cars only.
12. Based on 1972 modal averages. Rail service in high-density corridors may be more efficient by 1990.
13. Based on marginal fuel consumption for lower-hold cargo in passenger aircraft.
14. Depends on degree of separation between bicycle and motor traffic.
15. Although savings might eventually amount to 3% of TDTE, in 1990 the maximum likely savings is 1%.

TABLE 40

CONSERVATION MEASURE EVALUATION MATRIX (4)

Mode	Conservation Measure	1972 Base Consumption (Thousand Barrels per day)	Potential Savings Volumes* 1974 (Thousand Barrels per day)	Potential Savings Volumes* 1978 (Thousand Barrels per day)	Implementation Values: Methods & Incentives	Implementation Values: Relative Time†	Implementation Values: Relative Costs‡	Impact Factors & Relative Values§: Social	Impact Factors & Relative Values§: Economic	Impact Factors & Relative Values§: Political	Impact Factors & Relative Values§: Environment	Relative Public Acceptance	Feasibility Factor —Overall—
I. Highway													
A.	Passenger Cars												
	1. Car-pooling (To & From Work)	1,832	92	325	Priority parking, reduced tolls, tax deductions, insurance discounts, employer subsidies, etc.	Reasonably short 3	Low 3	Loss of independence, privacy, flexibility, status, etc. 1	Longer commuting time; loss of revenue to business and government; lower auto sales; lower commuting costs. 2	Negligible 2	Less pollution, congestion, & noise; reduced land requirements for roads & parking lots. 4	1	16
	2. Travel Characteristics a. Driving Restrictions	3,593	38	46	Auto use restrictions as auto free zones; reduced parking; higher parking rate & tolls; special permits, etc.	Moderate 2	Low 3	Arbitrary nature loss of personal freedom, discriminatory, changed locations of work & shopping centers. 1	Shift of sales patterns; higher motoring costs; increased government revenues (tolls, taxes, etc.); reduces low efficiency city driving. 2	Requires legislative action 1	Cleaner & less congested cities. Causes more urban sprawl 2	1	12
	b. Four-Day Work Week	2,267	102	125	Employer Options	Reasonably Short 3	Low 3	More leisure time 3	Increased sales of recreational equipment. 2	Negligible 2	Reduced congestion & pollution; greater demands on recreational areas. 2	2	17
	c. Walking & Bicycling	850	2	40	Auto disincentives and creation of bicycle & walkways.	Substantial 1	Moderate 2	Improved health; increased local awareness; higher accident potential 3	More or less travel time depending on distance & congestion; limited hauling capacity; lower demand for cars. 2	Significant implementation requires legislation. 2	Reduced pollution & congestion. 3	3	16
	d. Driver Behavior	5,425	57	70	Driver education & efficiency monitoring devices	Moderate 2	Low 3	Negligible 2	Negligible 2	Government programs & encouragement would be helpful 2	Negligible 2	2	15
	3. Speed Limits	5,425	168	190	Government Mandate	Immediate 3	Moderate 2	Balance of safety factors- longer driving time vs. lower fatality & injury rates 2	Cost in terms of lost time vs. lower driving costs and lower costs associated with reduced fatality & injury rates 2	Unclear 2	Negligible 2	1	14
	4. Auto Design	4,757	0	236	Economic incentives or mandate	Moderate 2	Moderate 2	Negligible 2	Lower driving costs; higher cost of cars 2	Legislative action might be required 2	Negligible 2	3	15
	5. Vehicle Maintenance	5,425	142	174	Mandatory requirements or educational programs	Immediate 3	High 1	Discriminates against low income group; Possible safety improvement 1	Higher maintenance cost vs. lower fuel consumption; Increased revenues for auto maintenance industry 2	Legislative action might be required 1	Less pollution 3	1	12
	6. Vehicle Changes (Small Cars)	4,757	73	361	Economic incentives; efficiency or fuel taxation; educational programs	Moderate 2	Moderate 2	Reduced safety 2	Lower driving costs; improve balance of payments; employment and production curtailment during conversion 2	Legislative action might be required. 2	Less pollution; lower resource requirements 3	3	16
	7. Emission Standards and Lead Phasedown	6,164	0	280	Government Mandate	Immediate 3	Negligible 3	Possible adverse health impact 2	Lower driving cost via improved fuel efficiency; lower refining investment & costs; lower cost cars; Higher costs due to pollution 3	Requires legislative action 2	Higher initial levels of pollution 1	2	16
	8. a. Mode Shifts (From Cars) 1. Urban Bus	4,757	0	33	Auto disincentives; bus lanes; encouragement of greater bus production and scheduling improvements; government subsidies.	Moderate 2	High 1	Loss of independence & flexibility, privacy, status, etc.—greater safety. 2	Longer commuter time & lower costs; lower auto sales; loss of revenues to business & government. 2	Subsidies and operating priorities (bus lanes) would require legislation. 3	Less pollution, congestion & lower parking needs 4	1	15
	b. Intercity: Bus Train Air		0 0 0	31 15 38	Government policies for encouragement and subsidies, especially for train service, auto disincentives (tolls & taxes), improved service.	Bus - Moderate 2 Train - Long 1 Plane - Short 3	Bus - Moderate 2 Train - High 1 Plane - Low 3	Increased safety; loss of convenience & flexibility on arrival. 2	Loss of time (except air); expansion would create jobs; lower car sales & associated revenues. 3	Subsidies & disincentives require legislation. 2	Less pollution, congestion 3	Bus 2 Train 1 Air 2	Bus 16 Train 13 Air 18
B.	Commercial Trucking 1. Speed Limits (Intercity)	1,289 609	18	22	Government Mandate	Immediate 3	Moderate 2	Balance of safety factors-longer driving time vs. lower fatality rate; time away from family. 1	Overall productivity loss. 0	Unclear 2	Negligible 2	2	12

2. Design	559	6	7	Economic incentives or mandate.	Moderate	2	Low	3	Negligible	2	Negligible	2	Negligible	2	Negligible	2	2	15
3. Weight (Heavy Trucks)	559	0	24	Government Mandate	Reasonably Short	3	Low	3	Negligible	2	Increased productivity & lower operating costs. Greater roadway wear.	3	Negligible	2	Reduced trips & less pollution & congestion.	3	2	18
4. Maintenance & Operating Procedure	559	20	37	Economic Incentives	Immediate	3	Low	3	Negligible	2	Lower operating costs.	3	Negligible	2	Negligible	2	2	17
5. Mode Shifts (From Trucks)	296	25	30	Economic incentive, subsidies to rail to improve service	Moderate	2	High	1	Negligible	2	Lower Shipping costs.	3	Questionable cost-value judgement.	1	Less rural congestion, more urban congestion & pollution	1	2	12
C. Intercity Buses																		
1. Expanded Utilization (See I. A. 8. b.)																		
2. Operating Efficiencies		– Insignificant –																
D. Roadway Improvements		– Insignificant –																
II. Airways																		
A. Operating Efficiencies	1,067	41	55	Reduced cruise speeds; improved traffic control; switch training to simulation	Reasonably short	3	Low	3	Negligible	2	Increased efficiency	3	Negligible	2	Less noise & pollution	3	2	18
B. Flight Reductions	1,067	104	Unclear	Reduced flights via increased load factors; economic incentives	Immediate	3	Low	3	Travel Difficulties	1	Reduce employment; increased unit costs; idle aircraft; less ability to absorb higher costs.	1	Negligible	2	Less noise, pollution & airport congestion.	3	1	14
III. Railways																		
Operating Efficiencies	251	15	20	Improved fuel management and maintenance; computerized control techniques; —economic incentives	Reasonably short	3	Low	3	Negligible	2	Increased Efficiency	3	Negligible	2	Negligible	2	2	17
IV. Waterways																		
A. Operating Efficiencies	348	23	25	Speed reductions; improved turnaround; economic incentives.	Reasonably short	3	Low	3	Negligible	2	Increased Efficiency	3	Negligible	2	Negligible	2	2	17
B. Mode Shifts (To Water)		0	3	Expanded use of St. Lawrence Seaway to maximize Great Lakes. Economic incentives thru change in freight rate schedules.	Moderate	2	Low	3	Negligible	2	Shift of revenues among carriers & ports; increased efficiency via lower transportation cost.	3	Requires legislation	1	Improved balance for water and land freight traffic.	3	2	16
V. Urban Public Transit																		
A. Increased peak hour ridership	1,832	14	14	Auto disincentives; Improved scheduling; bus lanes	Immediate	3	Negligible	3	Greater safety; loss of independence, flexibility, privacy, status, etc., increased crowding, standing, & discomfort	1	Longer commuter time; lower commuter costs, lower auto sales; loss of revenues to business and government	2	Operating priorities (bus lanes) and auto disincentives would require legislation	2	Less pollution, congestion, & lower parking needs	3	1	15
B. Spreading peak hour ridership	1,832	0	69	Staggering of work hours; Employer option	Reasonably short	3	Low	3	Inconvenience to employees and their families	1	Disruption to normal business patterns	1	Negligible	2	Less congestion	3	1	14
C. Improved bus load factor	(Unclear)	0	19	Off-peak utilization through improved service and subsidies	Reasonably short	3	Moderate	2	Greater safety; loss of independence, flexibility, privacy, status, etc.	2	Longer travel time; lower travel costs; lower auto sales; loss of revenues to business and government	2	Subsidies would require legislation	2	Less pollution; congestion & lower parking needs	3	1	15
D. Additional urban buses		0	33	(See Highway Mode Shifts, I. A. 8. a.)														
E. Mini-bus commuting system	1,832	0	8	Employer subsidies & incentives; Auto disincentives; Changes in laws and regulations	Moderate	2	Moderate	2	Greater safety; loss of independence, flexibility, privacy, status, etc.	2	Longer commuter time; lower commuter costs; lower auto sales vs. increased van sales	2	Changes in laws & regulations and disincentives would require legislation	3	Less pollution, congestion & lower parking needs	3	2	16
VI. Pipelines	539	5	6	Improved efficiency of pumping units dependent on overall economics of operation	Moderate	2	High	1	Negligible	2	Negligible	2	Negligible	2	Negligible	2	2	13
VII. Miscellaneous	632																	
A. Farm Equipment	278	70	23	Improved energy management and reduced tillage; education & economic incentives.	Moderate	2	Low	3	Negligible	2	Reduced operating costs.	3	Negligible	2	Improved soil conservation.	3	2	17
B. Construction Equip.	326																	
C. Utility Engines	22	(Insignificant)																
D. Snowmobiles	5																	
E. Race Cars	.5																	

*Most likely; Numbers in these columns are not additive. (See Transportation Task Group Report for basis of determination.)
†Relative time factors: 1 = greater than 4 yrs; 2 = less than 4 yrs; 3 = less than 2 yrs.
‡Relative cost factors: 1 = high; 2 = moderate; 3 = low.
§0 = intolerable; 4 = excellent.
‡Sum of arbitrary values; higher values indicate greater feasibility; total of 14 would be neutral.

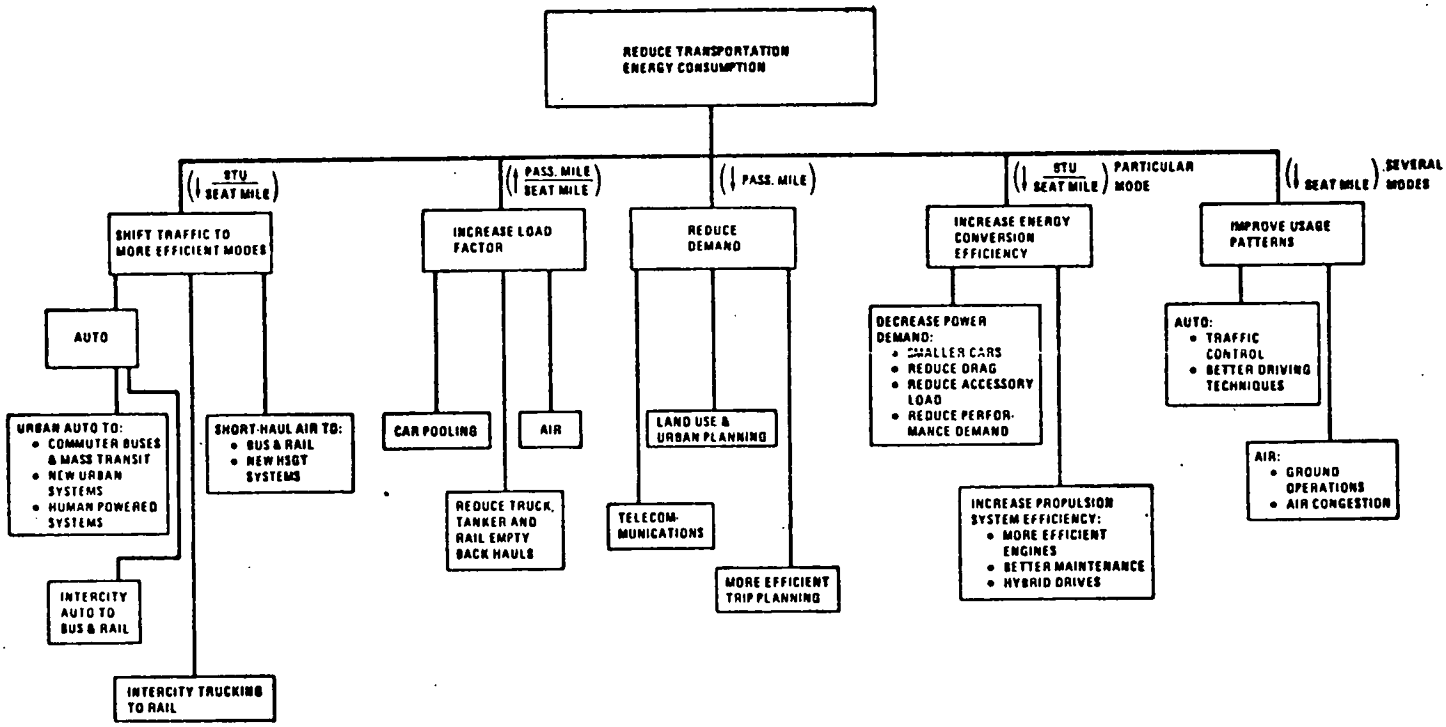


Figure 21. Alternatives for reducing transportation energy consumption (16).

because motor vehicles now consume the major share of transportation energy and operate at efficiencies below the state of the art. The savings could exceed 30 percent of TDTE by 1990 (*12*).

- Because gains in vehicle efficiency can have relatively little impact on the quality of the transportation service provided, they may not require changes in the behavior of either consumers or institutions—except for vehicle manufacturers, of course.
- Implementing improvements in vehicle efficiency can reduce total cost of transport; to the extent that it does, it is favored by market forces.

The major disadvantage of this measure is the relatively long implementation time—on the order of 20 years—required to realize its full benefit. It should be noted, however, that because newer vehicles account for a disproportionately large share of miles traveled, the prompt implementation of programs for improving vehicle efficiency could lower the growth rate in demand for motor fuels to zero by 1980.

Increasing load factors is the second most important class of options, particularly for aircraft, commuter automobiles, and perhaps trucking. Each of these three might generate savings of about 2 or 3 percent of TDTE. Although an increase in load factor tends to reduce the direct costs of transportation, the additional travel time and/or inconveniences entailed might render such an approach unattractive for many potential users. The most salient advantage of this approach is that it could be implemented very quickly with little or no capital cost.

Operational improvements in use patterns, such as lower speed limits or better maintenance, could conceivably generate savings of up to 5 percent of TDTE. Because some improvements are not perceived as cost-effective by users, government action would be necessary for their implementation. In the case of the permanent 55-mph (90-km/h) speed limit, the injuries and fatalities avoided represent more significant benefits than the fuel savings.

The expected declines in long-run growth rates for air and auto travel also constitute a major element in the reduction in expected energy consumption. These rate changes (from 4.8 to 2.6 percent for cars and from 14 to less than 6.3 percent for air) are related to what appear to be long-term shifts in demographic variables, growth rates of the gross national product, and relative prices of fuels. If there were a return to the pre-embargo growth trends, TDTE would be much greater than is projected here.

Shifts to more efficient modes offer substantial theoretical savings, but they are not likely to be induced to a significant degree solely by foreseeable fuel price increases. Service improvements on the efficient modes, general economic forces, and regulatory changes could produce increases in use sufficient to save up to 5 percent of TDTE. Such gains would require large increases in the physical plants of the efficient modes and thus require implementation periods of about the same length as those of improving vehicle efficiency. These large capital requirements also mean that some mode shifts are not necessarily cost-effective in terms of direct savings in fuel costs alone, although they may be justifiable when other benefits are included in the calculation.

Indirect energy consumption in transportation is about two-thirds as great as direct energy consumption. Appreciation of this fact is relatively new, however, and opportunities for conservation in this area have not been extensively researched. Such opportunities exist chiefly in petroleum refining, vehicle manufacture, and mode shifts (e.g., indirect energy costs per passenger-mile for rail service are lower than those of private autos). The energy costs associated with refining fuels for use in transportation result in a multiplier effect (about 1.2) for all measures that conserve direct fuel. Extending the service lives of passenger cars so that fewer need be produced each year could reduce their manufacturing energy cost by an amount equal to more than 1 percent of TDTE. However, adverse impacts on initial costs and offsetting interactions with technology improvement measures may render this option unattractive. Indirect energy savings associated with mode shifts are not yet sufficiently well understood to permit quantitative estimates of their magnitude.

Conservation implementation is another poorly understood matter. Knowing what actions will conserve energy is, unfortunately, not the same as making them happen. In general, the marketplace provides small incentive for individuals or industry to invest in more efficient vehicles, because fuel is relatively cheap even with the recent price increases. This is true because transportation is largely a derived demand and generally represents a small percentage of the total costs of final consumption of goods and services. Further, because energy generally represents less than 10 percent of the total cost of transportation (except for auto driving, in which it is approximately 25 percent), the demand for energy for transportation is very price inelastic.

Because the private automobile accounts for almost 80 percent of the energy used in passenger transportation and approximately 55 percent of the energy used in total transportation (passenger and freight), conservation measures for the private automobile are the most critical. Congress has mandated improved efficiency standards for production of new automobiles, and this will pay conservation dividends in the decades ahead. No action has been taken to reduce consumption either by restricting the supply or increasing the price of gasoline, the fuel consumed by the more than 100 million automobiles presently in use. This situation, if unchanged, could result in a growth in vehicle-miles traveled that more than counterbalances the effect of improved auto efficiency. To conserve, automobiles must be made more efficient *and* used more intelligently. Still needed are policies that will make it attractive to the individual to purchase the smaller, more efficient automobile; to want to car pool, or van pool if possible; and to adopt identified conservation practices. Similarly, policies that will stimulate industry to give higher priority to energy conservation are still needed. Tables 39 and 40 give a useful list of possible actions to accomplish this purpose.

CHAPTER FIVE

RESEARCH NEEDS

Certain gaps in energy data have become apparent during the preparation of this synthesis. To facilitate future work on this subject, research is suggested to close these gaps. In addition, the accuracy of data is frequently unknown. The most accurate data are available from businesses with records subject to the reporting requirements of regulatory agencies, such as records of fuel purchases by common carriers or records of revenue passenger-miles carried by air, rail, and so on. Total gasoline sales, which are linked to tax receipts, are well known, but their allocation among autos, trucks, and nonhighway uses introduces some error. Estimates of vehicle-miles traveled may contain errors on the order of 5 to 10 percent. Auto occupancy is either not reported in different studies or not well explained, a situation that allows for errors of 10 percent or more. Transit systems report only the number of passengers carried, not passenger-miles. Estimates of the length of the average transit trip vary widely; hence, the figures reported here can be inaccurate by 20 percent or more. Few data on energy consumption for oil pipelines have been compiled; the computations, based on engineering handbook formulas and estimates of parameters such as average viscosity and temperature, could easily lead to errors of 50 percent.

Another problem is the use of modal averages. The energy consumption per unit of service can vary widely from the modal average. For example, automobile fuel economy ranges from about 7 mpg (3 km/litre) for the heaviest cars in urban driving to about 35 mpg (15 km/litre) for the most efficient cars in highway driving. Occupancy varies from one to six or more. Thus, energy consumption per passenger-mile can range from about 20,000 Btu (13 MJ/km) for a large car with one occupant on a short urban trip to less than 1,000 Btu (0.7 MJ/km) for a compact car carrying six persons (or a subcompact carrying four) on the highway. Similarly, rail passenger service requires more than 10,000 Btu/passenger-mile (6.6

MJ/passenger-km) for certain long-haul luxury trains replete with lounges, dining cars, roomettes, and so on, but less than 2,000 Btu/passenger-mile (1.3 MJ/passenger-km) for bi-level commuter trains. Pumping energy per ton-mile for oil pipelines can vary as much as a hundredfold, depending on diameter, flow rate, temperature, viscosity, and terrain.

Despite these wide variations, it is still possible to compute realistic estimates of fuel savings for measures that would have approximately the same percentage of effect on all vehicles, such as the substitution of a more efficient engine, an increase in average load factor, or a reduction in speed limit. When mode shifts are considered, however, one must pay careful attention to exactly which segments of affected modes might be involved. For example, although average energy consumption per passenger-mile of intercity rail service is less than half that of air service, there is no savings at all in diverting long-distance air passengers to rail if long-distance trains are much more energy intensive than the average train. Conversely, the potential savings in diverting air travelers to auto travel is greater than what might be calculated on the basis of overall automobile averages. Moreover, the implementation of the mode shift might require or result in changes in load factors that could enhance or detract from the energy savings. To attract automobile commuters to transit, for example, it might be necessary to reduce peak-hour load factors. On the other hand, incentives for off-peak transit use could boost average load factors, cutting average energy consumption per passenger-mile.

The lack of complete historical data on auto versus mass transit hampers analysis of such problems. In addition, the lack of data on international air and water carriers hampers measurement and projection of traffic and fuel use of overseas aircraft and oceangoing vessels. For example, data are not available on either revenue freight ton-miles or total fuel used for bunkering inbound oceangoing vessels.

The "Study of Potential for Motor Vehicle Fuel Economy Improvement: Truck and Bus Panel Report" found that the major technological shortcoming identified during the study of fuel economy in trucks and buses involved the obtaining of viable and equitable techniques for measuring fuel economy (*26*). At the present time, there exists no accepted set of driving patterns for either road tests or dynamometer tests by which claims of fuel economy can be adequately judged. Furthermore, the most appropriate operational pattern for evaluating each type of vehicle is not known. High priority needs to be given to developing test procedures for determining fuel economy. Because the real efficiency of the commercial vehicle fleet is determined by the fuel consumed relative to the work performed (the transportation of material and people), the final measure of fuel economy of commercial vehicles should reflect productivity (such as ton-miles or passenger-miles per gallon of fuel consumed).

In addition to the need for further research on the aforementioned topics, there is a need to identify the policies that can bring about energy conservation actions. This is a most complex challenge involving all sectors of our society, governmental and private.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

- Great care needs to be exercised in comparisons of the energy intensity of one mode with that of another. One should not generalize. The theoretical efficiency of the technology can be seriously degraded, depending on how the transportation mode is used. For example, a fully loaded subcompact is a very efficient mode of transport, whereas a large automobile carrying only one or two persons is significantly less so. A bus loaded with passengers would seem to be much more efficient than the auto; however, the two can be compared only if they both serve the same market. In many locations, the only option might be the auto or, in the case of freight, the truck.
- In energy comparisons among modes, the emphasis should be on the mode's efficiency in getting the particular job done or service performed. Only then are the energy comparisons valid.
- Producing and using more efficient modes of transportation do not necessarily mean using less energy. To conserve vital energy reserves will require that the focus be not only on the efficiency of the transportation modes but also on how these modes can (and should) be used more intelligently in an energy-limited world.
- A major national effort is being directed toward developing, building, and selling more efficient automobiles. Unless a concomitant effort is developed to promote more socially responsible uses of transportation, the energy conservation gains of more efficient autos may be dissipated by wasteful and accelerated use patterns.

- Although technological improvement in fuel economy must be pursued, its effects are 5 to 15 years away. For early conservation gains, it is essential to focus more on better use of the transportation technology currently in existence.

RECOMMENDATIONS

It is recommended that transportation agencies consider alternative ways to achieve improved use of transportation modes. Improved use has the potential for achieving energy savings as large as or larger than those achieved through technological improvements. Obviously, both are needed.

Also requiring study are these related areas affecting travel demand and energy consumption:

- The value of mobility.
- The relationship between vehicle-miles traveled and job availability.
- The long-term options for reducing vehicle-miles traveled without causing adverse economic impacts.

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APPENDIX A

ENERGY EQUIVALENTS AND ENERGY CONVERSION FACTORS

The energy content of most fuels can vary, depending on, among other things, their source. The following energy equivalents are typical.

FUEL	(BTU/GAL)	(MJ/LITRE)
(a) Petroleum		
Bunker oil (vessels)	140,000	39
Diesel oil (locomotive)	138,000	38
Diesel oil (highway vehicle)	136,000	38
Jet fuel (naphtha-type)	127,619	36
Jet fuel (kerosine-type)	125,580	35
Gasoline (auto)	124,950	35
Gasoline (aviation)	111,190	31
(42 gallons in one petroleum barrel)		
(b) Natural Gas		
Dry	1,031 Btu/ft^3 at STP	38.4 MJ/m^3
Wet	1,103 Btu/ft^3 at STP	41.1 MJ/m^3
Liquids	4.1×10^6 Btu/42-gal bbl	27 MJ/litre
(c) Coal		
Anthracite	25.4×10^6 Btu/ton	29.5 MJ/t
Bituminous	26.2×10^6 Btu/ton	30.5 MJ/t
Subbituminous	19.0×10^6 Btu/ton	22.1 MJ/t
Lignite	13.4×10^6 Btu/ton	15.6 MJ/t

TABLE A-1

CONVERSION FACTORS AND ENERGY EQUIVALENTS

FROM \ TO	Btu	cal	kgf-m	ft-lbf	joule	hp-hr	kW-hr
Btu	1	252.0	107.6	778.0	1055	3.93×10^{-4}	2.93×10^{-4}
cal	0.00397	1	0.4268	3.087	4.186	1.56×10^{-6}	1.16×10^{-6}
kgf-m	0.00930	2.343	1	7.233	9.807	3.65×10^{-6}	2.72×10^{-6}
ft-lbf	0.00129	0.3239	0.1383	1	1.356	5.05×10^{-7}	3.77×10^{-7}
joule	9.48×10^{-4}	0.2389	0.1020	0.7376	1	3.73×10^{-7}	2.78×10^{-7}
hp-hr	2545	6.41×10^{5}	2.74×10^{5}	1.98×10^{6}	2.68×10^{6}	1	0.7457
kW-hr	3413	8.60×10^{5}	3.67×10^{5}	2.66×10^{6}	3.60×10^{6}	1.341	1

Abbreviations: Btu, British thermal unit; cal, calorie; kgf-m, kilogram force metre; ft-lbf, foot pound force; joule, joule; hp-hr, horsepower hour; kW-hr, kilowatt hour.

APPENDIX B

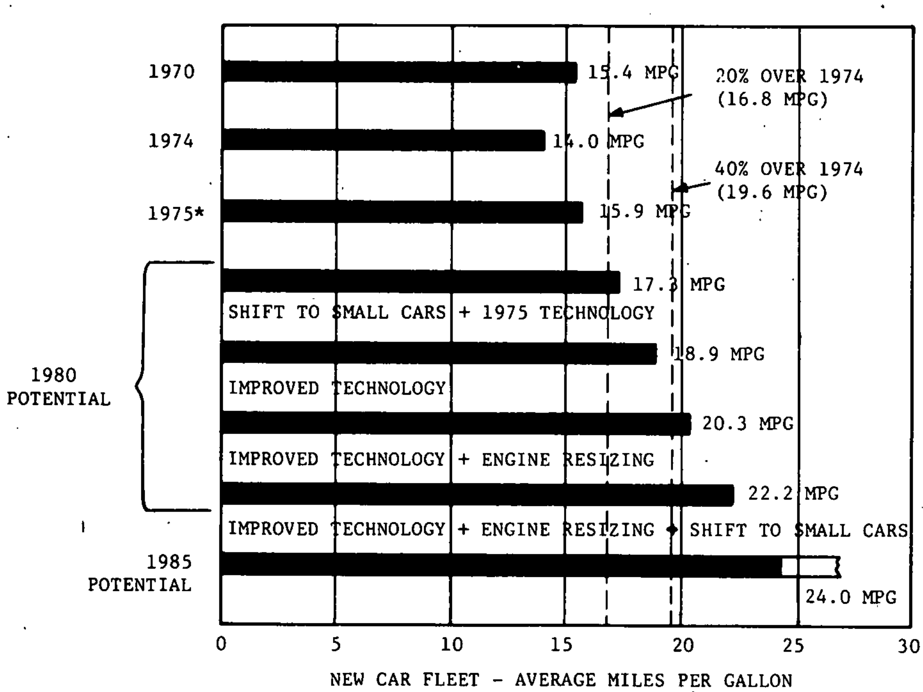
DETAILED CONCLUSIONS OF "POTENTIAL FOR MOTOR VEHICLE FUEL ECONOMY IMPROVEMENT: REPORT TO THE U.S. CONGRESS"

The following detailed conclusions summarize the main results of the study for automobiles (*23*).

1. *What is the fuel economy improvement potential by 1980 and 1985?*

- Fuel economy improvements may be obtained by three major methods: technological improvements in the engine and drive train to increase efficiency and in the tires and body structures to reduce drag and weight; a reduction in engine size for the larger cars; and a shift to a greater proportion of small cars in the fleet.
- Figure B-1 and Table B-1 indicate that from the 14.0 mpg* in 1974, a 25 to 60 percent (17.3 to 22.2 mpg) fuel economy gain is possible for 1980 model cars, depending on the improvement strategies used. Because of production constraints, improved technology and engine resizing offer more potential for improvement than the strategy of shifting to small cars by 1980. The 1975 fleet (15.9 mpg) demonstrated a 13.5 percent increase in fuel economy over that of 1974 (14.0 mpg) through improved technology. The 1970 fleet averaged 15.4 mpg. Thus, a combination of technological improvements in 1975 cars and changes in the model mix (i.e., a larger proportion of smaller cars) recouped the fuel economy lost between 1970 and 1974 due to emission control and added weight.
- Estimates of the average miles per gallon for the 1980 new car fleet shown in Figure B-1 vary, depending on which of the above methods is assumed (e.g., various forms of technological upgrading, shift in sales mix, or combinations thereof). Each estimate assumes the best effort possible. For estimation purposes, shift in mix was limited to that possible, given the availability of production facilities, but no limitations due to consumer demand were assumed. Some of the technological options considered require further development; however, their implementation is deemed feasible by 1980. Technological options were screened for consumer acceptability; once selected, however, eventual 100 percent application to the new car fleet was assumed.
- The impact, timing, and cost of emission and safety standards were considered; the trade-offs among them are

* The fuel economy in miles per gallon is based on miles traveled and fuel used in the city and highway driving schedules developed by EPA. The single number is obtained by assuming that 55 percent of the driving is represented by the city cycle and 45 percent by the highway cycle. Results for individual cars are weighted by the percentage of the production attributable to that car to obtain an average that is indicative of the fuel economy of the entire fleet.



*1974 New model production mix assumed.

Figure B-1. Potential for automobile fuel-economy improvement (23).

addressed in the following sections. Simultaneous achievement of improved fuel economy, low emissions, and occupant safety will increase the first cost of new vehicles.

2. *What are the relationships between fuel economy and safety?*

• Safety and fuel economy are related through a vehicle's weight and body structure. Today, a larger car with more crush space and heavier structure provides better protection but poorer fuel economy than a small car.

• Of equal importance to the crashworthiness of cars are the availability and the use rate of effective passenger restraint systems. Even in today's fleet, where the probability of being involved in an accident is relatively independent of car size, the belted occupant of a small car has approximately the same protection as the unbelted occupant of a large car.

• Because present national policy is directed toward reducing the serious injury and death rate on the highways, safety standards that would improve crashworthiness and the effectiveness of passenger restraint systems, especially for small cars, are necessary. If fuel economy improvements are achieved by shifting to a higher percentage of small cars in the fleet without concurrently upgrading their occupant protection capability, the serious injury and death rate will probably rise.

• The relationship between weight and safety is the reverse of that between weight and fuel economy. Consequently, the fuel economy penalty chargeable to increased occupant safety may be proportionately greater for a small car than for a large car. Bumper standards have added about 140 pounds and safety standards about 120 pounds, for a total of 260 pounds added to the average vehicle of today. The fuel economy penalties have been on the order of 3 to 4 percent for this additional weight.

• Presently identified future safety standards will add approximately 80 pounds to the average vehicle. The weight picture for future bumper standards is unclear, because the effects of various possible designs are as yet undefined.

• The fuel economy improvement feasible for the 1980 vehicles would be offset in part by the weight penalties of future safety and damageability features. It is possible that weight increases have been greater than technically necessary, because manufacturers have used proven engineering approaches and standard materials to increase structural strength. The increased cost of fuel and the emphasis on fuel economy are now causing manufacturers to consider alternative designs that include lighter-weight materials. Such technology advances, combined with increased use of effective passenger restraint systems, could greatly reduce the weight penalties of upgraded vehicle safety, particularly in vehicles manufactured after 1980.

• If engine size reduction for large cars is used to improve fuel economy, there may be no adverse effects on safety. Moderate reductions in acceleration capabilities and top-speed characteristics for large vehicles may provide safety benefits.

TABLE B-1

ADDENDUM TO FIGURE B-1 (*23*)

Scenario	PERCENT GAIN IN MPG 1980	1985	FUEL ECONOMY IMPROVEMENTS
Baseline	0	0	No improvements in fuel economy relative to base year* vehicles. Minimum changes to meet statutory emission standards.
A Modest Improvements	28%	27%	Optimized conventional engines, radial tires, slight weight and aerodynamic drag reductions (in line with announced industry goals). No improvements after 1979.
B Gradual Improvement Thru 1980's	33%	52%	Steady technological improvement through the 1980's: Weight reduction through materials substitution and minor redesign during the 1970's; further changes (unitized body) in the 1980's. Some aerodynamic drag reduction and substantial transmission improvements fully accomplished by 1984. Diesel engines phased in for larger cars from 1981 to 1989 plus some stratified charge engines for smaller cars. No performance degradation.
C Maximum Improvement by 1980	43%	44%	Maximum rate of improvement through 1980 with little further gain during the 1980's. Rapid weight reduction, aerodynamic drag reduction, and transmission improvements. Displacement reduction of optimized conventional engines, but no diesel or stratified charge engines.
D Scenario B Plus Shift to Smaller Cars	65%	84%	Same as B with 1980 sales mix assumed at 10 percent large cars, 25 percent intermediates, 25 percent compact, and 40 percent subcompact.

*Base year vehicles = all vehicle models 1972 fleet average. 13.5 mpg

Source: Highway Statistics 1972 *(6)*

3. *What is the relationship between fuel economy and emissions?*

• Fuel economy by 1980 can be significantly improved over that of 1974 and still allow the vehicle to meet statutory HC and CO standards.** Significant gains were achieved in 1975, and emissions of HC and CO were lower than they were in 1974. Such gains, while maintaining the fuel economy achievable with 1975 HC and CO emission standards, will come at increased first cost of the car and complexity of the engine system.

• For the oxides-of-nitrogen emission standard, the issue of level and cost achievable by 1980 concurrent with substantial improvement in fuel economy is unresolved.

• Several alternative engine systems have the potential in 1985 and beyond to improve fuel economy significantly over that of the conventional, spark ignition engine. The diesel and Stirling cycle concepts are examples. It would require on the order of 15 to 25 years, respectively, to realize the full benefits of these two alternative engines and fuels. The ultimate target level for the oxides-of-nitrogen emission standard, as well as for emissions for which there is now no standard, will have a major impact on which alternative engine systems, if any, can realistically be considered by the industry for large-scale implementation. An oxides-of-nitrogen level much below 1.0 to 1.5 g/m would

** The 1975 emission standards are 1.5 g/m HC, 15 g/m CO, and 3.1 g/m NO_x. Statutory emission standards, currently applicable in 1978, are 0.41 g/m of hydrocarbons (HC), 3.4 g/m of carbon monoxide (CO), and 0.4 g/m for oxides of nitrogen (NO_x).

greatly discourage commitments to the development of the diesel engine or some stratified charge engine concepts that could be offered in new vehicles in appreciable numbers between 1982 and 1985.

4. *Do engineering and manufacturing lead times forestall potential fuel economy improvement?*

- Present manufacturing capacity is sufficient to permit a model mix in which 60 percent of all new cars would be compacts or subcompacts.
- The automotive industry requires a lead time of 4 years for structural changes, some transmission changes, and other component modifications. A lead time of about 6 years is required for a new engine configuration of the current type. Eight to 15 years are required for a major technological advancement and change such as an alternative power system. An additional 10 years may be required to change the total motor vehicle fleet so as to realize the full benefit of such an advance.
- Lead items begin from the date on which a manufacturer decides to pursue a given course of action. Current uncertainty about future safety standards and the NO_x emission standard inhibits manufacturers from making firm decisions to commit resources to the development and use of fuel-conserving technologies.

5. *What test procedures should be used to measure fuel economy?*

- No single measure of fuel economy suffices for the needs of all users. Standardized tests that are either dynamometer-based or track-based and involve a range of driving conditions are currently used for measuring fuel economy.
- The driving cycles used to measure city and highway fuel economy must be as representative as possible of actual driving under such conditions. The EPA city and highway driving cycles are suitable for this purpose. Use of these cycles on a dynamometer would be an appropriate fuel economy test if the dynamometer procedures were modified to improve the road load factors used for individual cars. Because there are possible trade-offs between fuel economy and emission control, the EPA emissions measurement procedure would need to be used at least on a sampling basis to assure that fuel economy test cars complied with applicable emission standards. A track test procedure could also be acceptable, provided that adequate representation of driving characteristics and test accuracy and repeatability were reflected in the procedures. Track procedures do present special problems, however, because broad variations in ambient conditions can significantly affect fuel economy.
- Several options are available for determining the fuel economy of a manufacturer's entire fleet, as well as of individual vehicles, to an accuracy adequate to permit more informed consumer choice. Prototype testing by the federal government (as is now done by EPA for emissions) is one option. Another is the manufacturers' determination of the fuel economy of their production fleet, with federal verification of the testing and results. The selection criteria used to choose among these and other options, as well as among the test procedures, should include the total program cost, the administrative problems, and the technical requirements for a given accuracy to verify the results for the fleet.
- Current test procedures provide a measure of fuel economy that has a precision of 2 to 4 percent for most vehicles. An increase in this precision would likely result in considerably higher test costs.

6. *What are the various means for enforcing an improvement standard?*

- The potential of market forces to achieve major fuel economy gains is uncertain, although fuel economy in 1975 increased 13.5 percent over that of 1974. Information on the fuel economy of the individual cars available for purchase would allow operation of those market forces that influence fuel economy. However, the response to such information must be assessed extensively before one can know whether consumer information alone is sufficient to produce the needed fuel economy improvement. If stronger action is deferred until such an assessment is completed, the effect of such an action would be delayed well beyond 1980.
- Mandatory labeling, a mild form of federal action, is relatively easy to administer and operates to motivate market forces without causing any major adverse impacts. It would probably be an integral part of any stronger federal regulatory effort oriented toward establishing fuel economy standards.
- With respect to regulatory alternatives, no one approach appears to dominate the others. Each involves costs, problems, and risks. It may be concluded that if federal regulatory policy becomes stronger, the likelihood of achieving given fuel economy goals will increase. Stronger federal regulation, however, also involves risking adverse impacts on the economy, industry, consumers, and the costs of governmental administration. [The Congress chose the regulatory approach in HR 94163 and mandated fuel economy standards.] The following indications arise from an analysis of the impacts of various fuel economy standards.

  (a) A production-weighted standard requiring every manufacturer to improve average fuel economy by the same percentage would require larger absolute fuel economy gains on already efficient cars while requiring only minor improvements on inefficient cars that have the greatest potential for fuel economy improvement.

  (b) A production-weighted standard establishing one uniform specific fuel economy average for all manufacturers would, if sufficiently stringent to have the needed effect, have the heaviest impact on manufacturers who now have lower fuel economy and would not require manufacturers of vehicles that currently have good fuel economy to maintain or improve these vehicles' performance.

  (c) Production-weighted standards specifically tailored to each manufacturer would eliminate some inequities of (a) and (b) above, but they would be difficult to administer fairly.

(d) Establishing standards on the basis of vehicle class would induce technological advances for all vehicles while allowing maximum consumer choice. Class standards would not necessarily ensure attainment of an over-all fuel economy goal because of the possibility of increased sales of larger (although improved) models.

(e) Two types of tax strategies were considered. The first is a tax placed on new vehicles, the second an annual assessment on each vehicle. Both would depend on the fuel economy of the vehicle. Although such taxes allow for a high degree of consumer choice and producer flexibility, they rank below standards for ensuring achievement of a fuel economy goal because knowledge of their impact is lacking. In addition, the amount of tax necessary to produce the desired effect may be inordinately high, inasmuch as the present difference in price and operating cost of high- and low-fuel-economy cars is already large.

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