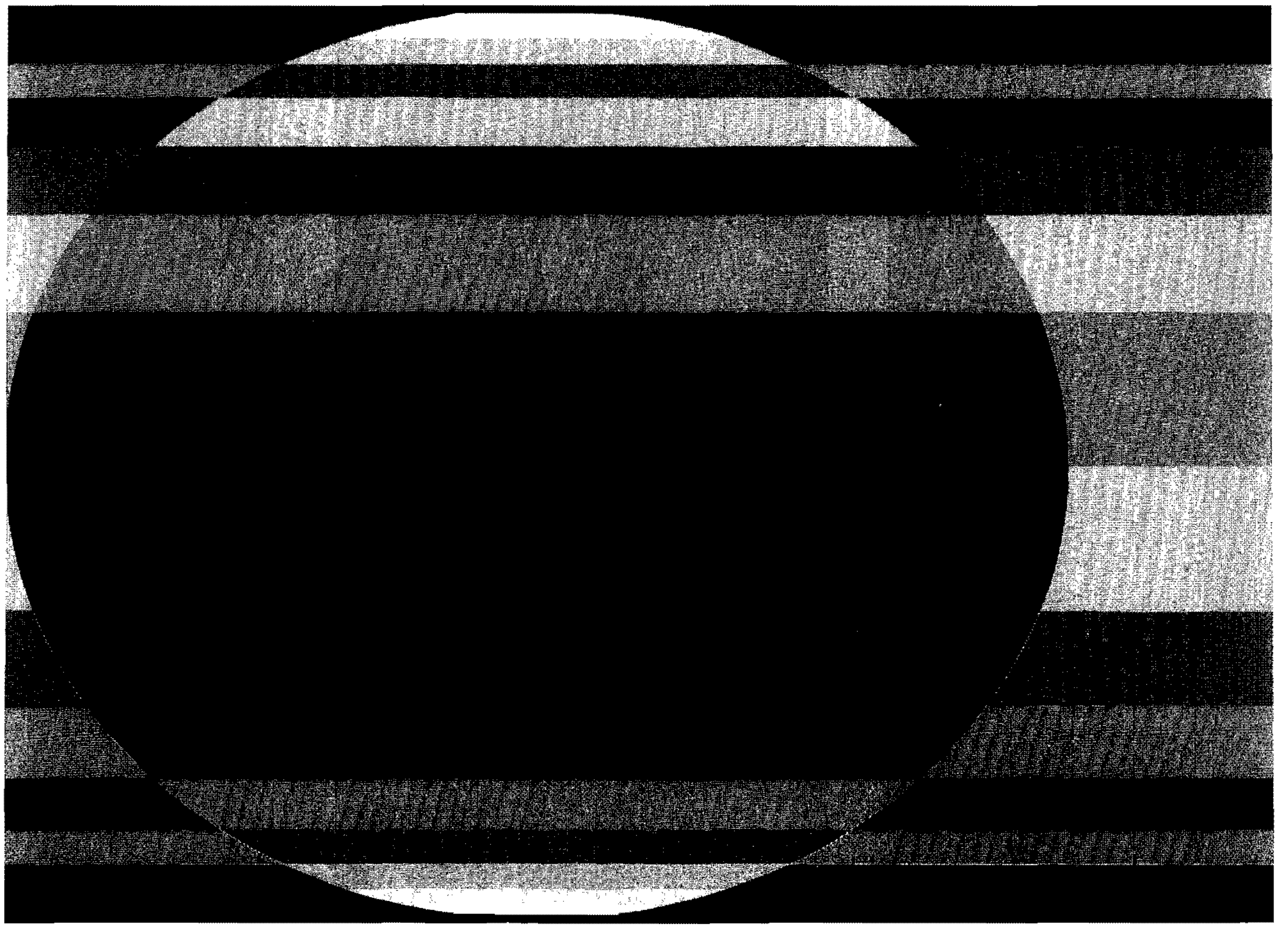
BACKGROUND PAPER

Urban Transportation and Energy: The Potential Savings of Different Modes

December 1977



Congress of the United States
Congressional Budget Office

URBAN TRANSPORTATION AND ENERGY: THE POTENTIAL SAVINGS OF DIFFERENT MODES

The Congress of the United States
Congressional Budget Office

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NOTE

Urban Transportation and Energy was initially issued in September 1977 as a publication of the Senate Committee on Environment and Public Works. The study was prepared at the request of Chairman Lloyd Bentsen of the Senate Subcommittee on Transportation. This reissue, by the Congressional Budget Office, has been undertaken with the authorization of the Committee.

December 1977

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United States Senate
COMMITTEE ON ENVIRONMENT AND PUBLIC WORKS
WASHINGTON, D.C. 20510

September 26, 1977

The Honorable Jennings Randolph
Chairman
Senate Committee on Environment and
Public Works
Dirksen Senate Office Building
Suite 4200
Washington, D.C. 20510

Dear Mr. Chairman:

As we approach the development of new highway and transportation legislation, the Committee will have to take into account the major energy questions which accompany such legislation. More than 50 percent of our petroleum is used in transportation, and it is imperative that National legislation encourage energy efficiency in this field insofar as practicable.

I have asked the Congressional Budget Office to prepare the following study for the Committee's use during upcoming hearings on the highway bill. I believe the information contained in the report will be useful to us as we make decisions on the financing of future transportation, the share of urban highway funds to be devoted to transit, and the modes of transit that could promote our energy goals. This report follows in the tradition of Committee hearings in the past that have examined transportation and the new energy policies following the Arab boycott of 1973, and the series of hearings on urban transportation that we held across the country in 1974.

I believe that Members of the Committee and the public as a whole will benefit from reviewing the report, which contains several conclusions that challenge conventional wisdom in this area.

Sincerely,

Lloyd Bentsen

Lloyd Bentsen
Chairman
Senate Subcommittee on Transportation
Senate Committee on Environment and Public Works

PREFACE

In the ongoing Congressional debate over a national energy plan, urban transportation is often cited as an area that could yield large fuel savings. Policy concerning urban transportation is likely to play an increasing role in the energy debate, particularly next year, when the 95th Congress will consider important mass transit and highway legislation.

At the request of the Subcommittee on Transportation of the Senate Committee on Environment and Public Works, the Congressional Budget Office has prepared this study of the potential for energy conservation in urban transportation. Urban Transportation and Energy includes analyses of the energy used by a variety of urban modes of travel. Since transportation operates under different circumstances in different cities, a range of estimates of the energy used by each mode is given. In keeping with the Congressional Budget Office's mandate to provide objective analysis of issues before the Congress, this report offers no recommendations.

The authors of the paper are Damian J. Kulash, Richard R. Mudge, and Daniel Prywes of CBO's Natural Resources and Commerce Division. For valuable comments and criticism, the authors are grateful to Patrick McCann and Robert Sunshine of CBO, Margaret F. Fels of Princeton University, and Ronald Kirby of the Urban Institute. Robert. L. Faherty and Johanna Zacharias edited the manuscript and Laurie L. Dye prepared it for publication.

Alice M. Rivlin
Director

September 1977

TABLE OF CONTENTS

Page

Preface V

Summary XIII

  Glossary XIX

Chapter I. Introduction 1

  Transportation Policy: Limits to Its Impact on Energy Consumption. 2
  Energy Intensiveness: A Useful but Sometimes Misleading Measure 4

Chapter II. A Framework for Evaluating Energy Savings from Urban Transportation 7

  Energy Intensiveness 9
  Line-Haul Energy 9
  Modal Energy 10
  Program Energy 12

Chapter III. Urban Transportation Energy Use: A Review of the Existing Evidence 13

Chapter IV. Representative Energy Requirements by Mode 31

  Summary of Quantitative Estimates. 31
  Description of Results 38

Chapter V. Conclusion. 41

Appendix A. Available Estimates of Urban Energy Consumption by Mode of Transportation and Type of Energy. 53

Appendix B. High and Low Values for Energy Framework 73

Appendix C. Details of Computational Procedures 79

LIST OF TEXT TABLES

Page

1. Estimates of Vehicle Propulsion Energy for Urban Transportation Modes 15

2. Estimates of Vehicle Occupancy for Urban Transportation Modes 20

3. Estimates of Maintenance and Station Energy for Urban Transportation Modes 23

4. Estimates of Guideway Construction Energy per Guideway-Mile for Urban Transportation Modes 25

5. Estimates of Guideway Construction Energy per Vehicle-Mile for Urban Transportation Modes. 25

6. Estimates of Vehicle Manufacturing Energy for Urban Transportation Modes 28

7. Middle Estimates of Basic Components of Operating Energy Intensiveness and Line-Haul Energy by Urban Transportation Modes 33

8. Middle Estimates of Access, Circuity, and Source of New Patronage by Urban Transportation Modes 34

9. Middle Estimates for Various Measures of Energy Requirements by Urban Transportation Modes 35

10. Low Estimates for Various Measures of Energy Requirements by Urban Transportation Modes 36

11. High Estimates for Various Measures of Energy Requirements by Urban Transportation Modes 37

LIST OF APPENDIX TABLES

Page

A-1. Various Estimates of Vehicle Propulsion Energy per Guideway-Mile for Urban Transportation Modes . . 55

A-2. Various Estimates of Vehicle Occupancy for Urban Transportation Modes 58

A-3. Various Estimates of Maintenance and Station Energy for Urban Transportation Modes 62

A-4. Various Estimates of Guideway Construction Energy per Guideway-Mile for Urban Transportation Modes . . 65

A-5. Various Estimates of Vehicle Manufacturing Energy for Urban Transportation Modes 66

A-6. Various Estimates of Vehicle and Guideway Lifespans for Urban Transportation Modes in Vehicle-Miles. 67

A-7. Various Estimates of Mode of Access to Line-Haul Trip 68

A-8. Source of New Patrons of Urban Transportation Modes by percent from Various Former Modes 69

B-1. Low Estimates of Basic Components of Operating Energy Intensiveness and Line-Haul Energy by Urban Transportation Modes 75

B-2. High Estimates of Basic Components of Operating Energy Intensiveness and Line-Haul Energy by Urban Transportation Modes 76

B-3. Low Estimates of Access, Circuity, and Source of New Patronage by Urban Transportation Modes . . . 77

B-4. High Estimates of Access, Circuity, and Source of New Patronage by Urban Transportation Modes . . . 78

SUMMARY

Transportation in cities consumes about one-fourth of the nation's petroleum--or about 10 percent of all its energy-producing fuel. Thus, large energy savings that potentially could be achieved through shifts in urban transportation policy have generated considerable interest in the Congress and elsewhere. This paper has two principal objectives: to describe the energy requirements of alternative urban transport technologies, and to assess the effects on urban transport fuel consumption of various programs the Congress might consider in order to save fuel.

FRAMEWORK

Most existing analyses of energy savings have focused only on the energy used to run transportation services. This is a very limited and often misleading measure of overall energy needs, however. The amounts of energy used in manufacturing vehicles, building right-of-ways (roads, rails, and so forth), and maintaining systems must be examined if an analysis is to be comprehensive. And such various uses of energy have to be weighed against one another. For example, differences in the energy needed to construct roadbeds or manufacture vehicles may offset the apparent gains in operating energy.

Furthermore, the ways people adapt to a new transportation system are as influential in determining how much energy can be saved as are the system's inherent technological features. New or changed service can stimulate more trips, prompt travelers to give up one mode of transportation for another, or change the average number of people a vehicle carries per trip. Buses, subways, trolleys, carpools, and vanpools (see the glossary overleaf) use relatively little energy for each passenger-mile of travel; but if improvements in any one of these services draw passengers from other energy-efficient modes, instead of from automobiles (which, on the average, carry fewer than two people), then the effect on energy can be small-possibly even wasteful.

Much of the travel on public transportation depends on private automobiles for access to stations. Combined automobile/transit trips are usually less direct than those made by auto alone. Hence a two-mode trip may yield little energy savings or none at all. In addition, new transit service usually encourages more trips than were made before. These trips in turn increase energy consumption and decrease the energy saving likely from a new transit program, no matter how energy-efficient it is.

Over a long period, changes to any mode of transportation can lead to changes in where people live, work, and shop. Such shifts in location are well known to be difficult to analyze because of the numerous other influences that enter decisions about where people settle. Of necessity, it is assumed in the analysis presented here that homes, jobs, and businesses do not move because of the changes in transportation programs that are being analyzed.

This analysis presents several measures of energy use, ranging from a narrow index of propulsion needs to a broad index of program energy savings. As computations of energy requirements become more broadly based, their scope expands to include consideration of the energy needed to build roadways and track, the energy needed to manufacture and maintain vehicles, the energy used to heat and light stations, the energy used to drive to stations, the directness of alternative modes of travel, and the energy implicit in travel patterns prior to changes in public transportation policy. Probably no city is "average" in all these respects, but focusing on typical conditions appears to be the best way to make the comparative evaluations that will inevitably be made.

TYPICAL ENERGY REQUIREMENTS BY MODE

In order to estimate the energy needs and conservation potential of each mode, typical values are selected for each of the major components of energy use. Two steps have been taken to ensure that the values selected are as representative as is reasonably possible:

- A comprehensive review was made of available estimates of urban transportation energy use, including both theoretical and applied studies; and,
- In all cases, three sets of estimates are generated--high, low, and middle. The middle set combines what are judged to be the most representative values at each stage.

The table that follows shows the energy requirements by mode according to three different summary measures of energy use. The measure in the first column refers to propulsion energy alone, while the measure in the final column shows the energy saved (or lost) for

MIDDLE ESTIMATES FOR VARIOUS MEASURES OF ENERGY REQUIRED BY URBAN TRANSPORTATION MODES: ALL MEASURES EXPRESSED IN BRITISH THERMAL UNITS (BTUs) PER PASSENGER-MILE

Mode	Operating Energy a/	Modal Energy b/	Program Energy c/
Single-Occupant Automobile	11,000	14,220	N/A
Average Automobile	7,860	10,160	N/A
Carpool	3,670	5,450	4,890
Vanpool	1,560	2,420	7,720
Dial-a-Ride	9,690	17,230	(12,350)
Heavy Rail Transit (Old)	2,540	3,990	N/A
Heavy Rail Transit (New)	3,570	6,580	(980)
Commuter Rail	2,625	5,020	970
Light Rail Transit	3,750	5,060	30
Bus	2,610	3,070	3,590 d/

N/A = Not Applicable.

a/ Propulsion only.

b/ All forms of energy, computed on a door-to-door basis, adjusted for roundabout journeys.

c/ Energy saved (lost) per passenger-mile of travel induced by new programs.

d/ For new express bus service. Regular urban bus service would show smaller savings.

each passenger-mile of travel attracted to that mode by new transport programs. The measure in the center column represents the typical energy requirements per mile computed from door to door. It allows for the fact that transit trips often use cars or feeder buses for part of the journey, it reflects the fact that some modes require more roundabout journeys than others, and it includes the energy needed to build and maintain road, track, and equipment. Energy that is expended only once (for example, energy used in constructing roadways) is converted to a per-mile requirement using the expected number of vehicle miles produced by a facility throughout its life.

Vanpool performs best on all measures, while dial-a-ride is the worst. Bus and carpool also show up consistently well, only slightly behind vanpool in expected energy savings. Heavy rail appears to be efficient in terms of its operating-energy requirements. With getting to and from stations and the roundaboutness of travel considered, however, rail transit drops considerably in the ranking. This is particularly true of commuter rail and the new, suburb-oriented heavy rail systems because many passengers drive to the rail line and because the very presence of the system stimulates additional travel. Old heavy rail transit also shows up as one of the most efficient modes even after these factors are considered. This is largely because of the dense concentrations of jobs and shops that characterize the areas that now have these systems. Dial-a-ride is particularly inefficient in its use of energy, largely because vehicles in dial-a-ride services are rarely loaded to capacity, because many of the miles that passengers travel on them are nonproductive detours, and because much of their travel is without any passengers on board.

Comparing the low, middle, and high estimates of these energy indexes shows little shift in the ranking of the modes: vanpools always appear to be the most energy efficient and dial-a-ride the least, with the other modes spread between them. Even under the most optimistic assumptions, new heavy rail systems show smaller expected energy savings than do the two most efficient modes under the middle estimates (vanpool and carpool and comparable savings to bus).

POLICY IMPLICATIONS

Any conclusions about the energy efficiency of transportation modes, or about the conservation potential of transportation programs, must be viewed as rules with numerous exceptions. Nevertheless, the rules that emerge from examination of existing technical information differ sharply from the rules that seem to be commonly held, and they are worth noting even if they are not universally true.

Vanpool. Vanpools can produce large fuel savings in special circumstances, although these circumstances apply to only a small segment of the overall travel market. Vanpool operations require little or no public financial support, and it does not appear that increased federal spending would be appropriate to spread the application of this energy-efficient mode. Currently, state and federal regulations inhibit the expansion of vanpools, and these could be removed by the Congress if it chooses to encourage this mode of transportation. In particular, the exemption from Interstate Commerce Commission and state regulation contained in the proposed National Energy Act could be extended to apply to nonfederal vanpooling without damaging existing public transportation services.

Carpool. A typical mile of travel diverted to carpools saves more energy than does diversion to any mode other than vanpools. Unlike vanpools, for which the potential market is very small, carpools could be used for a large share of all commuter travel. It is not clear, however, to what extent additional public spending can increase carpooling.

Bus. Of the conventional urban public transportation modes (subway, trolley, and bus), bus appears to offer the greatest fuel savings. Although its operating-energy intensity is typically only slightly better than other modes of public transportation its access requirements and route coverage are generally such that, all things considered, bus requires only about half the energy of new rail or trolley systems. Furthermore, because express bus service can be designed to draw heavily from segments of the market that are now largely automobile-oriented, the energy savings of programs that promote new bus service are probably greater than programs aimed at any other public transportation modes.

Some innovative services have shown that additional bus services can be operated at little or no expense to the public. The growth of new bus services that are tailored to the needs of special groups of travelers appear to be limited by local regulations that protect existing operators and by the concerns of labor. If the Congress wishes to provide financial assistance to promote this sort of service, its efforts would best be placed, not in massive expansion of existing capital or operating subsidy programs, but in programs that provide job security while relaxing local regulations.

Giving buses (along with carpools, vanpools, and other energy-efficient modes) priority in traffic by means of special traffic signaling or exclusive right-of-ways could greatly enhance the attractiveness and patronage of bus service. A more aggresive federal program in the area of acquisition and construction of exclusive right-of-ways promises to be a productive way to encourage this kind of service. Such a program could be broadly interpreted to include relocating on-street parking to off-street, which would yield additional capacity from existing facilities, and constructing bridges, by-passes, and other facilities to enhance the movement of high-occupancy vehicles. Additional incentives could be provided if separate federal operating assistance over and above the present operating aid program were available for those specific projects with relatively high energy-saving potential.

Automobiles. Automobiles require about twice as much energy per mile as do new rail rapid transit systems, and continued growth in automobile travel is clearly in conflict with fuel conservation goals. The gap between automobile energy requirements and those of other modes will shrink, however, as the fuel economy standards for new cars set out in the Energy Policy and Conservation Act and the additional automotive fuel economy measures now being considered by the Congress start to increase the average fuel economy of the nation's auto fleet. The relative advantage that other modes offer in terms of fuel savings will thus be eroded.

Heavy rail transit. Of all the commonly held notions about energy efficiency, probably the most misguided are those concerning rapid rail transit. The findings of this study indicate that, under typical conditions, new rapid rail systems actually waste energy rather than save it. This surprising finding appears to conflict with the fact that, in terms of propulsion energy per passenger-mile, rail ranks among the most energy-efficient modes. But when such factors as construction energy, the energy used to get to and from stations, and the roundaboutness rail travel involves are considered, the energy per passenger-mile computed from door-to-door for rail rapid transit is greater than that for any other public mode except dial-a-ride. A principal reason for this poor performance is that private cars, typically with only one or two passengers, are commonly used to get to new rapid transit stations. Admittedly, exceptions to the general patterns that underpin these estimates are probably easy to find. Slightly varied judgments about just what typical conditions are could lead to revised computations in which the energy impact of rapid rail transit appears somewhat favorable. But, even though one can argue about the precise value of each factor bearing on the potential energy savings of this mode, an examination of these savings under ideal conditions shows that such considerations do not change the substantive conclusion that rail rapid transit offers little aid to the nation's efforts to save fuel.

GLOSSARY

A comparative evaluation of the energy efficiencies of various means of transportation involves distinguishing among many modes that are available today or under consideration. For clarity, terms that may be unfamiliar to some readers are described as follows:

Carpool: A group of people who voluntarily band together to use one automobile to get to and from work.

Commuter Rail: A rail system usually used to carry people between suburbs and cities, mostly to and from work. Most commuter rail systems today use heavy rail technology and operate over track owned by intercity railroad companies.

Dial-A-Ride: A public service similar to a call cab except that dial-a-ride services attempt to combine individual trips into as few vehicle journeys as possible. Unlike most taxicab services, dial-a-ride may take you on detours to pick up or drop off other passengers.

Fixed Rail Transit: Any system with vehicles that must follow routes along which rails are installed. Both heavy and light rail as well as commuter rail fall into this category.

Heavy Rail Transit: Rail systems such as the Bay Area Rapid Transit (BART) in San Francisco or the METRO in Washington, D.C. These are examples of what the paper refers to as "new" heavy rail systems built during the last decade. "Old" systems, such as those in New York City, Boston, and Chicago, generally started operation at least 50 years ago.

Light Rail Transit: Trolleys are the best example. Light rail systems use smaller cars than heavy rail, have fewer cars per train, and may share a roadway with other wheeled vehicles.

Vanpool: A large carpool, typically riding in a van or miniature bus. The vehicles used in this service are usually furnished by, or rented from, an employer; the riders are workers who live in the same general area.

CHAPTER I. INTRODUCTION

Transportation is the primary user of the nation's energy, accounting for 60 percent of petroleum consumption and 25 percent of total energy consumption. [1] Ironically, however, from the standpoint of costs, energy is not of primary importance to transportation. Less than 20 percent of the costs of owning and operating a car are traceable to gasoline, [2] and less than 5 percent of the costs of urban public transportation are related to fuel. [3] Thus, from the vantage point of the provider of transportation service, costs other than fuel costs (for example, the costs of purchasing the vehicle, labor costs, and repair costs) tend to be largest; fuel costs take a position of secondary importance.

In public decisions, just as in private decisions, the issue of conservation of transportation energy is intertwined with numerous, often competing issues. No reasonable transportation policy could be based on energy alone, and, other issues will continue to dominate transportation policymaking. [4]

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[1] Federal Energy Administration, Project Independence and Energy Conservation: Transportation Sectors, vol. 2 (November 1974).

[2] Federal Highway Administration, "Costs of Owning and Operating an Automobile 1976" (1977).

[3] Jack Faucett Associates, "Inflation and the Transportation Sector: Trends, Problems, and Opportunities for Improvement," Report submitted to the Office of the Secretary, U.S. Department of Transportation (October 1974).

[4] For a somewhat broader discussion of federal urban mass transportation policy, see Congressional Budget Office, Urban Mass Transportation: Options for Federal Assistance, Budget Issue Paper (February 1977).

The aim of this paper is twofold:

- To describe, as objectively and completely as possible, the energy requirements of alternative urban transportation technologies; and
- To assess the effects on urban transportation fuel consumption of various steps that the federal government might consider to save fuel.

These objectives require looking beyond the technology itself and focusing on how technologies--and programs--actually function. All too often discussions of transportation choices center upon the capacity, efficiency, or environmental aspects of some technology under ideal conditions, only to encounter later on field conditions that lead to drastically different outcomes--outcomes that, if known in time, might have led to different choices.

The paper does not attempt to describe the other issues--environmental, developmental, fiscal, jurisdictional, and so forth--that are of critical importance to sound urban transportation policy. Its aim is limited to examining the effects on energy consumption of various transportation technologies and programs so that energy issues can be realistically weighed within the broader transportation policy-making context.

TRANSPORTATION POLICY: LIMITS TO ITS IMPACT ON ENERGY CONSUMPTION

Clearly, one can envision cities and transportation systems that are very much more energy efficient than those of today. Dense concentrations of housing, employment, shopping, and recreational facilities linked by high-capacity, energy-efficient public transportation could encourage urban life-styles that required very little transportation energy per resident.

Recent urban and suburban development has not gone in this direction, however. Between 1960 and 1970, the population of metropolitan areas grew by 17 percent, but most of this growth was in the relatively sparsely settled suburbs: central city population increased by only 7 percent, while areas outside the central city grew by 26 percent. Since 1970, the pattern has been even more extreme. Between 1970 and 1973, central cities within metropolitan areas lost 1 percent of their population, while areas outside the central city gained 6 percent. 5/ These statistics suggest that the nation's metropolitan areas are becoming more dispersed, not more concentrated. As this happens, longer trips become necessary to get people to work, to stores, and elsewhere. Dispersed residential patterns are extremely costly to serve with convenient forms of public transportation.

Today's housing and activity patterns are far from the optimum as far as transportation energy requirements are concerned. These patterns reflect a broad range of underlying forces such as lower costs for land in suburban fringes; a preference for single-family housing and open space; the availability of roads, cars, and fuel; and many other social and economic trends that have shaped modern life-styles.

The role of public transportation has been profoundly changed by these same forces. Other than a temporary surge in the use of public transportation related to economic conditions and availability of private automobiles during World War II, patronage of public transportation has been eroding since the 1930s. Many explanations have been proposed for this decline. Among the reasons most often cited are extensive highway construction; inexpensive mass-produced automobiles; rising transit fares; neglect of urban problems; cost differences between city and suburbs for housing, office, and retail space; inadequate investment in public transportation; and various other economic or developmental forces. Regardless of exactly why the nation's metropolitan areas developed as they did, there is little disagreement that the underlying forces are still active, continuing even now to mold the future of the nation's metropolitan areas.

Furthermore, much of the metropolitan growth pattern developed around widespread automobile use and is now critically dependent upon it. Attempting to nudge the country away from its current course of development means counteracting strong, deeply entrenched tastes and policies. And attempting to reverse the process--to get people to change where they live and to travel in more energy-efficient ways--is an extraordinarily difficult and complex task in which transportation changes play only a minor part, albeit a necessary part.

5/ U.S. Bureau of the Census, U.S. Census of the Population; 1960 and 1970, and Current Population Reports, Series P-25.

If, indeed, the current developmental process is ever to be reversed toward more concentrated (and planned) urban development, sweeping changes must occur in both public policy and private consumption patterns. Private decisions concerning housing sites, business locations, automobile ownership, and the like would have to be shaken from their established course; and public decisions about zoning, provision of public services, and pricing of services would have to be redirected dramatically. Many of the aspects of life affected by these public decisions are held as basic rights: for example, flexibility in zoning decisions, freedom to travel easily and economically, and the ability to choose one's desired type of housing. If public policy is to play a significant role in reshaping urban life-styles in more energy-efficient ways, acceptable ways must be found to harness and redirect the behavioral and organizational forces that have led to today's metropolitan areas.

Although transportation and land-use policy are necessarily tied together in the long run, this paper focuses on the energy impacts of transportation policy alone; that is, it is assumed that shifts in metropolitan development will not occur because of the variations in transportation policy considered here. This assumption is likely restrictive, but the evidence on how transportation policy affects land use is so fragmentary and inconclusive that little additional insight would be gained by relaxing the assumption. Nevertheless, evaluation of urban transportation energy can extend far beyond consideration of propulsion energy alone.

ENERGY INTENSIVENESS: A USEFUL BUT SOMETIMES MISLEADING MEASURE

The amount of fuel consumed in transporting people and goods has been a major concern to everyone interested in conserving energy. To explore potential gains in transport energy efficiency, considerable attention has been given to the technology of the vehicles themselves. By and large, these vehicles move either people or goods, and their technology is well known and easily observed. They may easily be characterized in terms of the energy that each requires to produce a person-mile (or, alternatively, a ton-mile) of transportation. Measures that describe the energy required per passenger-mile are usually referred to as the "energy intensiveness" of a transportation vehicle. When the measures are averaged for an entire system, they are referred to as the energy intensiveness of the mode.

Energy intensiveness measures have, for good or ill, become a focal point for discussions of conservation of transport energy. They are simple in concept, easy to compute and to understand, based on readily available information, and convenient for comparing vehicles or modes. Because of these virtues, energy intensiveness measures have gained considerable exposure as the nation explores ways to save energy. These measures, however, also have severe shortcomings that limit their usefulness. The "typical" vehicle is a statistical average and is thus an abstraction that brushes aside differences in design, age, operating conditions, and load among vehicles, effectively assuming that all vehicles in a class are identical in these respects.

For purposes of energy policy, statistical abstractions can be enormously misleading because differences in a particular vehicle's characteristics and use can make the energy intensiveness of that vehicle differ sharply from the modal average. Thus, although buses are, on average, unquestionably more energy-efficient than automobiles, a five-person carpool can be less energy-intensive than an average bus, and a single-passenger subcompact automobile can be less energy-intensive than a lightly loaded bus, such as those frequently found in late night service. Differences in vehicle speed, roadway condition, and vehicle design also influence energy intensiveness. None of these characteristics, however, interjects the dramatic changes--measured in the hundreds, and sometimes in the thousands, of percents--that variations in vehicle loads create within measures of fuel intensiveness.

Most of the above discussion concerns the fact that energy intensiveness measures are averages. As such, they over-simplify and occasionally mislead. Within the context of weighing alternative conservation programs, however, intensiveness measures have a much more serious shortcoming: they tell only part of the story--the part that has to do with energy used in operating vehicles per unit of travel. What they ignore is that public programs to conserve fuel may change the amount and composition of travel as well as the energy intensiveness of specific modes. In particular, public programs destined to promote the use of energy-efficient modes are likely to alter:

- The number of trips that are made,
- The number of persons per vehicle,
- The miles traveled for these trips, and
- The travel modes selected.

These associated changes may undermine the primary intent of the program. For example, a series of incentives to promote carpooling could increase the nation's energy consumption if the riders it attracts come mostly from buses and vanpools. A rapid rail system could increase the energy consumed if users make circuitous automobile trips to reach stations with adequate parking. Similarly, improvements to bus service (for example, frequent schedules, uncrowded vehicles) that are intended to increase patronage of public transportation could increase energy use since uncrowded buses are more energy-intensive than fully loaded buses. Although the above illustrations are not necessarily typical, the problem they point to is very real: the simple application of energy intensiveness measures can be very misleading. In evaluating alternative policies for conserving energy in transportation, the extent to which policies reshape total travel and the way in which they alter patronage, vehicle loads, and trip length on each mode are critical considerations that must be weighed along with energy intensiveness per se.

Another danger implicit in focusing exclusively on energy intensiveness measures is that they ignore the energy required to build and maintain transportation facilities and vehicles. Differences in the energy needed to construct or manufacture alternative transportation systems can be considerable, and these differences may offset or reinforce the apparent gains in operating energy.

In short, while energy intensiveness is a convenient yardstick for comparing the average fuel efficiency of existing transportation vehicles, it provides little help in examining the effects on fuel consumption of new programs. To overcome the shortcomings of energy intensiveness measures, a broader framework for evaluating transportation energy savings will be outlined.

CHAPTER II. A FRAMEWORK FOR EVALUATING ENERGY SAVINGS FROM URBAN TRANSPORTATION

Moving people around in urban areas consumes about one-fourth of the nation's petroleum--or about 10 percent of all its energy-producing fuel. 1/ In addition to this energy that goes into powering transport vehicles, energy is required to manufacture vehicles; to construct roadbeds, track, and pavement; to light, heat, and cool stations used by passengers; and to maintain vehicles and right-of-ways. When these other requirements are spread over the lifetime of the facilities and allocated on a passenger-mile basis, the amount of energy used in propulsion is usually larger than these nonpropulsion demands. Nevertheless, nonpropulsion energy requirements are substantial, and ignoring them can lead to erroneous conclusions about the overall energy requirements of various modes.

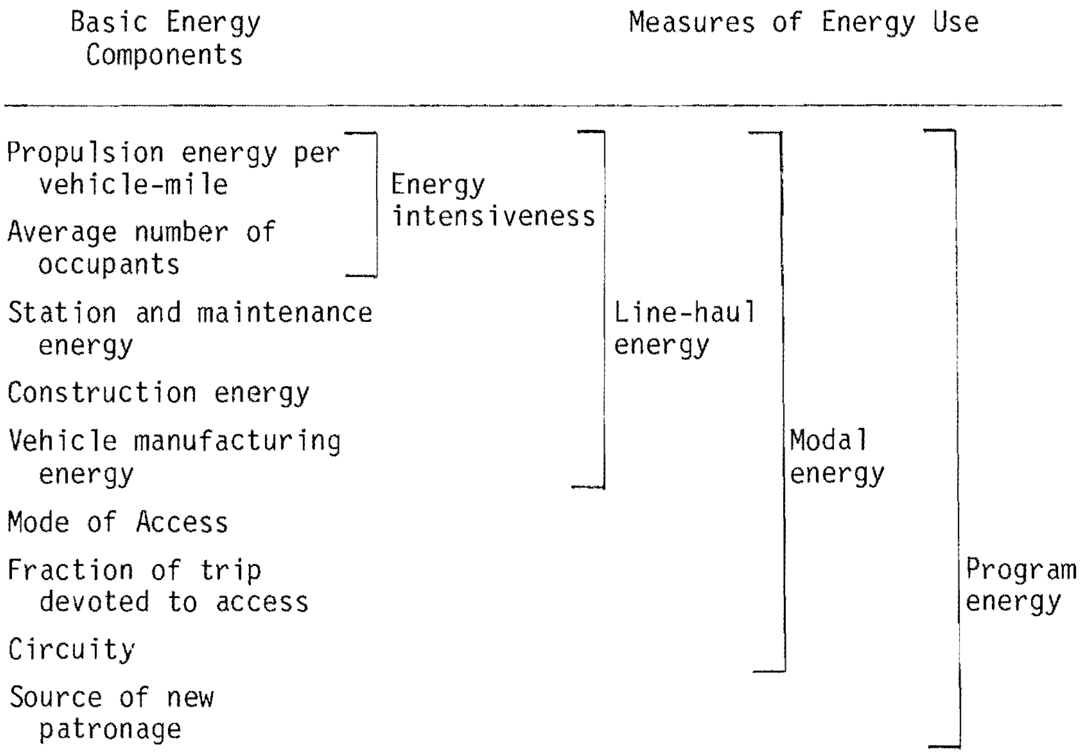
The energy savings of changes in urban transportation systems depend on behavioral responses such as increases in the number of trips made, shifts from other modes of travel, changes in vehicle occupancy, and the like. Bus, subway, trolley, carpool, and vanpool tend to be energy efficient on a passenger-mile basis, but if improvements in any one of these services draws passengers from other energy-efficient modes instead of from low-occupancy automobiles, then the effect on energy can be small and possibly wasteful.

Other factors to be considered in evaluating energy requirements are, first, getting to and from public transportation services and, second, the directness of such travel on a door-to-door basis. Fixed-route services are not as ubiquitous as automobile service, and much of the travel on fixed-route services depends on private automobiles for access to stations. As a result, the net energy savings of a trip that uses transit as opposed to a trip by private automobile is significantly smaller than appears from a glance at just the transit portion of the trip.

1/ Federal Energy Administration, Project Independence and Energy Conservation: Transportation Sectors, vol. 2 (November 1974).

In short, although some quick rules-of-thumb can be obtained from the conventional index of energy intensiveness (computed by dividing the propulsion energy per vehicle mile by the average number of people aboard the vehicle), a full review of energy savings requires examination of the energy used in manufacturing vehicles, constructing right-of-ways, and maintaining the system; adjustments for access and circuity; and allowance for the previous mode of travel of new users.

In an effort to reflect these broader factors, this paper delineates nine basic energy components of urban transportation. These nine components are combined to form a hierarchy of four measures of energy use, in which each measure has an increasing level of comprehensiveness. The four levels are energy intensiveness, line-haul energy, modal energy, and program energy. This framework for evaluating the energy savings of urban transportation can be depicted as follows:



The most comprehensive of the four measures--that is, program energy--combines the direct and indirect energy use of transit modes and adjusts for the behavioral response of travelers to arrive at the total change in energy consumption per passenger-mile that is likely to result from policies that promote the use of a particular mode of transportation. The steps required to estimate program energy are described separately in the remainder of this chapter.

ENERGY INTENSIVENESS

This is the most commonly used measure of energy use because the required data are relatively common. It is also, however, the most limited measure because it includes only the energy required to move the vehicle.

Propulsion energy per vehicle-mile. The miles per gallon (or per kilowatt-hour) that a vehicle can achieve has been widely used to describe vehicular fuel economy. Although the attempt to describe the "typical" vehicle can prove difficult, the problem is principally because of the variety of vehicles and operating conditions that exist, not because of the ability to define and measure this characteristic.

Average number of occupants. Since vehicle propulsion energy tends to be greater for high-capacity vehicles than for low-capacity ones, some adjustment for vehicle load is essential in order to compare modal energy efficiency. Seating capacity is sometimes used for this purpose, but since few automobiles, buses, or other vehicles are loaded to capacity over the course of a day, seating capacity is a poor index of passengers actually carried. Even though the average number of persons aboard the vehicle is highly variable, this is the best measure to use in reducing energy requirements from a vehicle-mile basis to a passenger-mile basis.

Computation of energy intensiveness. Using the vehicle propulsion energy per vehicle-mile and the average load, it is possible to compute the so-called energy intensiveness of the vehicle--that is, the propulsion energy per passenger-mile. As noted above this widely used index of energy efficiency is too narrow a concept to use exclusively in evaluating the conservation potential of alternative policies.

LINE-HAUL ENERGY

This measure is more comprehensive than energy intensiveness since it includes the energy used to operate stations and maintain vehicles as well as the energy used to construct right-of-ways and manufacture vehicles. Propulsion energy is the largest single component of line-haul energy, with station and maintenance energy usually second.

Station and maintenance energy. The energy used to operate stations and maintain vehicles and system facilities is small compared to propulsion energy. For many modes, however, it can be significant and should be included in making modal comparisons.

Construction energy. Huge quantities of energy are needed to dig tunnels, make and haul concrete, and perform the thousands of other tasks that go into building transportation facilities. Since construction energy is expended only once, it is generally not too important a factor when it is allocated over the many trips that use transportation facilities throughout their life. Nevertheless, the relative importance of construction energy varies by mode, and disregard of this factor can lead to erroneous conclusions about the relative energy efficiency of alternative modes.

Vehicle manufacturing energy. Like construction energy, vehicle manufacturing energy is spent once for a product that has a long life. The result is a relatively small expenditure per vehicle-mile. Vehicle manufacturing energy tends to be relatively small and of relatively minor importance in most comparisons of modal energy efficiency.

Computation of line-haul energy. Line-haul energy is computed by adding to propulsion energy the energy needed to operate stations and maintain vehicles and roadways, and the energy needed to construct facilities and to manufacture vehicles. Energy for construction and manufacturing is converted to a per-mile basis using the estimated life, in vehicle-miles, of roadways and vehicles, respectively. Computations are transformed to a passenger-mile basis by applying the average number of occupants used to compute energy intensiveness.

MODAL ENERGY

Combining the additional energy consumed in access and circuity with line-haul energy can sometimes result in dramatic shifts in relative modal energy efficiency. Many of the characteristics needed to estimate modal energy (for example, access distance and circuity) are highly variable and poorly documented. Nevertheless, a balanced view of overall modal use must take these factors into account.

Mode of access. Most short transit trips are made by walking to a bus stop (or transit station), riding to another stop, and then walking to a destination. Long transit trips frequently involve making a trip by automobile or feeder bus to reach the main part of the system. In such cases, the access mode often requires more energy per passenger-mile than the principal mode. Access energy requirements must be included along with line-haul energy requirements if a full picture of transport energy consumption is desired.

Fraction of trip devoted to access. In order to allocate access energy requirements to the principal mode, it is necessary to know what proportion of a typical trip is devoted to access. Given information on access energy per passenger-mile, this proportion (access miles/total miles) can be used to allocate access energy to the total trip energy.

Circuity. Since few passenger trips go directly "as the crow flies," some circuity is inevitable in passenger travel. 2/ In examining the energy efficiency of different modes, adjustments should be made for these additional, nonproductive miles of travel. Since many energy computations are made on a per-mile basis, a mode that requires nonproductive mileage would be given an unfair advantage in terms of its comparative energy efficiency if circuity were not taken into account.

Computation of modal energy. Modal energy combines line-haul energy with access energy requirements, and then adjusts the total for circuity. The computation involves three steps. First, the line-haul energy requirements of each access mode are multiplied by the fraction of trips that use the mode for access, and these products are summed to yield the average energy required per passenger-mile of access travel. Second, the average total energy (line-haul plus access) is computed, using as a weight the fraction of each trip that is access. Third, the average total energy is multiplied by the circuity to obtain an estimate of total energy

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2/ As used here, circuity refers to the door-to-door trip distance of a mode relative to the corresponding distance by automobile. Automobile is used as a base because it is generally the most direct form of urban passenger transportation.

required per productive mile of travel. This final result is referred to here as modal energy. 3/

PROGRAM ENERGY

As noted above, the energy savings of transportation programs cannot be inferred from the fuel efficiency of the vehicles used, although vehicular fuel economy is clearly a major consideration. Rather, the fuel savings of alternative urban transportation programs depends on how systems are operated and, more importantly, on how people use them relative to other existing systems.

Source of new patronage. Programs to promote energy-efficient urban transportation modes attempt to shift travelers from modes that are relatively inefficient in terms of energy to modes that are efficient. Usually, the goal is to get people out of their cars and onto public or group transportation of some sort. Experience with improvements in public transportation, however, shows that new systems also attract patrons from other public transportation services and carpools, as well as people who did not travel previously. In evaluating the changes in total energy consumption when a new program is introduced, a realistic comparison can be made only if previous travel modes are taken into account. A relatively energy-efficient mode can be energy-wasteful if it draws all of its patrons from an even more efficient mode.

Computation of program energy. Program energy savings are estimated by comparing the modal energy of some new transportation service with the modal energy of the old services from which the new patronage is drawn. Of particular interest are entirely new trips, since such trips were not made previously, and thus required no energy.

This section listed some of the principal technological, operational, and behavioral characteristics that must be considered in making a thorough evaluation of urban transportation energy savings. The next section will review available evidence relating to each of these characteristics.

3/ For further detail about the computation, refer to Appendix C.

CHAPTER III. URBAN TRANSPORTATION ENERGY USE: A REVIEW OF THE EXISTING EVIDENCE

This chapter reviews the range of numerical estimates for the nine basic energy components of the framework for evaluating urban transportation energy savings that was presented in Chapter II. These components are:

- Propulsion energy,
- Average number of occupants,
- Station and maintenance energy,
- Construction energy,
- Vehicle manufacturing energy,
- Access mode,
- Fraction of trip devoted to access,
- Circuity, and
- Source of new patronage.

The modes of urban transportation considered here are: automobile, carpool, vanpool, old heavy rail transit (subway), new heavy rail transit, commuter rail, light rail transit (trolley), bus, dial-a-ride, and taxi. Estimates are not available (or relevant) for some of the modes. Often the estimates cover a wide range. This chapter will review existing estimates and provide some perspective on their derivation; the following chapter will select typical values. Details on the sources of the estimates for each component are contained in a series of tables in Appendix A.

Throughout this paper the emphasis is on total energy consumption, without attempting to estimate which fuel is the primary resource. The ability to substitute different fuels is expected to improve in the future--as new technologies such as the electric automobile are developed. Also, the primary fuel source is not always obvious. For instance, much peak-hour electrical capacity is provided by turbines that burn petroleum-based products, so that what appear to be electrically powered transit systems may actually depend on petroleum.

Vehicle Propulsion Energy

The fundamental element of transportation energy consumption is vehicle propulsion energy, which is the amount of energy (in terms of primary fuel resources) needed to move a particular vehicle one mile. It is usually measured in British Thermal Units [1] (BTUs) per vehicle-mile, or in miles per gallon (of gasoline equivalents). Table 1 shows estimates of vehicle propulsion energy.

Defining the propulsion energy of electrically powered vehicles raises a problem because of the energy that is lost as fossil fuels are converted into electricity. Such conversion losses represent about two-thirds of the energy potentially available in the raw fuel; that is, the energy passed on as electricity is only about one-third of the total energy contained in the power plant's fuel. Power generators are unable to harness most of the energy potentially available in fuel and must waste much of this energy in the form of heat. In evaluating electrically powered transportation systems, it is appropriate to focus on their fossil fuel requirements rather than on the energy content of the electricity.

Automobile propulsion energy is influenced by two primary factors: vehicle design and operating conditions. The most important design characteristic affecting automobile fuel economy--and the propulsion energy of all modes--is vehicle weight. A 5,000-pound car burns approximately twice as much fuel as a 2,500-pound car (see Figure). Other design characteristics affecting automobile propulsion energy are acceleration performance, engine horsepower and displacement, aerodynamic drag, and amenities such as air conditioning, power steering, and automatic transmission. Some of these vehicle features have a substantial effect on fuel economy. Air conditioning, for instance, can increase automobile fuel consumption by as much as 20 percent.

Operating conditions influence automobile fuel economy in many ways. The grade, curvature, type of surface, and condition of roads can all be important. The important traffic characteristics affecting automobile fuel economy are operating speed, congestion, and phase of vehicle operation ("cold start" versus "warm start"). The most efficient speed for automobiles is between 30 and 45 miles per hour, but much urban travel occurs outside this range. Congestion, which results in frequent stops and starts, significantly impairs automobile fuel economy and is a major reason

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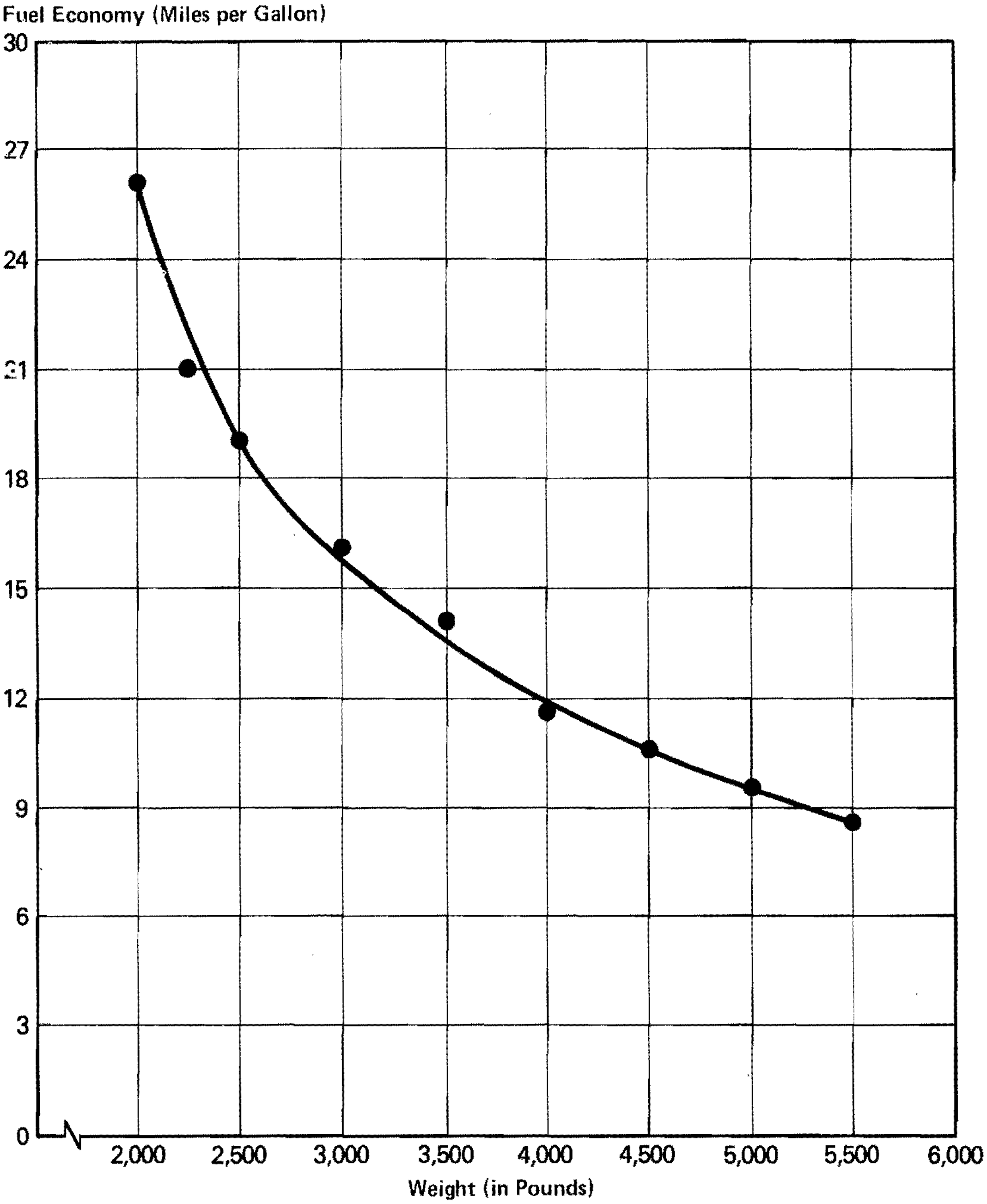
1/ One British Thermal Unit (BTU) is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit at about 39 degrees F. A gallon of gasoline is usually estimated to contain about 125,000 BTUs. See U.S. Department of Transportation, <u>Energy Impact Analysis Resource Information</u> (June 1976), p. iii.

TABLE 1. ESTIMATES OF VEHICLE PROPULSION ENERGY FOR URBAN TRANSPORTATION MODES

Mode	BTUs per Vehicle-Mile	Miles per Gallon
Automobile	10,400-11,100	11.3-12.0
Vanpool and Dial-a-Ride	13,900-17,900	7-9
Bus	26,100-32,900	3.8-4.8
Heavy Rail (New)	70,000-110,000	1.1-1.8
Heavy Rail (Old)	50,000-95,000	1.3-2.5
Light Rail	50,000-100,000	1.3-2.5
Commuter Rail	100,000-150,000	0.8-1.3
Automated Guideway Transit		
Personal Rapid Transit	4,000-20,000	6.2-31.3
Group Rapid Transit	8,100-30,000	4.2-15.4
Shuttle Loop Transit	11,000-24,000	5.3-11.4
Taxicab	12,500	10

SOURCE: Appendix Table A-1.

AUTOMOBILE FUEL ECONOMY AS A FUNCTION OF WEIGHT



SOURCE: Based on U.S. Environmental Protection Agency, Office of Air and Water Programs, "Fuel Economy and Emission Control," November 1972.

why automobiles use more fuel in city driving than on free-flowing highways. Cold, recently started engines have inefficient combustion because of a rich fuel-to-air ratio. As the engine warms up, combustion becomes more efficient and fuel is consumed less rapidly.

In composite terms, estimates of automobile fuel economy for urban travel lie between 11.3 and 12.0 miles per gallon for the 1973 fleet. Overall (city and highway) fuel economy decreased more than 10 percent between 1950 and 1973, but in recent years slight improvements have been made. 2/ Substantial further improvements in the fuel economy of new automobiles are likely, partly in response to provisions of the Energy Policy and Conservation Act of 1975 (EPCA). The EPCA calls for automobiles produced in 1978 to average 18 miles per gallon, with standards increasing to an average fuel economy of at least 27.5 miles per gallon in 1985. Cash penalties will be assessed on manufacturers who fail to meet these standards.

Factors influencing the fuel economy of urban buses are largely the same as those affecting automobiles. Heavy vehicle weight, high speeds, quick acceleration, and frequent stops all increase bus fuel consumption. The type of bus service directly affects the vehicle's energy efficiency; for example, express buses show greater efficiency than buses on local routes. Other characteristics, such as the type of fuel used (diesel or propane) affect fuel economy as well. Bus fuel economy typically ranges from 3.8 to 4.8 miles per gallon, and no major improvement is expected soon.

Vanpool and dial-a-ride systems use vehicles that may be described as small buses that seat from 8 to 12 passengers. The fuel economy of most vanpool and dial-a-ride systems averages 7 to 9 miles per gallon. Taxicabs, which are usually standard-sized cars (or larger), average about 10 miles per gallon.

The characteristics of rail systems are generally quite different from those of highway-based modes. Heavy rail transit vehicles weigh from 20 to 45 tons (compared to 10 tons for most buses and less than 2 tons for most automobiles), use electrically powered

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2/ U.S. Department of Transportation, Federal Highway Administration, Highway Statistics, annual.

motors, operate along fixed guideways with little congestion, and make numerous stops and starts at stations. Newer heavy rail systems--for example, the Bay Area Rapid Transit (BART) in San Francisco or the Lindenwold Line in Philadelphia--consume more energy for vehicle propulsion than older systems. The most efficient new system uses nearly twice as much energy for propulsion as the most efficient old system. 3/ Estimates of the propulsion energy required by rail transit systems vary widely. Generally, however, the estimates are between 70,000 and 110,000 BTUs per vehicle-mile (1.1 to 1.8 miles per gallon) for new systems, and between 50,000 and 95,000 BTUs per vehicle-mile (1.3-2.5 miles per gallon) for older systems.

Other rail modes used in urban areas are light rail (trolley) and commuter rail. Light rail vehicles vary in size, but they are often even heavier than rapid transit cars, have lower rates of acceleration and velocity, and can operate along tracks either on a separate right-of-way or in mixed traffic. Light rail energy consumption for propulsion ranges between 50,000 and 100,000 BTUs per vehicle-mile (1.3 to 2.5 miles per gallon), depending upon the particular system. Commuter rail systems use very heavy vehicles (the familiar railroad passenger cars which often weigh 90 tons) and operate along railroad right-of-ways. Variations in equipment and operating procedure among commuter rail systems lead to different propulsion energy characteristics with a range from 100,000 to 150,000 BTUs per vehicle-mile (0.8 to 1.3 miles per gallon).

Automated guideway transit systems--personal rapid transit, group rapid transit, and shuttle loop transit--are in early stages of development with few full-scale operations. 4/ Estimates of

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3/ American Public Transit Association, Transit Operating Report (1975).

4/ Automated guideway systems refer to a family of transit systems in which highly automated vehicles travel over a special guideway. Typically, each vehicle runs automatically, with no human operator. The major differences between automated guideways are vehicle size (ranging from automobile-sized vehicles for personal rapid transit to the equivalent of medium-sized buses for shuttle loop transit) and route complexity. Shuttle loop transit (now in use at some airports usually has a simple route in which the vehicle stops at every station, whereas personal and group rapid transit can have a complex network in which the vehicle goes directly to the traveler's desired destination.

propulsion energy consumption range from 4,000 to 20,000 BTUs per vehicle-mile (6.2 to 31.3 miles per gallon) for personal rapid transit; 8,100 to 30,000 BTUs per vehicle-mile (4.2 to 15.4 miles per gallon) for group rapid transit; and 11,000 to 24,000 BTUs per vehicle-mile (5.3 to 11.4 miles per gallon) for shuttle loop transit.

Vehicle Occupancy

Both the economic efficiency and the energy efficiency of transportation systems are profoundly influenced by vehicle occupancy. Vehicles used for urban transportation differ greatly by size and type of service provided. Consequently, there is great variance in occupancy levels among modes. Estimates of vehicle occupancy levels are summarized in Table 2.

Vehicle occupancy varies not only by mode but also by trip purpose, time of day, urban density, and cost. Most importantly, vehicle occupancy is determined by the public's travel preferences for particular modes. These preferences are a function of the comfort, privacy, speed, cost, and convenience of travel by different modes.

While the average occupancy of automobiles is often surveyed, the average load on public transportation vehicles, taxicabs, and dial-a-ride systems is not so easily gauged. Even peak-hour buses that are packed to capacity at the busiest point along their route may be running, on average, only one-third or so full because they must travel several miles to collect riders and several more miles to discharge them. Also, once a bus finishes its route and returns against the principal flow of traffic to make another run, it may travel nearly empty. The result is that, even during the peak time, the average load tends to be well under capacity, and over the course of a day the average loads of public transportation vehicles are sometimes surprisingly small.

Estimates of the nationwide average occupancy of urban automobiles range from 1.4 to 1.6 passenger-miles per vehicle-mile (PM/VM), 5/ with some variations from city to city. Carpools have average occupancy levels ranging from 2.9 to 3.7 PM/VM. Vanpooling

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5/ This means that, on the average, automobiles in urban areas carry from 0.4 to 0.6 passengers in addition to the driver.

TABLE 2. ESTIMATES OF VEHICLE OCCUPANCY FOR URBAN TRANSPORTATION MODES

Mode	Vehicle Occupancy (Passenger-Miles per Vehicle-Mile)	Vehicle Seating Capacity a/	Load Factor (Passenger-Miles per Seat-Mile)
Automobile	1.4-1.6	5	0.28-0.32
Carpool	2.9-3.7	5	0.58-0.74
Vanpool	8.0-11.4	12	0.67-0.95
Dial-a-Ride	1.0-2.9	12	0.08-0.24
Bus	4.9-20.9	50	0.10-0.42
Heavy Rail (New)	19.8-22.5	72	0.28-0.31
Heavy Rail (Old)	17.3-28.8	72	0.24-0.40
Light Rail	17.7-27.8	63	0.28-0.44
Commuter Rail	25.6-59.5	150	0.17-0.40
Automated Guideway Transit			
Personal Rapid Transit	N/A	3-6	N/A
Group Rapid Transit	N/A	12-15	N/A
Shuttle Loop Transit	N/A	6-25	N/A

SOURCE: Appendix Table A-2.

N/A = Not Available.

a/ Seating estimates from T.J. Healy, "The Energy Use of Public Transit Systems," in *Effects of Energy Constraints on Transportation Systems*, Energy Research and Development Administration, (1976), p. 190.

is a larger and slightly more complex application of the carpool concept in which the riders share the capital and operating costs. Experience with vanpooling is limited, but occupancy levels between 8.0 and 11.4 PM/VM have been achieved in vans with 10 to 12 seats. Dial-a-ride systems use van-sized vehicles but have very low average occupancy levels, ranging from 1.0 to 2.9 PM/VM. These low occupancy levels are partly because of "deadheading"--that is, the dial-a-ride vehicles frequently operate empty because of travel to pick up passengers. The vehicle occupancy levels of all these modes are affected greatly by the extent to which people have similar travel patterns. For instance, neighbors who work on opposite sides of a city are unlikely to form carpools with each other.

Bus occupancy levels in different cities range from 4.9 to 20.9 PM/VM, with higher occupancy in large, dense cities. In 1973 the national average occupancy of urban buses was approximately 11.5 PM/VM. 6/ Factors affecting bus occupancy are frequency and quality of service. Unless it is matched by a suitable increase in ridership, more frequent bus service reduces average bus occupancy. Less frequent bus service might result in higher occupancy and thus be more energy-efficient per mile, but it would also result in a lower level of service. Poor quality of service (for example, slow and uncomfortable buses) might cause some passengers to use alternative modes.

Occupancy levels for new heavy rail transit systems range from 19.8 to 22.5 PM/VM. For old systems, occupancy levels are comparable, ranging from 17.3 to 28.8 PM/VM. Besides frequency and quality of service, heavy rail occupancy levels are affected by many factors, including system access, peak-hour characteristics, and the density of residences and businesses along the transit line's travel corridor.

Light rail vehicles, which are usually smaller than heavy rail cars but larger than buses, have occupancy levels ranging from 17.7 to 27.8 PM/VM. Commuter railroads, which use very large vehicles, have widely varying average occupancy levels, ranging from 25.6 to 59.3 PM/VM.

6/ Based on data from the American Public Transit Association and the National Transportation Survey.

Since actual operating experience with automated guideway transit systems is limited, reliable data on occupancy levels for these modes are not available. Proponents of these systems claim that load factors between 40 percent and 60 percent will be common, but this claim is questionable. Load factors in this range would be substantially greater than those experienced by other modes.

Maintenance and Station Energy

Energy used to maintain vehicles and stations can be substantial, often equaling 10 to 20 percent or more of propulsion energy per vehicle-mile. Maintenance energy is primarily used for repairs, parts, and lubrication. Station energy is relevant only for rail transit and other fixed guideway systems such as people movers and, in some cases, busways. Station energy is quite variable and depends on the type of passenger access (stairs or escalators and elevators), the type of station (underground, at-grade, or aerial), whether or not air conditioning or heating are provided, and whether or not lighting is required for parking lots. Since the more energy intensive options are typical of new transit systems, the new systems tend to have relatively high station energy use. Station energy is largely independent of patronage, so that its importance diminishes on a per-passenger-mile or per-vehicle-mile basis if passenger volumes can be increased.

Table 3 presents some typical values for maintenance and station energy for different urban transportation modes. In contrast to the case of propulsion energy, relatively few estimates are available. Data on maintenance and station energy requirements are rarely segregated from overall energy consumption data, and there has been relatively little research to identify these requirements.

Automobile maintenance energy varies with the age and size of the vehicle and with the number and complexity of its optional items (air conditioning, for example). An estimate of 1,600 BTUs per vehicle-mile is shown in Table 3, but considerable variation around this value is likely. The maintenance energy for vanpools may well be similar to that for automobiles.

Heavy rail transit maintenance energy depends on the age of the vehicle, among other factors. Older systems appear to use about twice as much maintenance energy per vehicle-mile as do the newer systems (about 4,000 BTUs per vehicle-mile versus 2,000 BTUs per vehicle-mile). Whether this gap will narrow as the present generation of vehicles gets older is not clear. Older and newer

TABLE 3. ESTIMATES OF MAINTENANCE AND STATION ENERGY FOR URBAN TRANSPORTATION MODES

Mode	BTUs per Vehicle-Mile
Automobile	
Maintenance	1,600 a/
Heavy Rail (Old) b/	
Maintenance	3,500-4,100
Station	3,300-6,400
Combined	7,300-10,000
Heavy Rail (New) c/	
Maintenance	2,000-2,200
Station	11,900-12,500
Combined	13,900-14,700 a/
Bus	
Maintenance	800-1,000

SOURCE: Appendix Table A-3.

a/ At least one estimate is substantially higher.

b/ New York City Transit Authority and PATH (northern New Jersey).

c/ BART (San Francisco) and Lindenwold Line (Philadelphia).

systems display an even greater difference in the amount of station energy they use. On a per-vehicle-mile basis, new systems use from two to four times more energy for station operations than typical older systems--a clear reflection of the more abundant amenities provided in the newer transit systems. This gap could be narrowed if passenger volumes on the new systems increased. For older heavy rail systems, station and maintenance energy is between 7,300 and 10,000 BTUs per vehicle-mile. For new systems, the comparable estimates are about 14,000 BTUs per vehicle-mile (one estimate is 50 percent higher).

Comparable data are not available for commuter rail or for light rail transit. It is likely, however, that maintenance energy requirements on a per-vehicle-mile basis are higher for commuter rail systems than for older conventional rail systems because commuter rail cars tend to be larger and heavier.

Maintenance requirements for light rail transit are harder to estimate. Existing systems use old vehicles and probably have high maintenance needs, whereas any new system would have a new generation of vehicles and might have needs similar to those of new heavy rail transit systems. The station energy requirements of commuter rail and light rail are almost certainly lower than those for heavy rail. Commuter rail stations are usually at-grade and tend to be further apart than most conventional heavy rail systems. On the other hand, they sometimes have large parking lots with extensive lighting. Light rail stations can be small because trains are only one or two vehicles long, but the stations are often closer together than heavy rail stations.

Bus maintenance energy is estimated at about 800 to 1,000 BTUs per vehicle-mile. This figure is taken from only one source and may be unreliable.

Guideway Construction Energy

All urban transportation modes require some sort of guideways, such as highways, or rail tracks; some proposed innovative transit systems require special automated guideways. This section treats the amount of energy consumed in the construction of different types of guideways and presents some rough estimates of the guideway construction energy required per guideway-mile and per vehicle-mile. Tables 4 and 5 summarize the discussion.

TABLE 4. ESTIMATES OF GUIDEWAY CONSTRUCTION ENERGY PER GUIDEWAY-MILE FOR URBAN TRANSPORTATION MODES

Mode	Billion BTUs per One-Way Guideway-Mile
Highway	9.0-41.6
Heavy Rail (New)	85.0-775.0
Light Rail	12.0-100.0 a/
Commuter Rail	12.0-19.0 b/
Automated Guideway Transit	
Personal Rapid Transit	29.0-58.0
Group Rapid Transit	20.0-88.0

SOURCE: Appendix Table A-4.

a/ Construction of guideways: range from all at-grade to all subway.

b/ Construction of guideways: range from at-grade only.

TABLE 5. ESTIMATES OF GUIDEWAY CONSTRUCTION ENERGY PER VEHICLE-MILE FOR URBAN TRANSPORTATION MODES

Mode	BTUs per Vehicle-Mile
Automobile	100-130
Bus	300-400
Dial-a-Ride	150-200
Heavy Rail (New)	2,400-22,000
Light Rail	Not Available
Commuter Rail	Not Available
Automated Guideway Transit	68-171

SOURCE: Appendix Tables A-4 and A-6.

Two approaches have generally been used to estimate the amount of energy consumed in construction. These methods yield quite different results. One method, sometimes called process analysis, is to identify all the basic materials used (for example, tons of steel or cubic yards of concrete) and determine the amount of energy (both direct and indirect) required to produce each input. The resulting requirements are then totaled to estimate total construction energy. The second method is to divide the major construction inputs by industry and apply input-output analysis to estimate direct and indirect energy requirements. For major construction projects such as highways and subways, the input-output approach consistently results in much higher estimates of energy requirements. (The difference between the two methods is relatively minor for smaller, routine processes such as automobile manufacturing.) The two methods probably provide reasonable upper and lower bounds on the "true" values.

Highway construction energy depends on many factors, including the location of the highway, the number of bridges and embankments per mile, whether or not the highway is built for truck use, and the type of construction materials used. Most process analysis estimates of highway construction energy range from 9 billion to 26 billion BTUs per lane-mile, whereas the input-output analysis estimate is 41.6 billion BTUs per lane-mile.

Guideway construction energy for heavy rail transit systems is influenced by many factors, the most important being the type of construction. The four principal types, in order of increasing energy intensity, are at-grade track, aerial structures (elevated), subways built by "cut-and-cover" techniques, and subways built by tunneling. Recent studies of guideway construction energy for heavy rail have used the BART system for a case study. Estimates vary from 85 billion to 775 billion BTUs (using input-output analysis) per single mile of track. This enormous variation in estimates suggests that the estimation process needs more refinement. The lower part of this range seems more realistic than the higher part.

Good estimates of the construction energy required for light rail guideways--mostly at-grade--are not available, but the requirements are likely similar to those for at-grade heavy rail track. The energy consumed in constructing commuter rail guideways is probably also the same as that for at-grade heavy rail track.

Construction energy used for automated guideways varies by type of guideway and type of system. At-grade guideways require less construction energy than elevated or underground guideways. The estimates for construction of personal rapid transit systems range from 29 to 55 billion BTUs per one-way guideway-mile; for group rapid transit they range from 20 to 88 billion BTUs per one-way guideway-mile (depending on guideway grade). Estimates made using input-output analysis would likely be larger by a factor of at least two or three.

Using estimates of guideway lifespans, it is possible to estimate the construction energy required per vehicle-mile. 7/ These figures are shown in Table 5. New heavy rail transit systems require by far the most construction energy per vehicle-mile, followed in turn by urban bus, dial-a-ride systems, and either automated guideway transit vehicles or automobiles. No figures are shown for light rail and commuter rail because reliable estimates of track lifespans and construction energy are not available. The construction energy per vehicle-mile for these modes, however, most likely lies between that of heavy rail transit systems and urban bus.

Vehicle Manufacturing Energy

Although, the total energy used in the manufacturing of vehicles is substantial, it is usually not of major importance when spread over the effective life of the vehicle. Table 6 presents estimates of manufacturing energy per vehicle and per vehicle-mile. A key variable is the expected vehicle life, and this accounts for most of the variations in estimates. In general, the lower range of estimates for BTUs per vehicle-mile are probably more reasonable.

Manufacturing energy depends on the materials used in the vehicle. Newer vehicles, particularly those that incorporate advanced technologies, tend to have greater quantities of energy intensive materials. For example, aluminum requires three to four times as much energy per ton as does carbon steel. This is partially compensated for by the greater strength of aluminum. An automobile is usually 90 percent steel and only 2 percent aluminum. The

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7/ Margaret F. Fels, "Comparative Energy Costs of Urban Transportation Systems," Transportation Research, 1975, pp. 303-5.

TABLE 6. ESTIMATES OF VEHICLE MANUFACTURING ENERGY FOR URBAN TRANSPORTATION MODES

Mode	Million BTUs per Vehicle	BTUs per Vehicle-Mile
Automobile	72-133	720-1,330
Vanpool	180-280	1,800-2,800
Heavy Rail Transit (New)	4,100	1,350-8,100
Light Rail Transit	N/A	2,200-13,000
Urban Bus	1,020	950-2,600
Personal Rapid Transit	290-610	650-1,400
Group Rapid Transit	N/A	740-1,330

SOURCE: Appendix Table A-5.

N/A = Not Available.

corresponding figures for a bus are 63 percent and 15 percent; for a new heavy rail car, 47 percent and 22 percent; and for a typical personal rapid transit vehicle, 33 percent and 43 percent. 8/ The result of this trend toward use of energy intensive materials is more lightweight vehicles and, probably, lower propulsion energy requirements.

On a per-vehicle-mile basis, there is relatively little difference in vehicle manufacturing energy across modes. Most of the modes fall into the 1,000 to 2,000 BTUs per vehicle-mile range. The

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8/ Ibid., p. 299.

lower part of this range is more realistic. This means that vehicle manufacturing energy for bus and rail transit is negligible, for all practical purposes, because of the large number of passengers carried by the modes.

Access Mode

Data on the mode used to gain access to the line-haul trip are not widely collected. For new heavy rail transit systems, between 50 percent and 90 percent of passengers use automobiles for access (either "park and ride" or "kiss and ride"). The highest percentages are found on suburb-oriented operations such as the Lindenwold Line in the Philadelphia area. Between 5 percent and 16 percent of the passengers use buses for access, and between 5 percent and 32 percent walk. Data about access to line-haul bus routes are even more spotty. Experience with the express buses along the Shirley Highway outside Washington, D.C., shows that about 75 percent of riders gain access by walking and 20 percent by automobile.

Amount of Trip Devoted to Access

Data have not been collected precisely about the question of the portion of a trip that is devoted to access. Detailed origin and destination data available for the Lindenwold Line indicate, however, that about 18 percent of the average trip is spent gaining access to the rail stations and the remaining 82 percent represents the line-haul trip. 9/ The access factor is likely to be smaller for systems that are less suburb-oriented and for those with more extensive line-haul networks (such as buses).

Circuity

The typical transit trip involves additional miles of travel because of the need to gain access to the line-haul vehicle and because transit vehicles normally follow fixed routes that do not usually conform to the most direct route desired by each traveler. These problems are most severe for dial-a-ride services and for fixed guideway systems such as subway or trolley. Dial-a-ride services average about 40 percent more miles than would be required by automobile trips. Carpools and vanpools use 15 percent more miles, while most buses require even fewer extra miles.

9/ David Boyce et al., "Impact of a Suburban Rapid Transit Line on Fuel Consumption and Cost for the Journey to Work," Federal Energy Administration, December 1975.

Source of New Patronage

Before the likely energy savings of a particular transit program can be estimated, the energy that would have been used in the absence of that program must be estimated. This requires information on the mode of travel used before the new service. The most important factor is the number of new trips generated, since these represent additional energy consumption. For new rail systems and new extensions to existing, older rail systems, new trips represent between 6 and 28 percent of travelers, with most results in the 12 to 16 percent range. The Shirley Highway express bus service generates more than 50 percent new trips.

Since the automobile is the most energy-intensive transportation mode in common use, the number of passengers diverted from the automobile is significant in determing the net energy savings or the program energy. New heavy rail systems report that between 35 and 40 percent of travelers previously used automobiles, although a large number were not in single-occupanct automobiles. Extensions to older rail systems report smaller numbers of converts from automobiles--10 to 30 percent. Express bus experience is quite varied. The Shirley Highway bus system reports that about 30 percent of its passengers have been diverted from automobiles, and some other express bus systems claim more than 70 percent.

CHAPTER IV. REPRESENTATIVE ENERGY REQUIREMENTS BY MODE

In the previous chapter the range of estimates for each of the nine components being used to analyze the energy impact of the major urban transportation modes was presented. In order to estimate the energy needs and the conservation potential of each mode, typical values should be identified for each component. In this chapter the best estimate of these representative values will be presented.

SUMMARY OF QUANTITATIVE ESTIMATES

Two steps have been taken to ensure that the values selected are as representative as possible. First, a comprehensive review has been made of available estimates of urban transportation energy use, including both theoretical and applied studies (see Appendix A for details). Second, three sets of estimates are presented--high, low, and middle--for each energy component of each mode of urban transportation. The middle estimates combine what appear to be the most representative values at each stage, and they may be viewed as the best estimate. The results from this middle set of estimates are useful in analyzing national policy, although they are not necessarily applicable to every city. The low set, which presents those estimates that reflect the minimum energy requirements for each mode, represents the most optimistic case for each mode. The high option presents the most pessimistic estimates of energy requirements for each mode.

In those cases in which no specific estimates are available, extrapolations are made from data for other modes. For example, station and maintenance energy requirements for commuter rail are based on data for heavy rail transit. The high and low estimates do not always reflect the most extreme value reported in the literature, particularly when that extreme estimate is substantially above or below the most common values. In cases in which only a few estimates are available, the high and low values selected may be outside the range of data available.

Table 7 contains for each mode middle estimates of propulsion energy, number of occupants, station and maintenance energy, construction energy, and vehicle manufacturing energy. Low and high estimates are shown in Tables B-1 and B-2 in Appendix B. With these estimates the operating energy intensiveness and line-haul energy requirements of each mode can be calculated. Table 8 presents middle values for mode access, fraction of trip devoted to access, circuity, and source of new patronage. Low and high estimates can be found in Tables B-3 and B-4 in Appendix B. With these additional estimates, the modal energy and program energy requirements of each mode can be calculated.

Finally, Tables 9, 10, and 11 combine these basic component values into middle, low, and high estimates of the major summary measures of the total energy requirements of the mode: operating energy intensiveness, line-haul energy, modal energy, and program energy. In calculating the low and high estimates of modal energy and program energy, the estimates of energy use by other modes needed to calculate access energy and program energy are taken from Table 9, the middle estimates. Clearly, other assumptions could be made that would generate different numerical results, but the relative order established by these estimates is unlikely to change.

TABLE 7. MIDDLE ESTIMATES OF BASIC COMPONENTS OF OPERATING ENERGY INTENSIVENESS AND LINE-HAUL ENERGY BY URBAN TRANSPORTATION MODES: IN BRITISH THERMAL UNITS (BTUs) PER VEHICLE-MILE

Mode	Propulsion Energy	Average Number of Occupants	Station and Maintenance Energy	Construction Energy	Vehicle Manufacturing Energy
Single-Occupant Automobile	11,000	1.0	2,000	125	1,100
Average Automobile	11,000	1.4	2,000	125	1,100
Carpool	11,000	3	2,000	125	1,100
Vanpool	14,000	9	2,000	200	2,000
Dial-a-Ride	15,500	1.6	2,000	200	2,000
Heavy Rail (Old)	61,000	24	9,000	3,000	1,500
Heavy Rail (New)	75,000	21	15,000	4,000	1,500
Commuter Rail	105,000	40	7,000	1,200	2,500
Light Rail Transit	75,000	20	7,000	1,700	2,000
Bus	30,000	11.5	900	370	1,200
Personal Rapid Transit	11,000	2	5,000	300	1,000
Group Rapid Transit	20,000	6	6,000	600	1,000
Shuttle Loop Transit	23,000	10	7,000	600	1,000

TABLE 8. MIDDLE ESTIMATES OF ACCESS, CIRCUITY, AND SOURCE OF PATRONAGE BY URBAN TRANSPORTATION MODES

Mode	Mode of Access (Percent)	Percent of Trip Devoted to Access	Circuity (Relative to Trip by Auto)	Percent of New Patrons by Former Mode
Automobile	N/A	0	1.0	N/A
Carpool	N/A	0	1.15	15 bus 25 carpool 60 single-occupant auto
Vanpool	N/A	0	1.2	5 bus 40 carpool 55 single-occupant auto
Dial-a-Ride	N/A	0	1.4	10 bus 25 walk 45 auto (15 taxi) 20 new trip a/
Heavy Rail (Old)	20 bus 40 auto 40 walk	15	1.2	N/A
Heavy Rail (New)	10 bus 70 auto 20 walk	18	1.3	45 bus 35 auto 10 new trip a/ 10 other
Commuter Rail	5 bus 15 walk 80 auto	18	1.3	30 bus 40 auto 10 new trip a/ 20 other
Light Rail	20 bus 50 walk 30 auto	10	1.2	50 bus 30 auto 10 new trip a/ 10 other
Bus (Express)	25 auto 75 walk	10	1.1	25 bus 55 auto 10 new trip a/ 10 other

N/A = Not Applicable.

a/ There is no diversion from a former mode; a person who previously did not use a mode of urban transportation is using the new mode.

TABLE 9. MIDDLE ESTIMATES FOR VARIOUS MEASURES OF ENERGY REQUIREMENTS BY URBAN TRANSPORTATION MODES: IN BRITISH THERMAL UNITS (BTUs) PER PASSENGER-MILE

Mode	Operating Energy Intensity	Line-Haul Energy	Modal Energy	Program Energy (Net Savings)
Single-Occupant Automobile	11,000	14,220	14,220 a/	N/A
Average Automobile	7,860	10,160	10,160 a/	N/A
Carpool	3,670	4,740	5,450	4,890
Vanpool	1,560	2,020	2,420	7,720
Dial-a-Ride	9,690	12,310	17,230	(12,350) b/
Heavy Rail (Old)	2,540	3,100	3,990	N/A
Heavy Rail (New)	3,570	4,550	6,580	(980) b/
Commuter Rail	2,625	2,890	5,020	970
Light Rail	3,750	4,280	5,060	30
Bus	2,610	2,820	3,070	3,590 c/
Personal Rapid Transit	5,500	8,650	d/	d/
Group Rapid Transit	3,330	4,600	d/	d/
Shuttle Loop Transit	2,300	3,160	d/	d/

N/A = Not Applicable.

a/ By definition, there are no access energy requirements for automobiles, so modal energy equals line-haul energy.

b/ Energy loss.

c/ For new express bus service. Conventional bus service would show smaller savings.

d/ Data not available for access modes and source of patronage since these modes are still largely under development.

TABLE 10. LOW ESTIMATES FOR VARIOUS MEASURES OF ENERGY REQUIREMENTS BY URBAN TRANSPORTATION MODES: IN BRITISH THERMAL UNITS (BTUs) PER PASSENGER-MILE

Mode	Operating Energy Intensity	Line-Haul Energy	Modal Energy	Program Energy (Net Savings)
Single-Occupant Automobile	6,000	8,360	8,360 a/	N/A
Average Automobile	3,750	5,225	5,225 a/	N/A
Carpool	1,710	2,390	2,630	7,590
Vanpool	1,090	1,400	1,540	8,940
Dial-a-Ride	4,500	5,630	7,320	(1,420) b/
Heavy Rail (Old)	1,920	2,300		N/A
Heavy Rail (New)	2,390	3,140	4,220	2,500
Commuter Rail	1,400	1,550	2,940	3,700
Light Rail	2,120	2,390	2,660	3,610
Bus	1,320	1,410	1,610	6,250 c/
Personal Rapid Transit	2,000	3,290	d/	d/
Group Rapid Transit	1,250	1,900	d/	d/
Shuttle Loop Transit	1,070	1,510	d/	d/

N/A = Not Applicable.

a/ By definition, there are no access energy requirements for automobiles, so modal energy equals line-haul energy.

b/ Energy loss.

c/ For new express bus service. Conventional bus service would show smaller savings.

d/ Data not available for access modes and source of patronage since these modes are still largely under development.

TABLE 11. HIGH ESTIMATES FOR VARIOUS MEASURES OF ENERGY REQUIREMENTS BY URBAN TRANSPORTATION MODES: IN BRITISH THERMAL UNITS (BTUs) PER PASSENGER-MILE

Mode	Operating Energy Intensity	Line-Haul Energy	Modal Energy	Program Energy (Net Savings)
Single-Occupant Automobile	15,000	20,550	20,550 a/	N/A
Average Automobile	13,640	18,680	18,680 a/	N/A
Carpool	6,000	8,220	10,690	(200) b/
Vanpool	2,125	2,990	4,190	3,650
Dial-a-Ride	17,500	24,400	39,040	(33,150) b/
Heavy Rail (Old)	4,890	6,370		N/A
Heavy Rail (New)	4,740	7,000	10,600	(6,530) b/
Commuter Rail	5,200	6,020	9,520	(4,910) b/
Light Rail	6,000	7,390	9,440	(5,470) b/
Bus	5,830	6,710	8,120	(4,150) b/ c/
Personal Rapid Transit	18,000	25,800	d/	d/
Group Rapid Transit	7,500	9,950	d/	d/
Shuttle Loop Transit	11,670	13,470	d/	d/

N/A = Not Applicable.

a/ By definition, there are no access energy requirements for automobiles, so modal energy equals line-haul energy.

b/ Energy loss.

c/ For new express bus service. Conventional bus service would show a greater loss.

d/ Data not available for access modes and source of patronage since these modes are still largely under development.

DESCRIPTION OF RESULTS

This section describes the major differences across modes for the components of energy use and for the measures of energy requirements. The middle estimates will be used as the primary example; it should be noted, however, that there is little shifting in the relative ranking of modes among low, middle, and high estimates.

In terms of propulsion energy per vehicle-mile, there are three clusters of modes (see Table 7):

- Automobiles and other light vehicles such as vans have modest energy requirements (about 10,000-15,000 BTU/VM).
- Buses and the larger automated guideway transit vehicles require two to three times as much energy as the light vehicles (about 20,000-30,000 BTU/VM).
- Rail vehicles require three to four times as much energy as the middle-cluster vehicles (about 60,000-105,000 BTU/VM).

On the basis of energy per passenger-mile, the results are quite different (see Table 9). Vehicles with low load factors [1] or low absolute loads have the highest energy requirements (for example, automobile and dial-a-ride). Bus, rail transit, carpool, and most automated guideway transit systems have substantially lower requirements. Because of its high load factor (0.75, or 9 passengers for 12 seats), vanpool has by far the lowest operating energy requirements per passenger-mile.

Not surprisingly, the larger the vehicle, the greater the average number of passengers carried. Rail vehicles carry the greatest number of passengers, followed by bus and vanpool. In terms of load factor, however, vanpools and carpools perform best. The automated guideway systems are also assigned high load factors (about 0.5), but these estimates are based on theoretical studies and

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[1] Load factor refers to the percentage of seats occupied; it is a measure of how close a mode comes to its potential seating capacity.

are less reliable than estimates based on experience. The major weakness of the automobile as a mode of urban transportation is clearly the large number of vehicles with only one occupant.

Maintenance energy needs are relatively uniform, about 2,000 BTUs or less per vehicle-mile for all modes except older heavy rail transit, for which 4,000 BTUs per vehicle-mile is more realistic. Station energy varies a great deal, however, and is particularly high for new heavy rail systems, which emphasize amenities such as air conditioning and escalators in order to attract passengers. New rail systems such as BART require about 15,000 BTUs per vehicle-mile for station and maintenance energy, or about twice as much as other fixed guideway systems.

When guideway construction energy is prorated over the expected life of the guideway, energy requirements are negligible for most modes. The exception is heavy rail transit which requires 3,000-4,000 BTUs per vehicle-mile, several times more than that used by other modes. The primary reason for the difference is the large amount of energy consumed in underground construction. Averaging this large amount over the decades of expected guideway use, however, makes construction energy per vehicle-mile a relatively minor factor compared with propulsion energy, access energy, and station energy.

Vehicle manufacturing energy is almost uniform across all modes and thus has little influence on relative energy efficiency.

Table 9 shows the energy requirements by mode according to the different measures of energy use presented in Chapter II. Operating energy intensity reflects propulsion requirements only. Line-haul energy is a more complete measure because it includes construction energy and maintenance energy not included in propulsion requirements. Modal energy is even more comprehensive because it includes estimates of energy used in gaining access to the line-haul mode. Program energy attempts to measure expected energy savings (or losses) that result from patrons converting to a mode from other modes.

Vanpool displays the best performance on all measures, while dial-a-ride shows up worst. Buses and carpools also perform consistently well, only slightly behind vanpools in expected energy savings. Most rail transit does quite well on operating energy intensity and even line-haul energy. When the effects of access energy and circuity are added in, however, the ranking of rail transit drops considerably. This is particularly true of commuter rail and the new, heavy rail systems because access is largely by low occupancy automobile and many new trips are encouraged. Old heavy rail transit also appears as one of the most efficient modes even after access energy is included. This is largely because of its location in older, more densely populated areas.

There is little difference in the ranking of the modes in the low, middle, and high estimates of the summary measures of energy intensiveness: in each case vanpools are the most energy-efficient and dial-a-ride the least energy-efficient, with the other modes spread between them roughly as in the middle estimates. Comparisons among the three sets can be made to discover the wide range of results that would likely occur in actual implementation.

For example, under the low estimates of energy requirements, only dial-a-ride shows up as a net energy-losing program. Using the low estimates, the rail transit systems show significant net energy savings. These savings are better than the savings under the high estimates for all modes except vanpool. Even under the most optimistic assumptions, however, rail systems show smaller expected energy savings than do the two best modes under the middle estimates (vanpool and carpool).

CHAPTER V. CONCLUSION

As noted at several points throughout this paper, a balanced and realistic assessment of energy conservation in urban transportation operations requires consideration of a wide range of technological, operational, and behavioral factors. Almost all these factors are marked by considerable variation from city to city, from one time of day to another, and from route to route. Any conclusions about the energy efficiency of transportation modes, or about the conservation potential of transportation programs, must be viewed as rules with numerous exceptions. Nevertheless, the rules that emerge from examination of existing technical information differ sharply from the normally accepted rules, and they are worth noting even if they are not universally true.

Long-term energy savings are particularly uncertain because, over a period of many years, there will be shifts in the locations of jobs, stores, and houses. These shifts will occur because urban growth is influenced by zoning policies, land costs, real estate tax differentials, quality of public schools, availability of parking, and myriad other such factors. The quality of available transportation is one of the forces shaping urban development, albeit a force that is notoriously difficult to isolate. Nevertheless, any shift in transport policy that facilitates long-distance travel may direct growth so as to create more such travel, and any policy that makes it easier to move in congested central parts of cities may lead to more concentrated growth and correspondingly shorter trips. Thus, insofar as expansion of vanpooling or express bus service leads to longer trips, the energy savings per passenger-mile of these modes may be offset somewhat by increases in miles traveled, while the opposite may hold true for rapid rail, light rail, or personal rapid transit systems that serve downtown areas.

Because urban growth depends on so many factors, the influence of transportation programs per se is difficult to quantify. The largest new public transportation project completed in recent years is San Francisco's BART system, and experience to date does not suggest that any significant shifts in metropolitan development have occurred there. 1/ None of the changes in bus, vanpool, or carpool programs discussed here would involve anywhere near the level of public financial support that BART did, and the impacts of such change on urban development would probably not be any more noticeable. Nevertheless, the effects that changes in transportation policy have on metropolitan development patterns are poorly documented, and it should be noted that no developmental effects have been taken into account in making the estimates presented here.

In this context, the remainder of this section summarizes CBO's principal findings regarding energy conservation in urban transportation and some of their implications for design of the federal mass transit program.

Vanpools

Of all the urban transport modes, vanpools can probably make the greatest contribution to energy savings on a per-passenger-mile basis. The chief advantage of vanpools lies, not in their technology, which is essentially that of conventional light trucks, but in the exceptionally high load factors that characterize existing vanpool operations. Indeed, if any of the other urban transportation modes could operate as near to seating capacity as do vanpools, their fuel conservation potential would be equally impressive. 2/ This is unlikely, however, because none of the other

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1/ There is some speculation that the BART system may encourage more sprawl than concentration, although this concern has little hard evidence to support it. See Henry Bain, "New Directions for METRO: Lessons from the BART Experience," The Washington Center for Metropolitan Studies (December 1976), p. 22; and Melvin M. Webber, "The BART Experience--What Have We Learned?" The Public interest, No. 24 (Fall 1976).

2/ Two reasons vanpools achieve such a high load factor are: first, the requirement that there be enough passengers to pay both capital and operating costs; second, the driver's financial incentive to keep the number of passengers at or near capacity.

public modes operate in the peak-hour-only, single direction, prearranged fashion that is characteristic of vanpools, and it is very difficult to maintain near-capacity loads in the absence of these features. Thus, the superior energy efficiency of vanpools, on a per-passenger-mile basis, is not apt to be challanged. Rather, the conservation potential of vanpools and carpools will probably increase relative to that of other public modes in future years since improvements in the fuel economy of light trucks (and hence of vanpools) are anticipated to be large compared to those of other forms of public transportation.

In spite of the clear advantages of vanpools on a per-passenger-mile basis, the contribution of vanpooling programs to national fuel conservation remains limited because of the very special conditions under which successful vanpools operate. Existing vanpool programs typically operate between relatively dense concentrations of homes and a common, distant workplace. Round-trips of 40 to 100 miles are common among vanpools, although some operate over considerably shorter routes. 3/ Because of the long trip lengths characteristic of vanpools, the potential market for this service represents a small fraction of the nation's work trips. Thus, even though vanpool programs will probably not lead to large fuel savings at the national level, they provide one of the potentially most productive parts of any program directed at urban transport energy in general.

Furthermore, vanpool programs now in existence indicate that this mode can be largely self-supporting and that massive federal assistance is not needed to start or maintain vanpools. Currently, the spread of such systems is severely impeded by state and federal regulations imposed by state public utility commissions, the Interstate Commerce Commission, the Bureau of Motor Carrier Safety, and various labor laws. These regulations sometimes discourage companies from getting involved in vanpooling and sometimes prevent several employers from getting together to start or extend vanpool service.

3/ Gerald K. Miller and Melinda A. Green, "Guidelines for the Organization of Commuter Van Programs," Report prepared by the Urban Institute for the Urban Mass Transportation Administration, February 1976.

These regulatory constraints on vanpool expansion are probably the most fertile area for legislative action. In particular, the exemption from Interstate Commerce Commission and state regulation contained in the proposed National Energy Act 4/ could be extended to apply to nonfederal vanpooling without damage to the existing public transportation services that these regulations are intended to protect.

In summary, vanpools can produce large fuel savings in special circumstances, although these circumstances apply to only a small segment of the overall travel market. Vanpool operations require little or no public financial support, and it does not appear that increased federal spending would be appropriate to spread the application of this energy-efficient mode. At present, state and federal regulations inhibit the expansion of vanpools, and these appear to be amenable to legislative action if the Congress elects to encourage this mode of transportation.

Buses

Of the conventional urban public transportation modes (subway, trolley, and bus), buses appear to offer the greatest promise in terms of energy conservation. Although typically the operating-energy intensity of buses is only slightly better than that of other conventional public transport modes, their modal energy is only about half that of new rail or trolley systems because of the access conditions and route coverage that generally characterize bus service. Furthermore, because express bus service can be designed to draw heavily from segments of the market that are now automobile-oriented, the energy savings of programs that promote new bus service are probably greater than programs aimed at any other public transport mode. That is, a new bus trip typically means greater energy savings than a new rapid rail, commuter rail, or trolley trip. Also, new bus services--even those requiring exclusive right-of-ways--tend to be less expensive ways to draw new patronage than these other modes.

4/ "Neither the offering of a vanpooling arrangement pursuant to this subsection nor the operation of a van pursuant to such an arrangement shall subject any person to regulation as a motor carrier under part II of the Interstate Commerce Act (49 U.S.C., 301 et seq.) or to any similar regulation under the laws of the District of Columbia or of any State or political subdivision thereof." (H.R. 8444, section 701, subsection c6.)

Current federal programs provide extensive support for capital costs of transit systems on an 80 to 20 matching basis. Although private bus service providers are not eligible for this support, the overall level of capital cost support for buses does not appear to be a major problem, at least as far as existing capital programs go.

Probably the greatest constraint to expansion of energy-efficient bus service is operating costs. Operating deficits have risen at an alarming rate in recent years, and both federal and local governments are cautious about taking any steps that might aggravate this problem. Under Section 5 of the Urban Mass Transportation Act of 1964, the Urban Mass Transportation Administration provides up to 50 percent of the transit operating deficit. These funds, however, are allocated among urban areas on a formula basis and generally cover substantially less than half of the operating losses in larger metropolitan areas. Many observers fear that increases in the federal money for this purpose would lead to more inefficient operations, and it is not clear that expansion of Section 5 support would be appropriate as part of an energy conservation program. Because bus operating costs are overwhelmingly labor costs, attempts to curb costs may immediately run counter to employment goals, and there appear to be no simple ways to make substantial cost cuts that are acceptable to all parties involved.

Nevertheless, some of the innovative bus services--particularly, subscription service such as the Reston Express bus outside Washington, D.C.; Specialty Transit in St. Louis, Missouri; and COM-BUS in Los Angeles, California--have shown that additional bus service can be operated at little or no expense to the public. 5/ The growth of this service appears to be limited by local regulations that protect existing operators and by the concerns of labor (many peak-hour-only services are most efficiently run using part-time help).

By their nature, subscription buses usually provide private, peak-hour-only service. The primary need of this type of service is not federal financial support, but exemption from the institutional obstacles that limit its growth. If the Congress wishes to provide financial assistance to promote this service, its efforts would best

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5/ Ronald N. Kirby et al., Para-Transit: Neglected Options for Urban Mobility (The Urban Institute, 1974).

be placed, not in existing capital or operating subsidy programs, but in programs that relax local regulations by creating job security. That is, federal underwriting of existing transit jobs or services could give localities the assurance that they need to experiment with innovative supplements to existing bus service.

Giving buses priority in traffic through special traffic signaling or reservation of lanes, and giving buses (along with carpools, vanpools, and other energy-efficient modes) exclusive right-of-way can also greatly enhance the attractiveness and patronage of the service. Existing federal programs provide for capital support of these services, 6/ but in many situations the changes required to implement bus priority schemes require relatively little capital expenditure, and federal assistance offers little incentive to local officials. Exclusive right-of-ways for buses, such as those on the Shirley Highway outside Washington, D.C., are more capital-intensive than other bus priority measures, and they do not have the adverse effects on automobile traffic that separating off an existing lane for bus use implies. A more aggressive federal program in the area of acquiring and constructing exclusive right-of-ways could be a productive way to promote the energy-saving advantages of bus service. Such a program could be broadly interpreted to include relocating on-street parking to off-street, which would yield additional capacity from existing facilities, and constructing bridges, by-passes, and other facilities to enhance the movement of high-occupancy vehicles. Local conditions are too diverse to attempt to specify such a program in detail, but designating additional money for Urban Mass Transportation Administration Section 3 funds for this purpose could be a fruitful approach. Additional incentives could be provided if separate federal operating assistance over and above the existing operating aid program were available for those specific projects with a relatively high potential for saving energy. As with the current aid program, the federal share of operating losses should probably be held to a maximum of 50 percent, to ensure some incentives for efficient local operations.

6/ Many of these projects are classified as Transportation System Management (TSM) by the Urban Mass Transportation Administration and are funded with capital grants (Section 3) or, in some cases, demonstration grants. Some Federal Highway Administration funds (primarily money for urban systems) can also be used for these purposes.

Carpools

Carpools can make a significant contribution to energy conservation. A typical mile of travel diverted to carpool saves more energy than does diversion to any other mode except vanpool, according to the results shown in Table 9. Unlike vanpools, for which the potential market is very small, carpools could potentially be used for a large portion of all commuter travel. It is not clear, however, to what extent additional spending can increase carpooling. Promotion programs that locate and match potential carpoolers are relatively inexpensive, but they produce modest gains at best. Incentives such as free parking, or permission to use reserved right-of-ways along with other high-occupancy vehicles are promising ways to use federal funding to promote carpools.

Dial-a-Ride

From the standpoint of energy conservation, dial-a-ride service appears to be counterproductive. Because of low load factors and high route circuity, dial-a-ride is an energy-wasteful mode by almost any measure. This service, however, has some unique advantages in being of use to the handicapped and the elderly, and its energy costs must be weighed against its social contributions.

Light Rail Transit

Although much attention has been given to light rail transit in recent discussions, the energy properties of this mode are generally comparable to those of heavy rail transit, except for some savings in construction energy and station and maintenance energy. In terms of the estimates shown in Table 9, these advantages are sufficient to make light rail transit marginally effective in conserving energy, although it appears to rank significantly lower than bus, vanpool, or carpool in terms of its conservation potential.

Automobiles

Automobiles are generally the least energy-efficient of the urban transportation modes. The figures in Table 9 show that automobiles currently require about twice as much energy per passenger-mile as do new rail rapid transit systems. Some of the differences apparent in a comparison of line-haul energy requirements become modified, however, when the access and circuity of fixed-route modes are taken into account. Moreover, the gap between the automobile's energy requirements and those of other modes will shrink even further as the fuel economy standards for new cars set out in the Energy Policy and Conservation Act and the additional automotive fuel economy measures now being considered by the Congress start to increase the average fuel economy of the nation's automobile fleet.

Even though earlier analysis by the Congressional Budget Office indicates that the 1985 fuel economy standard of 27.5 miles per gallon is unlikely to be met, average new car fuel economy (combined city and highway cycles) is nonetheless expected to jump from 17.8 miles per gallon in 1977 to 23.3 miles per gallon in 1985, and the automobile fleet as a whole will probably average more than 23 miles per gallon by 1990. 7/ Comparable fuel efficiency gains are not anticipated for buses or rail systems. Thus by the time major extensions to these services could be built, their fuel efficiency advantages, where they now exist, would be reduced by roughly 20 percent. Indeed, one study concludes that "with present power sources, the subways will lose their (operating) energy advantage over the automobile by the end of the century." 8/

Rapid Rail

Of all the commonly held notions about energy efficiency, probably the most misguided are those concerning rapid rail transit. The findings of the previous chapter indicate that under typical conditions, new rapid rail systems actually waste energy rather than save it. This surprising finding appears to conflict with the fact that, in terms of operating energy per passenger-mile, rail ranks among the most energy-efficient of all modes. But when construction and station energy are considered as well, rapid rail ranks among the least energy-efficient of the conventional urban public transportation modes. Furthermore, when mode of access and circuity are included, the energy per productive mile computed over the entire

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7/ Congressional Budget Office, President Carter's Energy Proposals: A Perspective, Staff Working Paper (June 1977). (The figures reported do not assume that any new car fuel economy regulations are in force other than those contained in the Energy Policy and Conservation Act.)

8/ Regional Plan Association, "Power for the MTA," June 1977, p. 4. Subways would still play a significant role in energy conservation since they permit New York City and other large eastern cities to maintain their energy-efficient, high-density nature.

trip is greater than that of all the other public modes except dial-a-ride. The principal reason for this poor performance is the considerable use of low-occupancy private automobiles to access new rapid transit stations. Finally, the average patron of mass transit systems is drawn from a mode in which energy efficiency is better than that for the rail system. This produces a small net loss of energy overall.

As noted earlier, exceptions to patterns such as this are probably not difficult to find. Slight variations in the judgments about exactly what constitutes typical conditions could lead to a revised set of computations in which the energy impact of rapid rail transit appears somewhat favorable. But, even though it is possible to argue about the precise value of all of the factors bearing on the energy intensiveness of rail rapid transit, these fine points of discussion have little to do with the substantive conclusion that rail rapid transit offers hardly any aid to the nation's efforts to save fuel. Indeed, even wildly optimistic assumptions about all aspects of rapid rail transit lead to the same conclusion.

For the purposes of illustration, consider a program recently proposed in the House of Representatives that would have used half of the revenues from a 5 cent per gallon tax on gasoline and diesel fuel to fund various transit programs. 9/ Although it was never intended that these revenues would be devoted to new rail transit projects exclusively, for sake of illustration it is assumed here that they are. Over ten years, the revenues from a 2.5 cent gasoline tax would total about $28 billion. Based on the existing 80:20 matching ratio between federal and local funds, this leads to transit construction expenditures of $35 billion over ten years. Even at today's prices, this sum would buy fewer than six systems the size of Washington's proposed 98-mile Metro. Since the gasoline tax would be collected and spent in future years when the dollar will buy less than it does now, the gasoline tax revenues would probably not even support four Metro-like systems.

Nonetheless, assume that six Metro-like systems are built and that each of these systems is fully in use by 1990. Further, suppose that each of the six new systems carries 300 million trips per year. This is the number of trips that the promoters of the Metro system

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9/ Congressional Record, daily ed., July 29, 1977, pp. 8132-33.

claim will ride Washington's subway in 1990. This figure has been attacked as being an unrealistically optimistic projection; 10/ it represents about eight times as many passengers per year as San Francisco's 72-mile BART system now attracts.

Further, suppose that each of these new trips is five miles long and that each new transit trip replaces an auto trip of identical length. Again, these assumptions overstate the likely effects of transit since many new transit patrons would be former bus or carpool travelers, and thus would not diminish automobile traffic very much. Also, a great number of transit trips would still require use of a car to get to the station.

Finally, assume that cars in 1990 average 15 miles per gallon in urban traffic, and that rail transit systems require absolutely no energy to operate. Again, these assumptions favor rail transit. The energy savings of the $35 billion program would then be: 6 new rapid rail systems x 300 million trips per year per system x 5 miles per trip = 9 billion miles of automobile travel eliminated per year, assuming new transit trips replace automobile trips mile for mile. The associated fuel savings, in terms of the conventional measure of barrels per day, are: 9 billion miles of automobile travel ÷ 15 miles per gallon ÷ 42 gallons per barrel ÷ 365 days per year = 39,000 barrels per day, or 0.7 percent of 1976 daily consumption.

Thus, even under wildly optimistic assumptions, this $35 billion transit program would lead to 1990 fuel savings of fewer than 40,000 barrels of oil per day. If transit systems are assumed to have a life of 50 years, these savings are equivalent to a price of about $50 per barrel of oil, versus the current world price of about $14.

Changing a few assumptions to more realistic values reduces the estimated fuel savings considerably. For example, assuming an average of 150 million persons per year (still four times the level of BART) leads to fuel savings of 20 thousand barrels per day in 1990. Similarly, more realistic assumptions about the rate at which automobile trips are displaced, about inflation and the likely costs

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10/ "Washington Area Metro Rail System: Perspective and Alternatives," Study and Report from the Library of Congress, Congressional Research Service, for the Subcommittee on Fiscal Affairs of the Committee on the District of Columbia, House of Representatives, Committee Print S-4, February 1976.

of future heavy rail systems, about future automotive fuel efficiency, and about transit fuel efficiency can be shown to lead to substantially lower fuel savings.

In view of the limited energy conservation potential of rail rapid transit and the enormous capital costs of such systems, expenditure of federal funds on these systems for purposes of energy conservation appears to be misguided and possibly even counterproductive.

APPENDIX A. AVAILABLE ESTIMATES OF URBAN ENERGY CONSUMPTION BY MODE AND TYPE OF ENERGY

TABLE A-1. VARIOUS ESTIMATES OF VEHICLE PROPULSION ENERGY FOR URBAN TRANSPORTATION MODES: AVERAGES FOR GENERAL URBAN AREAS AND SPECIFIC CITIES (SYSTEMS)

Mode of Transportation	Miles per Gallon a/	BTUs per Mile	City (System)
Automobile	7.5	16,790	General urban (six seat) b/
	11.4	10,970	General urban c/
	13.5	9,260	General urban d/
	13.9	8,990	New York metropolitan area (1972) r/
	15.0	8,330	General urban (four seat) b/
	22.5	5,260	General urban (light car) e/
Vanpool	9.0	13,900	Minneapolis f/
Dial-a-Ride	4.2	29,780	Los Angeles g/
	7.0	17,850	General urban (gas vehicle) e/
	7.3-9.0	13,900-17,130	Nine cities h/
	13.5	9,250	General urban (diesel vehicle) e/
Heavy Rail Transit (Old)	.52	241,240	New York City (Staten Island Rapid Transit) i/
	.52	240,880	Boston (includes light rail) i/
	1.33	93,830	Cleveland i/
	1.35	92,560	New York City (Transit Authority) i/
	1.44	86,680	Philadelphia i/
	1.71	73,180	New York City (Transit Authority) r/
	1.72	72,880	New York/New Jersey (PATH) i/
	2.02-3.31	37,800-62,000	Five cities (1964) j/
	2.04	61,400	New York City (Transit Authority) m/
	2.09	59,800	New York/New Jersey (PATH) m/
	2.41	51,879	Chicago i/
	4.00	31,300	Cleveland d/
Heavy Rail Transit (New)	1.07	117,100	San Francisco (BART) i/
	1.15	109,020	Philadelphia (Lindenwold) i/
	1.23	101,780	San Francisco (BART) k/
	1.44	86,900	Philadelphia (Lindenwold) l/
	1.45	86,100	Philadelphia (Lindenwold) m/
	1.78	70,080	San Francisco (BART, actual) m/
	2.13	58,800	San Francisco (BART, projected) m/
	2.23	56,175	San Francisco (BART, actual) n/
	2.57-2.84	44,000-48,580	San Francisco (BART, projected) n/
Commuter Rail	.80	154,500	San Francisco g/
	.96	129,900	San Francisco i/
	1.14	109,350	Chicago (average) i/
	1.21	103,500	New York (average) i/
	1.21	103,000	Philadelphia (average) i/
	1.27	98,213	Boston i/
	1.80-2.90	43,150-69,540	Several cities (1964) j/

(Continued)

TABLE A-1. (Continued)

Mode of Transportation	Miles per Gallon a/	BTUs per Mile	City (System)
Light Rail	1.19	105,000	Philadelphia (SEPTA, city) i/
	1.45	86,400	Philadelphia (SEPTA, Red Arrow) i/
	1.54	81,284	Pittsburgh i/
	1.66	75,147	San Francisco (MUNI) i/
	2.17	57,750	Rochester (proposed) g/
	2.41	51,992	Newark i/
Bus	3.6	34,940	New York City (Transit Authority) r/
	3.6	34,740	General urban (local bus) g/
	3.8	32,660	General urban e/
	4.0	31,270	Atlanta (1976) p/
	4.1	30,500	Cleveland d/
	4.4	28,430	Atlanta (projected, 2000) p/
	4.8	26,310	Northern New Jersey r/
	4.8	26,060	General urban (express bus) g/
	5.6	22,330	Oakland (efficient bus) n/
Personal Rapid Transit	6.2-13.1	9,560-20,205	Two systems e/
	9.6-31.0	4,030-13,000	General urban b/
Group Rapid Transit	4.2-15.4	8,100-30,000	General urban b/
Shuttle Loop Transit	7.4-11.4	11,000-17,000	General urban b/
	5.3	23,800	Dallas (Airtrans) b/
	5.0	25,200	Dallas (Airtrans) q/
Downtown People Mover	1.75	71,400	Los Angeles (proposed) o/

NOTE: Not all sources have used the same conversion factors between different energy units. For consistency, estimates have been converted by using the following equations: 1 gallon of gasoline = 125,071 BTUs; 1 electrical kwh = 10,500 BTUs.

a/ Miles per gallon of gasoline or equivalent.

b/ H. Lee Tucker, Jr., "Energy Efficiency of Urban Transit Systems," presented at Fourth National Conference on the Effects of Energy Constraints on Transportation, August 1977.

c/ R. H. Pratt et al., "The Potential for Transit as an Energy Saving Option," prepared for Federal Energy Administration, March 1976.

d/ American Public Transit Association, Transit Fact Book, 75-76 Edition, p. 46.

TABLE A-1. (Continued)

e/ Margaret Fels, "Comparative Energy Costs of Urban Transportation Systems," Transportation Research, vol. 9 (1975), pp. 197-308.

f/ Robert D. Owens and Helen L. Sever, "The 3M Commute-A-Van Program," in Urban Transportation Efficiency (American Society of Civil Engineers, 1977).

g/ Timothy Healy, "Energy Demands of Urban Transit Systems," in Proceedings of the Third National Conference on the Effects of Energy Constraints on Transportation, Energy Research and Development Administration (May 1977).

h/ Reid Ewing and Nigel Wilson, "Innovations in Demand-Responsive Transit," prepared for U.S. Department of Transportation (October 1976).

i/ Stanford Research Institute, "Railroad Energy Study: Description of Rail Transportation in the United States," vol. II: "Rail Passenger Transportation," prepared for the Energy Research and Development Administration (January 1977), pp. 13-10 through 13-12. SRI data may include station and maintenance energy as well as traction energy.

j/ Lang and Soberman, Urban Rail Transit: Its Economics and Technology (Massachusetts Institute of Technology Press, 1964). Traction energy only.

k/ Charles Lave, "Rail Rapid Transit: The Modern Way to Waste Energy," Social Science Working Paper 122, University of California at Irvine (March 1977).

l/ David E. Boyce et al., "Impact of a Suburban Rapid Transit Line on Fuel Consumption and Cost for the Journey to Work," prepared for Federal Energy Administration (December 1975).

m / Margaret Fels, "Breakdown of Energy Costs for Rapid Rail Systems," The Center for Environmental Studies, Princeton University, Report PU/CES 44, (January 1977); to be published in Energy.

n/ T. W. Usowicz and M. M. Hawley, "Discussion Paper," San Francisco Bay Area Rapid Transit District (March 30, 1977).

o/ Charles Lave, "The Energy Loss from Downtown People Movers," University of California at Irvine (1977).

p/ Metropolitan Atlanta Rapid Transit Authority, "The Effects of MARTA on Gasoline Consumption in the Atlanta Region," no date.

q/ Jeffrey Bowe et al., "Assessment of Operational Automated Guideway Systems -- Airtrans (Phase 1)," Transportation Systems Center Report UMTA-MA-06-0067-76-1 (September 1976), p. 5-11.

r/ Tri-State Regional Planning Commission, "Energy Propulsion Efficiency of Tri-State Ground Modes of Passenger Transportation," Interim Technical Report 4502-2601 (March 1975), pp. 12, 48.

TABLE A-2. VARIOUS ESTIMATES OF VEHICLE OCCUPANCY FOR URBAN TRANSPORTATION MODES: AVERAGES FOR GENERAL URBAN AREAS AND SPECIFIC CITIES (SYSTEMS)

Mode and City (System)	Vehicle Occupancy (Passenger-Miles per Vehicle-Mile)	Load Factor (Passenger-Miles per Seat-Mile)
Automobile		
National home-to-work and work-related travel a/	1.4	0.28
Average for specific cities		
Philadelphia b/	1.14	0.23
New Jersey c/	1.12-1.24	0.22-0.25
Albuquerque d/	1.43	0.29
Chicago d/	1.43	0.29
San Diego d/	1.48	0.30
Baltimore d/	1.49	0.30
New York metropolitan area e/	1.5	0.30
National urban area average d/	1.63	0.33
Light Rail		
Average for specific cities		
Newark f/	9.4	0.15
Philadelphia (SEPTA, city) f/	17.7	0.28
Philadelphia (SEPTA, Red Arrow) f/	17.8	0.28
San Francisco f/	23.6	0.37
Cleveland d/	26.5	0.42
Pittsburgh f/	27.8	0.44
Heavy Rail		
Old systems		
New York/New Jersey (PATH) f/	17.3	0.24
Chicago (1973) g/	18.6	0.26
New York City (Transit Authority, 1973) g/	19.7	0.27
Boston (includes light rail) f/	25.6	0.36
Chicago f/	20.7	0.29
Cleveland f/	23.9	0.33
New York City (Transit Authority) f/	25.0	0.35
Philadelphia (SEPTA) f/	28.8	0.40

(Continued)

TABLE A-2. (Continued)

Mode and City (System)	Vehicle Occupancy (Passenger-Miles per Vehicle-Mile)	Load Factor (Passenger-Miles per Seat-Mile)
New systems		
San Francisco (BART) f/	19.8	0.27
San Francisco (BART, 1975) g/	21.4	0.30
Philadelphia (Lindenwold) f/	22.5	0.31
National urban area average h/	24.5	0.34
Urban Bus		
Average for specific cities		
Albuquerque d/	4.9	0.10
Southern Connecticut e/	9.8	0.20
Chicago d/	10.9	0.22
San Diego d/	11.7	0.23
New York City(Transit Authority) e/	13.8	0.28
Baltimore d/	19.1	0.28
National urban area average, 1973 h/	11.5	0.23
Dial-a-Ride		
Nine cities h/	1.00-2.86	0.05-0.15
Seven cities i/	0.8-3.3	0.04-0.17
Median	1.62	0.09
Commuter Rail		
Average for specific cities		
New York metropolitan area f/	24.2	0.24
Boston f/	25.6	0.26
Philadelphia f/	29.4	0.29
New York metropolitan area e/	32.2	0.32
Chicago f/		
Burlington Northern	58.7	0.59
Chicago and Northwestern	47.7	0.48
Illinois Central	59.5	0.60

(Continued)

TABLE A-2. (Continued)

Mode and City (System)	Vehicle Occupancy (Passenger-Miles per Vehicle-Mile)	Load Factor (Passenger-Miles per Seat-Mile)
Milwaukee	50.2	0.50
Norfolk & Western	20.7	0.21
Rock Island	36.7	0.37
San Francisco f/	47.5	0.48
National urban area average h/	42.6	0.43
Vanpool		
Minneapolis (3M Company) j/	10.5	0.87
Carpool		
New York/New Jersey (Port Authority) k/	2.94	0.59
El Segunda, California l/	3.09	0.62
Boston m/	3.16	0.63
Connecticut n/	3.70	0.74

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a/ U.S. Department of Transportation, Federal Highway Administration, National Personal Transportation Study, Report No. 1, April 1972.

b/ David E. Boyce et al., "Impact of a Suburban Rapid Transit Line on Fuel Consumption and Cost for the Journey to Work," prepared for Federal Energy Administration, December 1975.

c/ Jerome Lutin, "Energy Savings for Work Trips: Analysis of Alternative Commuting Patterns for New Jersey," Transportation Research Record 561, 1976, pp. 23-26.

d/ R. H. Pratt et al., "The Potential for Transit as an Energy Saving Option," prepared for Federal Energy Administration, March 1976.

TABLE A-2. (Continued)

e/ Tri-State Regional Planning Commission, "Energy Propulsion Efficiency of Tri-State Ground Modes of Passenger Transportation," Interim Technical Report 4502-2601, March 1975, pp. 12, 48. data are for 1972.

f/ Stanford Research Institute, "Railroad Energy Study: Description of Rail Transportation in the United States," vol. II, "Rail Passenger Transportation," prepared for Energy Research and Development Administration, January 1977.

g/ Raymond Ellis and Alistair Sherret, "Transportation and Travel Impact of BART, Interim Service Findings," Peat Marwick, Mitchell & Company, April 1976.

h/ Mayo S. Stuntz, Jr., and Eric Hirst, "Energy Conservation Potential of Urban Mass Transit," prepared for Federal Energy Administration, Conservation Paper No. 34, December 1975.

i/ Reid Ewing and Nigel Wilson, "Innovations in Demand Responsive Transit," prepared for U.S. Department of Transportation, October 1976, p. 13.

j/ Robert Owens and Helen Sever, "The 3M Commute-A-Van Program," in Urban Transportation Efficiency (American Society of Civil Engineers, 1977), pp. 146-74.

k/ Brendan O'Malley, "Port Authority Carpool Program Telephone Follow-Up Survey," in Urban Transportation Efficiency (American Society of Civil Engineers 1977), pp. 125-45.

l/ Federal Highway Administration Carpool Incentive and Opportunities (February 1975).

m/ Carla Heaton, "Case Study Evaluation of the Boston Area Carpooling Program," prepared for the U.S. Department of Transportation, May 1976.

n/ Charles Gudatis, "Successful Approaches to Increased Ride Sharing in Connecticut," in Urban Transportation Efficiency (American Society of Civil Engineers, 1977), p. 118.

TABLE A-3. VARIOUS ESTIMATES OF MAINTENANCE AND STATION ENERGY FOR URBAN TRANSPORTATION MODES

Mode of Transportation	BTUs per Vehicle-Mile	Million BTUs per Month	City (System)
Automobile	1,634		General urban a/
	4,930		General urban (includes tolls, insurance, parking) b/
Vanpool			Minneapolis (3M Company) c/
Heavy Rail (Old)	3,550		New York City (Transit Authority, maintenance) d/
	4,030		New York/New Jersey PATH, maintenance) d/
	3,360		New York/New Jersey (PATH, station) d/
	6,390		New York City (Transit Authority, station) d/
	7,390		New York/New Jersey (PATH, combined) d/
	9,940		New York City (Transit Authority, combined) d/
		231	New York/New Jersey (PATH, station, average) d/
		349	New York City (Transit Authority, station, average-derived) d/
Heavy Rail (New)	2,000		Philadelphia (Lindenwold, maintenance) d/
	2,200		San Francisco (BART, maintenance) d/
	11,970		Philadelphia (Lindenwold, station) d/
	12,500		San Francisco (BART, station) d/

(Continued)

TABLE A-3. (Continued)

Mode of Transportation	BTUs per Vehicle-Mile	Million BTUs per Month	City (System)
	13,970		Philadelphia (Lindenwold, combined) d/
	14,700		San Francisco (BART, combined) d/
	22,700		San Francisco (BART, combined, current) a/
	15,190-16,690		San Francisco (BART, combined, future) a/
		368	Philadelphia (Lindenwold, station average) d/
		735	San Francisco (BART, aerial station, average d/
		1,995	San Francisco (BART, underground station, average) d/
		1,260	San Francisco (BART, station, average) d/
Bus	861		General urban a/

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a/ T.W. Usowicz and M.M. Hawley, "Discussion Paper," San Francisco Bay Area Rapid Transit District, March 30, 1977, Table 2. Assumes that maintenance costs equal 23 percent of propulsion costs. Uses data from Eric Hirst "Energy Consumption for Transportation in the U.S.," Oak Ridge National Laboratory, ORNL-NSF-EP-15, March 1972.

b/ Office of Technology Assessment, Energy, the Economy and Mass Transit (December 1975), p. 22.

c/ Robert D. Owens and Helen L. Sever, "The 3M Commute-A-Van Program," in Urban Transportation Efficiency (American Society of Civil Engineers, 1977), p. 158.

d/ Margaret Fels, "Breakdown of Energy Costs for Rapid Rail Systems," The Center for Environmenal Studies, Princeton University, Report PU/CES 44, January 1977, pp. 33, 39; to be published in Energy.

TABLE A-4. VARIOUS ESTIMATES OF GUIDEWAY CONSTRUCTION ENERGY PER GUIDEWAY-MILE FOR URBAN TRANSPORTATION MODES: BTUs IN BILLIONS

Mode of Transportation	BTUs per One-Way Guideway-Mile	Source (Comment)
Highway	15.70	Fels (one overpass per six-lane miles, average) a/
	17.07	DeLeuw (roadway only, average) b/
	9.21-26.28	DeLeuw (roadway only, range) b/
	130.38	DeLeuw (bridge only, average) b/
	40.96-327.31	DeLeuw (bridge only, range) b/
	41.64	Bezdek and Hannon (derived estimate) c/
Heavy Rail (New)	84.98	Fels (San Francisco, BART, average) a/
	17.07-19.11	Fels (San Francisco, BART, at-grade) a/
	55.63	Fels (San Francisco, BART, elevated) a/
	163.14	Fels (San Francisco, BART, subway, cut and cover) a/
	328.33	Fels (San Francisco, BART, subway, tunnel) a/
	12.29	DeLeuw (typical systems, at-grade) b/
	55.46	DeLeuw (typical systems, elevated) b/
	117.07	DeLeuw (typical systems, subway) b/
	330.00	Bezdek and Hannon (San Francisco, BART, derived estimate, includes stations) c/
	774.65	Healy (San Francisco, BART, derived estimate, includes stations) d/
Light Rail	12.29	DeLeuw (typical system, at-grade) b/
	55.46	DeLeuw (typical system, elevated) b/
	99.51	DeLeuw (typical system, subway) b/
Personal Rapid Transit	57.68	Fels (small car system) a/
	29.01	Fels (large car system) a/
Group Rapid Transit	19.97	DeLeuw (at-grade) b/
	38.91	DeLeuw (elevated) b/
	87.71	DeLeuw (subway) b/

a/ Margaret F. Fels, "Comparative Energy Costs of Urban Transportation Systems," Transportation Research, vol. 9 (1975), pp. 297-308.

b/ DeLeuw, Cather and Company, "Indirect Energy Consumption for Transportation Projects," prepared for California Department of Transportation (October 1976).

c/ R. Bezdek and B. Hannon, "Energy, Manpower, and the Highway Trust Fund," Science, vol. 185 (1974), pp. 669-75.

d/ Timothy Healy, "Energy Requirements of the Bay Area Rapid Transit System," California Department of Transportation (1973).

TABLE A-5. VARIOUS ESTIMATES OF VEHICLE MANUFACTURING ENERGY FOR URBAN TRANSPORTATION MODES

Mode	Million BTUs per Vehicle	BTUs per Vehicle-Mile a/	Source/ Comments
Automobile	71.7	717	Fels/2000 lb. car b/
	132.0	1,056	Tucker c/
	108.5	N/A	Hirst/1970 d/
	N/A	1,200	Usowicz and Hawley e/
	133.1	1,331	Fels/3600 lb. car b/
	129.0	N/A	DeLeuw/3500 lb. car f/
	120.7	N/A	DeLeuw/2500 lb. car f/
Vanpool/ Dial-A-Ride	184.3	1,843	Fels/gas b/
	279.9	2,799	Fels/diesel b/
Heavy Rail (New)	4096.0	1,365	Fels/BART car in San Francisco b/
Light Rail		2,199-13,010	Tucker c/
Bus	1024.0	1,024	Fels b/
	N/A	955-2,629	Tucker c/
Personal Rapid Transit	292.0-614.0	648-1,365	Fels b/
	410.0	N/A	DeLeuw f/
Group Rapid Transit	N/A	743-1,322	Tucker c/

N/A = Not Available.

a/ Uses estimate of vehicle life used by source.

b/ Margaret Fels, "Comparative Energy Costs of Urban Transportation Systems," Transportation Research, vol. 9 (1975), pp. 197-308.

c/ H. Lee Tucker, Jr., "Energy Efficiency of Urban Transit Systems," presented at Fourth National Conference on the Effects of Energy Constraints on Transportation, August 1977.

d/ Eric Hirst, "Energy Consumption for Transportation in the U.S.," Oak Ridge National Laboratory, ORNL-NSF-EP-15, March 1972.

e/ T.W. Usowicz and M.M. Hawley, "Discussion Paper," BART, March 30, 1977, Table 2.

f/ DeLeuw, Cather and Company, "Indirect Energy Consumption for Transportation Projects," prepared for California Department of Transportation, , October 1975, p. 21.

TABLE A-6. VARIOUS ESTIMATES OF VEHICLE AND GUIDEWAY LIFESPANS FOR URBAN TRANSPORTATION MODES IN VEHICLE-MILES

Mode	Vehicle Lifespan	Guideway Lifespan	Source
Automobile	80,000	N/A	Deleuw a/
	100,000	160,000,000	Fels b/
	125,000	N/A	Tucker c/
Vanpool/ Dial-A-Ride	100,000	100,000,000	Fels b/
Heavy Rail Transit	3,000,000	35,000,000	Fels b/
	1,500,000	N/A	Tucker c/
Bus	1,000,000	54,000,000	Fels b/
	1,000,000	N/A	Tucker c/
Personal Rapid Transit	450,000	360,000,000	Fels b/
	1,000,000	N/A	Tucker c/
Group Rapid Transit	475,000-1,500,000	N/A	Tucker c/
Shuttle Loop Transit	475,000-1,500,000	N/A	Tucker c/

N/A = Not Available.

a/ DeLeuw, Cather and Company, "Indirect Energy Consumption for Transportation Projects," prepared for California Department of Transportation, October 1975, p. 5.

b/ Margaret Fels, "Comparative Energy Costs of Urban Transportation Systems," Transportation Research, vol. 9 (1975), p. 304.

c/ H. Lee Tucker, Jr., "Energy Efficiency of Urban Transit Systems," presented at Fourth National Conference on the Effects of Energy Constraints on Transportation, August 1977.

TABLE A-7. VARIOUS ESTIMATES OF MODE OF ACCESS TO LINE-HAUL TRIP: IN PERCENTAGES

Mode and City (System)	Park and Ride	Dropped Off	Feeder Bus	Walk	Other
Heavy Rail (New)					
Philadelphia (Lindenwold) a/	67	23	5	5	
San Francisco (BART) b/	47	13	16	22	2
Boston (South Shore Extension) c/	33	16	16	32	
Bus					
Washington (Shirley corridor) d/					
Before highway	20			75	5
After highway	16	11		74	

a/ DeLeuw, Cather and Company, "Case Studies of Transit Energy and Air Pollution Impacts," prepared for Environmental Protection Agency, May 1976, p. 155.

b/ Raymond Ellis and Alistair Sherret, "Transportation and Travel Impacts of BART: Interim Service Findings," prepared for U.S. Department of Transportation, April 1976, p. 88.

c/ Metropolitan Area Planning Council, "South Shore Rail Rapid Transit Extension: Preliminary Impact Study," report prepared for the Massachusetts Bay Transportation Authority, October 1973.

d/ J.M. McLynn and Keith M. Goodman, "Mode Choice and the Shirley Highway Experiment," report prepared by DTM Inc. for the National Bureau of Standards, November 1973, pp. 20, 37.

TABLE A-8. SOURCE OF NEW PATRONS OF URBAN TRANSPORTATION MODES BY PERCENT FROM VARIOUS FORMER MODES

Mode and City(System)	Former Mode Auto Driver	 Auto Rider	 Bus	 Other Transit	 Other	 New Trip a/
Vanpool Minneapolis (3M Company) b/	56	42	2			
Carpool						
Boston c/	53	28		18 d/		1
Eastern Massachusetts c/	75	N/A		19 e/		6
New York/New Jersey (Port Authority program) f/	61	20	11	8 g/		
Connecticut h/	25	60			3	12
Heavy Rail Transit						
Philadelphia (Lindenwold) i/	28	12	36		11	13
San Francisco (BART) j/	27	8	54			11
Boston (South Shore Extension) k/	42	39			3	16
Chicago (Dan Ryan) l/	8		72 m/	8 n/	6	6
Chicago (Skokie Swiftie improved service) l/	24	5	28	9 n/	6	28
Bus						
Honolulu (express bus CBD route) o/	57	22	18		3	
Honolulu (express bus university route) o/	39	27	27		6	
Washington (reserved lane) p/	23	8	18			51
Miami (contraflow lane) q/	65	13 r/	17		6	
Atlanta (fare reduction weekday) s/	42	22		10	5 t/	22
Atlanta (fare reduction Saturday) s/	33	19		11	8 t/	29
Atlanta (fare reduction Sunday) s/	30	21		6	16 t/	27

(Continued)

TABLE A-8. (Continued)

Dial-A-Ride u/					
Ann Arbor, Michigan	47(10 taxi)	N/A	23 t/	4	26
Benton Harbor, Mich.	45(2 taxi)	N/A	15 t/	6	34
Columbus, Ohio	31(15 taxi)	36	26 t/	0	7
Ludington, Michigan	43(20 taxi)	0	30 t/	13	14
Midland, Michigan	49(10 taxi)	0	25 t/	8	18
Niles, Michigan	42(34 taxi)	0	40 t/	10	8
Oneonta, New York	44(19 taxi)	0	44 t/	12	N/A
Rochester, New York	28	22	13 t/	5	32
Santa Clara County California	67(5 taxi)	N/A	19 t/	0	14
Xenia, Ohio	36	0	34 t/	11	19

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a/ There is no diversion from a former mode; a person who previously did not use a mode of transportation is using the new mode.

b/ Robert D. Owens and Helen Sewer, "The 3M Commute-A-Van Program," Urban Transportation Efficiency (American Society of Civil Engineers, 1977), p. 163. Of the automobile drivers, 44 percent drove alone. Of the riders in automobiles, 39 percent were in carpools.

c/ Carla Heaton, "Case Study Evaluation of the Boston Area Carpooling Program,"Transportation Systems Center, May 1976. The Boston data refer to the results of a special carpool matching effort. Eastern Massachusetts refers to a control part of this special effort.

d/ 11 percent involved combined auto-transit trips.

e/ 8 percent involved combined auto-transit trips.

f/ Brendan O'Malley, "Port Authority Carpool Program Telephone Follow-Up Survey," in Urban Transportation Efficiency (American Society of Civil Engineers, 1977), p. 130.

g/ The former mode of this group was rail.

h/ Charles Gudaitis, "Successful Approaches to Increased Ride Sharing in Connecticut," in Urban Transportation Efficiency (American Society of Civil Engineers, 1977), p. 116.

i/ DeLeuw, Cather and Company, "Case Studies of Transit Energy and Air Pollution Impacts," prepared for Environmental Protection Agency, May 1976, p. 150.

j/ Raymond Ellis and Alistair Sherret, "Transportation and Travel Impacts of BART: Interim Service Findings," prepared for U.S. Department of Transportation, April 1976, p. 110.

TABLE A-8. (Continued)

k/ Metropolitan Area Planning Council, "South Shore Rail Rapid Transit Extension: Preliminary Impact Study," report prepared for the Massachusetts Bay Transportation Authority, October 1973.

l/ George W. Hilton, Federal Transit Subsidies (American Enterprise Institute, 1974), pp. 36, 67.

m/ 35 percent made combined bus-rail trips.

n/ The former mode of this group was commuter rail.

o/ Mark Bennett et al., "Express Bus Use in Honolulu: A Case Study," Transportation Research Record, No. 606 (1976), pp. 6-11.

p/ J.M. McLynn and Keith M. Goodman, "Mode Choice and the Shirley Highway Experiment," report prepared by DTM Inc. for the National Bureau of Standards, November 1973.

q/ Harry S. Rose and David H. Hinds, "South Dixie Highway Contraflow Bus and Carpool Lane," Transportation Research Recrod, No. 606 (1976), pp. 18-22.

r/ The former mode of this group was carpool.

s/ John W. Bates, "Effect of Fare Reduction on Transit Ridership in the Atlanta Region: Summary of Transit Passenger Data," Transportation Research Record, No. 499 (1974), pp. 1-11.

t/ The former mode of this group was walking.

u/ Reid Ewing and Nigel Wilson, "Innovations in Demand--Responsive Transit," prepared for U.S. Department of Transportation, October 1976, p. 23.

APPENDIX B. HIGH AND LOW VALUES FOR ENERGY FRAMEWORK

TABLE B-1. LOW ESTIMATES OF BASIC COMPONENTS OF OPERATING ENERGY INTENSIVENESS AND LINE-HAUL ENERGY BY URBAN TRANSPORTATION MODES: IN BRITISH THERMAL UNITS (BTUs) PER VEHICLE-MILE

Mode	Propulsion Energy	Average Number of Occupants	Station and Maintenance Energy	Construction Energy	Vehicle Manufacturing Energy
Single-Occupant Automobile	6,000	1.0	1,500	60	800
Average Automobile	6,000	1.6	1,500	60	800
Carpool	6,000	3.5	1,500	60	800
Vanpool	12,000	11	1,500	100	1,800
Dial-a-Ride	13,500	3	1,500	100	1,800
Heavy Rail (Old)	50,000	26	7,000	1,400	1,300
Heavy Rail (New)	55,000	23	14,000	2,000	1,300
Commuter Rail	70,000	50	5,000	500	2,000
Light Rail Transit	55,000	26	5,000	600	1,500
Bus	25,000	19	700	180	1,000
Personal Rapid Transit	6,000	3	3,000	160	700
Group Rapid Transit	10,000	8	4,000	400	800
Shuttle Loop Transit	15,000	14	5,000	400	800

TABLE B-2. HIGH ESTIMATES OF BASIC COMPONENTS OF OPERATING ENERGY INTENSIVENESS AND LINE-HAUL ENERGY BY URBAN TRANSPORTATION MODES: IN BRITISH THERMAL UNITS (BTUs) PER VEHICLE-MILE

Mode	Propulsion Energy	Average Number of Occupants	Station and Maintenance Energy	Construction Energy	Vehicle Manufacturing Energy
Single-Occupant Automobile	15,000	1.0	4,000	250	1,300
Average Automobile	15,000	1.1	4,000	250	1,300
Carpool	15,000	2.5	4,000	250	1,300
Vanpool	17,000	8	4,000	400	2,500
Dial-a-Ride	17,500	1	4,000	400	2,500
Heavy Rail (Old)	93,000	19	10,000	12,000	6,000
Heavy Rail (New)	90,000	19	20,000	17,000	6,000
Commuter Rail	130,000	25	8,000	2,500	10,000
Light Rail Transit	90,000	15	8,000	2,900	10,000
Bus	35,000	6	2,000	750	2,500
Personal Rapid Transit	18,000	1	6,000	500	1,300
Group Rapid Transit	30,000	4	7,000	1,500	1,300
Shuttle Loop Transit	70,000	6	8,000	1,500	1,300

TABLE B-3. LOW ESTIMATES OF ACCESS, CIRCUITY, AND SOURCE OF PATRONAGE BY URBAN TRANSPORTATION MODES

Mode	Mode of Access (Percent)	Percent of Trip Devoted to Access	Circuity (Relative to Trip by Auto)	Percent of New Patrons by Former Mode
Automobile	N/A	0	1.0	N/A
Carpool	N/A	0	1.1	15 bus 65 single-occupant auto 20 carpool
Vanpool	N/A	0	1.1	2 bus 40 carpool 58 single-occupant auto
Dial-a-Ride	N/A	0	1.3	10 bus 15 walk 55 auto (15 taxi) 20 new trip a/
Heavy Rail (Old)		10	1.1	
Heavy Rail (New)	20 bus 50 auto 30 walk	15	1.2	30 bus 55 auto 10 new trip a/ 5 other
Commuter Rail	15 bus 70 auto 15 walk	15	1.2	15 bus 55 auto 10 new trip a/ 20 other
Light Rail	25 bus 25 auto 50 walk	8	1.1	30 bus 50 auto 10 new trip a/ 10 other
Bus (Express)	20 auto 80 walk	8	1.1	15 bus 75 auto 10 other

N/A = Not Applicable.

a/ There is no diversion from a former mode; a person who previously did not use a mode of urban transportation is using the new mode.

TABLE B-4. HIGH ESTIMATES OF ACCESS, CIRCUITY, AND SOURCE OF PATRONAGE BY URBAN TRANSPORTATION MODES

Mode	Mode of Access (Percent)	Percent of Trip Devoted to Access (Percent)	Circuity (Relative to Trip by Auto)	Percent of New Patrons by Former Mode
Automobile	N/A	0	1.0	N/A
Carpool	N/A	0	1.3	20 bus 50 single-occupant auto 30 carpool
Vanpool	N/A	0	1.4	10 bus 60 carpool 30 single-occupant auto
Dial-A-Ride	N/A	0	1.6	10 bus 40 walk 30 auto (10 taxi) 20 new trip a/
Heavy Rail (Old)		20	1.3	
Heavy Rail (New)	5 bus 90 auto 5 walk	25	1.4	25 auto 50 bus 25 new trip a/
Commuter Rail	10 walk 90 auto	25	1.4	30 auto 20 bus 40 new trip a/ 10 other
Light Rail	15 bus 60 auto 15 walk	15	1.3	30 auto 30 bus 40 new trip a/
Bus (Express)	70 auto 30 walk	15	1.2	30 auto 30 bus 40 new trip a/

N/A = Not Applicable.

a/ There is no diversion from a former mode; a person who previsously did not use a mode of urban transportation is using the new mode.

APPENDIX C. DETAILS OF COMPUTATIONAL PROCEDURES

Operating Energy Intensiveness

Operating energy intensiveness is calculated by dividing the propulsion energy per vehicle-mile by the average number of passengers.

Line-Haul energy

Line-haul energy combines operating energy with the energy used for stations and maintenance, guideway construction, and vehicle manufacturing. Station and maintenance energy is measured in terms of energy used per vehicle-mile. Guideway construction energy is divided by an estimate of the lifespan of the roadway, measured in vehicle-miles, to arrive at construction energy per vehicle-mile. Similarly, the energy used to manufacture the vehicle is divided by an estimate of the vehicle life, resulting in vehicle manufacturing energy per vehicle-mile. All three (station and maintenance energy per vehicle-mile, construction energy per vehicle-mile, and vehicle manufacturing energy per vehicle-mile) are summed and then divided by the average number of passengers per vehicle. This total is added to operating energy intensiveness (per passenger-mile) to yield line-haul energy.

Modal Energy

Modal energy combines line-haul energy, as calculated above, with an estimate of energy used in gaining access to the mode. It is adjusted for any roundaboutness (extra miles traveled) as compared with a similar trip by automobile. Typically, a different mode of transportation is used to reach the line-haul part of a trip. The energy used by each such access mode is approximated using its line-haul energy per passenger-mile, as calculated above. The access energy per passenger-mile for each access mode is multiplied by the fraction of travelers using that mode for access and then summed across all access modes. This results in average access energy per passenger-mile. In mathematical shorthand this is:

$$\text{Access energy} = \sum_{i=1}^{n} K_i E_i$$

where:

n = number of access modes,

K_i = the fraction of travelers who use mode i for access,

E_i = energy per passenger-mile for access mode i (energy consumed in walking is assumed to be negligible).

The total access energy is then multiplied by a measure of how important access is compared with the line-haul trip. The result is added to line-haul energy, and this new total is multiplied by the circuity factor for the line-haul mode. In mathematical shorthand:

$$Mj = C_j(fA_j + (1-f)L_j)$$

where:

M_j = modal energy per passenger-mile for mode j (the line-haul mode),

C_j = circuity factor for mode j (total access and line-haul miles for mode j divided by the total miles for the same trip by a single-occupant automobile),

f = fraction of total trip miles (access plus line-haul) represented by access,

A_j = access energy per passenger-mile for mode j, as computed above,

L_j = line-haul energy per passenger-mile for mode j.

Program Energy

Program energy, or the expected net energy savings from a new transportation service, is simply the modal energy that would have been used without any change in the transportation system minus the modal energy used by the new service. Usually, a new transportation service attracts riders from a number of modes. The fraction of passengers previously using each of these modes is multiplied by the modal energy of the respective modes, and the results are summed to equal the energy per passsenger-mile, exclusive of energy required by the new service. In mathematical terms:

$$W_j = \sum_{i=1}^{m} F_i M_i$$

where:

W_j = energy per passenger-mile without new transportation service j,

m = number of modes used before j is introduced,

F_i = fraction of passengers who previously used mode i,

M_i = modal energy for mode i.

The modal energy for the new service is then subtracted from this sum (W_j) to arrive at the net savings or program energy ($P_j = W_j - M_j$).

In calculating W_j, it is assumed that new trips used no energy previously, and thus they represent increased energy use after the new service is introduced. Trips formerly made by modes classified under "other," are assumed to use the same energy per passenger-mile as the new mode that replaced them.

The middle estimates for program energy are obtained by applying the above process to the middle estimates for previous mode shares (F_i) and modal energy (M_i). High estimates of program energy are constructed by applying the high values of the previous mode shares (F_i), the high estimate of the modal energy (M_i) of the mode under consideration, and middle estimates of the modal energy of all the other previous modes of travel. Similarly, the low estimates of program energy apply the middle values for modal energy for previous travel modes other than the one under consideration.

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