Technical Report Documentation Page

1. REPORT No.

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE

Energy and Transportation Systems

5. REPORT DATE

December 1978

6. PERFORMING ORGANIZATION

7. AUTHOR(S)

J.A. Apostolos, W.R. Shoemaker, E.C. Shirley

8. PERFORMING ORGANIZATION REPORT No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Office of Transportation Laboratory
Division of Construction
California Department of Transportation

10. WORK UNIT No.

11. CONTRACT OR GRANT No.

13. TYPE OF REPORT & PERIOD COVERED

Final Report

12. SPONSORING AGENCY NAME AND ADDRESS

American Association of State Highway and Transportation Officials

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This work was sponsored by the American Association of State Highway and Transportation Officials, in cooperation with the Federal Highway Administration, and was conducted in the National Cooperative Highway Research Program, which is administered by the Transportation Research Board of the National Research Council.

16. ABSTRACT

Summary

This report represents a synthesis of current information on the energy-related aspects of transportation systems. It is intended to be a source of data and a textbook for engineers, planners and others responsible for performing energy analyses and preparing environmental impact statements.

The text presents the following:

1.) An introduction to the current use of energy in transportation, which is primarily in the form of petroleum fuels, and predictions indicating the rapid depletion of sources by the end of the 20th century; and a discussion of the method followed by the researchers, which was primarily a far-reaching literature search and evaluation of existing information.

2.) A discussion of the basic considerations relating to the subject, including: the need to consider not only the fuel (direct energy) used by vehicles, but the remaining (indirect) energy required to manufacture and maintain necessary facilities such as roads, airports, peripheral equipment, pipeline pumps, etc.; the need to consider the actual service being rendered by a system or a vehicle, which is usually far below its theoretical potential; the need to consider the potential; the need to consider the potential effects a project may have in the fuel/energy distribution of a geographic region; and other considerations.

17. KEYWORDS

18. No. OF PAGES:

294

19. DRI WEBSITE LINK

http://www.dot.ca.gov/hq/research/researchreports/1978-1980/78-39.pdf

20. FILE NAME

78-39.pdf

ENERGY

AND

TRANSPORTATION SYSTEMS

FINAL REPORT

PREPARED FOR

PROJECT 20-7, TASK 8
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

TRANSPORTATION RESEARCH BOARD

NATIONAL RESEARCH COUNCIL

J. A. APOSTOLOS, W. R. SHOEMAKER, E. C. SHIRLEY

OFFICE OF TRANSPORTATION LABORATORY

DIVISION OF CONSTRUCTION
CALIFORNIA DEPARTMENT OF TRANSPORTATION

December 1978

Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

Acknowledgment

This work was sponsored by the American Association of State Highway and Transportation Officials, in cooperation with the Federal Highway Administration, and was conducted in the National Cooperative Highway Research Program, which is administered by the Transportation Research Board of the National Research Council.

LIST OF FIGURES

LIST OF TABLES

TABLE OF CONTENTS

Acknowledgments

The research reported herein was performed under NCHRP Project 20-7 by the Enviro-Chemical Branch, Office of Transportation Laboratory, Division of Construction, California Department of Transportation, with Earl C. Shirley, Chief, Enviro-Chemical Branch, as principal investigator. The other authors of this report are: John A. Apostolos, Assistant Physical Testing Engineer; and William R. Shoemaker, Associate Environmental Planner, California Department of Transportation.

The work was performed under the general supervision of Mr. Shirley. Initial work in accumulation of references and data and in authoring an interim report was performed by Michael D. Batham, Roger D. Smith, and Donald J. Ames, Assistant Physical Testing Engineers, California Department of Transportation. Additional references and assistance were provided by Richard R. Trimble, Associate Materials and Research Engineer; Deane M. Coats, Associate Transportation Engineer; and Ronald D. Duncan, Highway Engineering Technician I, California Department of Transportation.

The review of the sources and development of data were performed by Messrs. Apostolos and Shoemaker. The final report was prepared by Mr. Apostolos and reviewed and augmented by Mr. Shirley.

The assistance of the many individuals who provided the authors with their data and personal expertise, and the work by the many authors upon which an effort of this type is ultimately based, is gratefully acknowledged.

SUMMARY

This report represents a synthesis of current information on the energy-related aspects of transportation systems. It is intended to be a source of data and a textbook for engineers, planners and others responsible for performing energy analyses and preparing environmental impact statements.

The text presents the following:

1) An introduction to the current use of energy in transportation, which is primarily in the form of petroleum fuels, and predictions indicating the rapid depletion of sources by the end of the 20th century; and a discussion of the method followed by the researchers, which was primarily a far-reaching literature search and evaluation of existing information.

2) A discussion of the basic considerations relating to the subject, including: the need to consider not only the fuel (direct energy) used by vehicles, but the remaining (indirect) energy required to manufacture and maintain the vehicles, as well as to construct and maintain necessary facilities such as roads, airports, peripheral equipment, pipeline pumps, etc.; the need to consider the actual service being rendered by a system or a vehicle, which is usually far below its theoretical potential; the need to consider the potential effects a project may have in the fuel/energy distribution of a geographic region; and other considerations.

3) Descriptions of the most important parameters affecting the rate of energy consumption of vehicles (such as engine type and fuel, weight, speed, altitude, and grade), depending on the particular transportation mode; and descriptions of the facility-related parameters (such as type and quantity of materials used, construction methods, practical useful lives, operation, and maintenance). Studies correlating construction/maintenance energy vs dollar expenditures are also discussed.

4) Recommended procedures for performing analyses of transportation energy consumption and comparing alternatives are discussed, along with a rational method of presentation of the results of an energy analysis.

5) An "Energy Factor Handbook" (Appendix A), containing substantial quantities of numerical data relating to energy associated with fuels, materials, vehicles, construction, operation, maintenance, dollar costs, etc. It is keyed to the source for the handbook (Appendix C).

CHAPTER ONE

INTRODUCTION

Background and Problem Statement

Every activity consumes some form of energy. Transportation in the twentieth century is directly consuming ever-increasing amounts of energy, approximately 96% of which is obtained from petroleum(1). Various estimates of domestic petroleum reserves and consumption rates indicate that these reserves will be depleted between the years 1993 and 2086(2). Also, the indirect consumption of energy for transportation system materials and processes competes with other important energy needs. It is anticipated that these needs will continue to grow more rapidly than the available energy supply.

These predictions point to the need for conservation and a shift to transportation technologies using alternative energy (fuel) sources. Conservation requires a reduction in the rate of energy consumption. Achievement of this result requires the careful selection and use of transportation facilities which provide the required service with minimum energy consumption.

Society, as represented by government and industry, has only recently recognized the potential impact of depleting petroleum fuels. Thus, transportation systems have developed without adequate study of their energy consumption characteristics. Studies of this nature have been conducted by a handful of farseeing individuals, and their work has acted as a nucleus for the subsequent research effort sponsored by government. It should be recognized that not much is known about transportation energy, and a large portion of the available data is based on informed estimates rather than scientific test.

Research Objectives and Approach

The objectives of this study were threefold. The first was to establish a list of "energy factors" for materials of construction, construction processes, maintenance processes, and operation of the system based on a synthesis of existing information. The second was to develop procedures for evaluating transportation systems in terms of relative energy use with respect to modal, spatial, and temporal alternatives both for planning and design using the energy factors established. The final objective was to develop a rational method for reporting the results of an energy use analysis.

The approach to the first objective involved conducting a far-reaching literature search, as well as in-house studies, to obtain and organize as much of the current knowledge on transportation-related energy as possible. Following the acquisition of available information, the material was reviewed, cross-referenced and compared. Where there were substantial differences in data for the same item, the authors exercised their prerogative of making the - often difficult - choice of which values to present. Finally, the selected data were organized for presentation.

For following this approach, an apology is due to the many authors whose material is incorporated in this report. The brevity of presentation has, of necessity, eliminated many of the amplifying remarks and caveats to be found in the source documents. The sources - keyed in the appendices to specific subjects - should be consulted for a broader understanding of the methods used by each author to develop his data and arrive at his conclusions.

Development of the procedures in the second objective was oriented toward assisting engineers, planners, and other professionals responsible for producing energy analyses. The purpose of the procedures would be to provide basic guidelines for comparison of alternative transportation facilities and projects and energy conservation measures based on their respective energy consumptions.

This orientation required procedures that could be applied without having to search through other references or having to possess an extensive knowledge of the energy field. It also required procedures sufficiently definitive to enable analyses ranging from project design to system alternatives.

Energy use had to be categorized in many ways: as being direct or indirect, in terms of transportation mode, in terms of vehicle operation mode, and in terms of materials and processes.

The approach to the reporting method was based on the uses that might be made of an energy analysis. In most cases, an energy analysis would serve as an additional element in the decision-making process and, in some cases, would be required as an input to an environmental impact statement. The latter application would probably be the most stringent and it was that application the approach addressed.

Conforming to the objectives and the research approach, the report is organized as a manual/handbook, and is intended as a basic text on the subject of energy and transportation systems. It includes a broad discussion of the subject, important points and theory for consideration, recommended methodology for preparation of energy comparisons in environmental impact reports and, in the appendices, includes comprehensive lists of energy factors and a glossary of terms.

Parallel and additional information on energy factors is included in "Energy Effects, Efficiencies, and Prospects for Various Modes of Transportation"(3).

General Transportation Energy Discussion

Every physical action requires the expenditure of energy. Primitive societies relied almost entirely on one form of solar energy for their needs - that which made plants grow for food directly or as food for game animals (biomass energy). As societies, through the genius of inventors, become technologically more complex, other forms of solar energy effects were used - wind for ships and windmills, falling water, and again, biomass, both for food and firewood. More recent technology, seeking new sources of energy, has added solar effects such as coal, oil, and gas to the list. Finally, in the twentieth century, additional solar sources (such as photovoltaic) as well as nonsolar energy sources (such as chemical and nuclear energy) have been developed.

Historically, technological advances have been followed by increased demand for energy. This fact, combined with a rising world population, has been increasing the rate of energy consumption at an accelerating pace, particularly in the developing countries. The result is that certain finite energy sources are being rapidly depleted. These sources are, primarily, petroleum and natural gas. The known or estimated reserves of petroleum, used as fuels and as raw materials for plastics, etc., are expected to be consumed in the late part of the 20th Century or the early part of the 21st Century, as indicated by the various predictions presented in Figure 1.

Population growth, along with technological advances and price, places a severe strain on the materials and energy requirements of a society. Recent estimates place the annual growth in world oil consumption over the next few years at 3.5%. Due to the sharp price increases since 1973, this is down from the 7% figure that prevailed between 1955 and 1973.

Petroleum fuels are of vital importance to transportation because they embody two qualities not shared with most other fuels: they provide, simultaneously, highly concentrated and portable energy. In comparison, electric batteries are portable, but their energy density, even in advanced concepts, cannot even approach that of gasoline; nuclear power is highly concentrated, but weight penalties for shielding, etc., severely limit its portability; other fuels, such as hydrogen, require large-volume, heavy pressure tanks (for compressed gas) or a continuous leakage rate to maintain supercold temperature (for liquid hydrogen). The potential of hydrogen fuel stored as iron-titanium hydride is also being studied in prototype vehicles. Fuels such as alcohol, derived from biomass, and synthetic fuels from coal are most likely to receive increasing attention because they share some of the attributes of petroleum fuels and would require a minimum investment in changes to fuel distribution systems and the internal combustion engine.

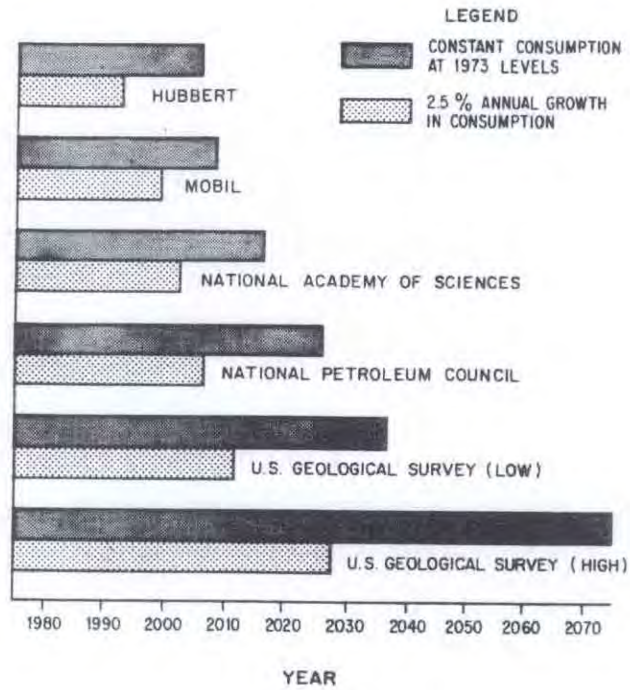


Fig. 1 Estimates of exhaustion date for domestic oil and natural gas liquids, assuming 35 percent imports.
Source: Ref. (2)

Under current technology, however, the advantages of petroleum fuels make them the overwhelming choice for providing the energy required in transportation. This fact is reflected in the estimate that 96% of energy used by transportation is derived from petroleum, and much of the remainder from natural gas(1).

Not only does transportation consume the most rapidly depleting form of energy; it also accounts for a significant portion of the over all energy consumption for all purposes. Recent estimates indicate that transportation fuel consumes 25% of the total national energy expenditure(4). When combined with indirect items such as vehicle manufacture, facility construction, maintenance, peripheral facilities, etc., the total transportation system consumes about 43% of the total expenditure, as shown in Figure 2.

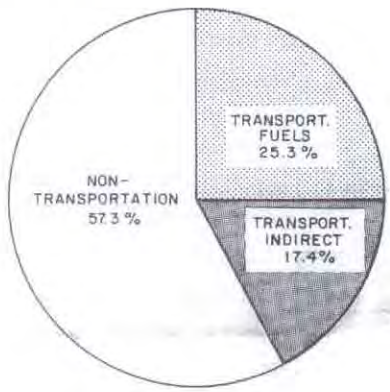


Fig. 2. Distribution of total U.S. energy consumption (1967).
Source: Loebl et al.(6).

A preeminent factor influencing transportation system development has been economics. From an energy standpoint, the choice of fuel for transportation - or for any other use, for that matter - was governed by the financial cost/benefit ratio inherent in any fuel-vehicle-service system. The effects of depletion were ignored, or regarded as inevitable, and short-term viewpoints were more attractive, especially in the face of low prices for raw petroleum.

Another factor that must be considered at this time is that the current transportation system is in existence and represents a tremendous investment by society, which is not willing to drastically change its life-styles.

Rising prices for petroleum and petrochemicals, and increasing concern over limited supplies, is forcing a review of priorities in decision-making on how and what type of energy should be consumed. Although new technologies are evolving, the emphasis on energy conservation is increasing. Modern transportation systems - evolving over the last century on an "abundant energy" basis - cannot be eliminated, nor can adequate substitutes be found in the short-term future. However, the fact that such systems were not designed with energy conservation as a primary criterion allows substantial improvement in their energy consumption characteristics. A mid-term conservation technique, for example, has been the requirement under U.S. Public Law 94-163, known as the Energy Policy and Conservation Act of 1975, that new private cars should travel an average of 27.5 miles per gallon of gas line by 1985, as opposed to the prevailir rate of 14 to 15 miles per gallon in 197 when the law was signed.

Long-term conservation techniques involve research in the field of transpor tation energy with the purpose of identifying exactly where the energy is being consumed. This research is followed by critical analysis and decisions on transportation-related projects, with emphasis on conservation, and research ir the field of alternative modes of transpc tation that would provide more energy-efficient service. This research is just beginning to bear fruit, and the energy consumption by various modes of transportation is being identified (Fig. 3).

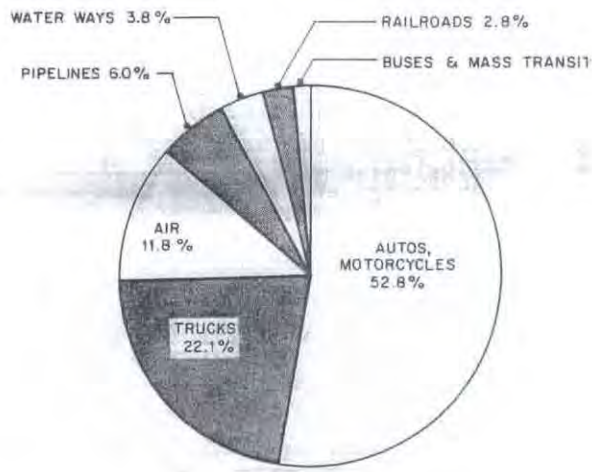


Fig. 3. Proportion of direct energy consumed, by transportation mode (1972).
Source: Pollard et al (5).

The real problem, however, is one inescapable fact: All indications are th natural petroleum fuels - the life blood of transportation as we know it - will become unavailable, in a practical sense, within the foreseeable future. Conservation will not alter that fact. As the supply of natural petroleum decreases, prices will increase and will probably le to the use of synthetic fuels from tar sands, oil shale, and coal as supplements. Eventually, new technologies will have to be developed to provide for the world's ever-expanding energy needs. The true benefit of conservation is that it may buy time for the development of synthetic fuel and new energy source technologies, thus providing a more orderly transition to the future.

Decisions on transportation systems and related projects must be based on predictions of future effects these system projects may cause. These predictions are incorporated in environmental impact statements (EIS) or reports (EIR). Among other considerations, such as social and economic impacts, these reports must also address the impact of energy consumption, conservation, and other energy-related factors. Adequate data will permit inform decisions on energy vs economic trade-offs, similar to pollution vs economic trade-offs made in current practice.

Public Law 91-190, known as The National Environmental Policy Act of 1969 (NEPA), requires that an EIS be prepared for federally funded projects and submitted for approval. This Act also established the Council on Environmental Quality (CEQ), which in turn established guidelines for the contents of EIS's. One of the required subjects for discussion is covered by the phrase: "Any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented". Energy consumption, although not specifically mentioned, is irreversible and irretrievable and should be included under this guideline.

The U.S. Department of Transportation, recognizing the necessity for incorporating an energy discussion in an EIS, issued DOT Order 5610.15. This order requires a discussion of significant effects on either energy production or energy consumption.

The Federal Highway Administration (FHWA) includes a requirement for discussion of significant energy impacts in the Federal-Aid Highway Program Manual (FHPM). This requirement (FHPM 7-7-2) appears under the heading, "Natural, Ecological, or Scenic Resources Impacts."

Public Law 94-163, previously mentioned, places strong emphasis on energy conservation, and requires states to produce plans to that effect and submit them to Federal authorities. This law further augments the NEPA-CEQ requirements.

Agencies responsible for transportation systems must meet certain legal requirements. In the United States, transportation agencies must meet federal law and federal agency regulations, as well as comply with state and local laws and regulations.

Section 108 of Public Law 95-95, The Clean Air Act Amendments of 1977, requires assessment of the energy impact of various transportation control measures and strategies. Individual states (e.g., California) are beginning to require by statute that energy be addressed in environmental impact reports.

This report is intended to assist responsible agencies to comply with these existing regulations, as well as future ones, for the preparation of comprehensive and factual analyses of energy use due to proposed transportation projects.

CHAPTER TWO

FINDINGS

OBJECTIVES OF THE STUDY

This study has addressed itself to attainment of the following objectives:

1. Establishing a list of "energy factors" for materials of construction, construction processes, maintenance processes, and operation of the system based on a synthesis of existing information.
2. Developing procedures for evaluating transportation systems in terms of relative energy use with respect to modal, spatial, and temporal alternatives for both planning and design using the energy factors developed.
3. Developing a rational method for reporting the results of an energy use analysis.

BASIC CONSIDERATIONS

Energy Units

Transportation may be described as the act of moving an object from one location to another. To perform this act, certain impeding forces (gravity, friction, etc.) must be overcome. To overcome these forces and achieve the desired transportation, work must be performed, which requires the expenditure of energy. Energy is defined as the ability to do work. It is thus convenient to describe energy in terms of units of work. A typical unit of work, for example, is a foot-pound, and a substance - say a fuel - capable of producing one foot-pound of work may be said to contain one foot-pound of energy.

Energy is present in many forms, such as chemical, kinetic, nuclear, potential, and thermal. One of the most important forms related to transportation is thermal energy; i.e., the heat value contained in fuels used for propulsion of vehicles. Classical experiments have determined the correlation between thermal energy and mechanical energy (foot-pounds) and, in fact, the units for all forms of physical energy are convertible to each other.

Commonly used units of transportation-related energy are the British thermal unit (Btu) in the English System and the Joule in the International System of Units (SI). Still in considerable use is the kwh (kilowatt-hour), which usually describes electrical energy. The American Society for Testing and Materials (ASTM) recommends that the kwh units be avoided, and expects their use in electrical applications to be superseded by the megajoule(7).

These units of energy should be used in the technical calculations required in an energy study. In order to provide a common unit to which a layman can relate, and to facilitate comparisons between alternatives using different forms of energy, it is recommended that the final values obtained through analyses be converted to "equivalent barrels of crude oil" (see Appendix D).

Direct and Indirect Energy

Transportation-related energy is usually separated into two main categories:

"Direct," defined as the energy consumed in the actual propulsive effort of a vehicle, such as the thermal value of the fuel, or quantity of electricity used in the engine or motor.

"Indirect," defined, in the broadest terms, as all the remaining energy consumed to run a transportation system. Although the definition of direct energy is relatively simple, both in concept and in measurement, the concept of indirect energy requires some in-depth discussion:

Indirect energy may be divided into two broad subcategories: central energy use and peripheral energy change. Central energy use encompasses all the energy resources used indirectly in building and operating a transportation system. It addresses the fact that energy must be expended to create and support a transportation system; for example, mining and refining raw materials into useful products such as vehicles or roads, exploring for and refining oil into various fuels, constructing and maintaining dams, power plants, transmission lines, fuel distribution systems, train stations, airports, maintenance facilities, etc. Thus, central energy use includes all but the fuel used for propulsion in a transportation system. It may be argued that items such as lubricants or tires should come under the "direct" category, and, although this does have some merit, it makes no difference in the final analysis, as long as these items are included in either direct or indirect energy consumption.

Peripheral energy change recognizes energy resources that are not used in any manner by the system itself. Rather, it addresses the potential effect that a transportation system may have on energy use and availability in the area it serves. For example, a highway through an agricultural area preempts certain acreage that would otherwise be used in the production of crops to produce energy in the form of food or as raw fuel for biomass conversion plants; or a sizeable shift in population density, land use, or transportation patterns may be fostered, or induced, by a project, which will have an impact on the energy demand, supply, and distribution within a certain geographical area.

It is much simpler to define qualitatively the concept of direct and indirect energy consumption, than to obtain reliable numerical data. The energy content of fuels may be obtained in the laboratory from bomb calorimeter tests. Fuel consumption rates of vehicles, especially road vehicles, are constantly being measured by the Environmental Protection Agency (EPA) and other organizations. Thus, measurement of direct energy is relatively well documented, especially for roadway vehicles. However, measurement of indirect energy consumption is very complex and its study is still in its infancy, especially the subject of peripheral energy change.

The current state of the art requires that almost all data presented in this report be labeled as "approximate," or "estimates." Continuous repetition of these adjectives, however, would create a cumbersome and unmanageable document; their use has therefore been reduced to a minimum. The informed reader will appreciate the need for this, and make the appropriate allowances.

Considerations in an Analysis

The purpose of an energy analysis is, usually, to provide meaningful comparisons between alternatives, including the "do nothing" alternative. This requires careful consideration of the factors involved in analyzing the energy impacts of each alternative. The relative lack of specific data tends to promote simplification of portions of the analysis, and this may be proper, provided due attention has been paid to certain philosophical considerations, as discussed in the following.

1. Direct and indirect energy must both be considered, otherwise erroneous comparisons may result. A car cannot operate without a road, nor an aircraft without an airport... or even a ship without periodic dredging of channels. Even within the same mode, two alternatives may vary substantially as to their direct and indirect energy. For example, a roadway tunnel may cut the distance and grade traveled by vehicles, thus reducing direct energy consumption, but will probably require more indirect energy to construct than a more circuitous route. This fact must be brought out by the analysis.

2. Transportation is portal to portal; i.e., the fact is that people and goods are transported from specific geographic locations to others, and not from airport to airport, or train station to train station. Energy analyses must consider the total transportation system (and energy use) required to transport, say, a commuter, from a specific address (his home) to another specific address (his place of work). This may involve several modes of transportation.

3. The difference between actual and potential transportation must be given careful consideration. Potential service of a vehicle would be the maximum rated capacity for passengers or cargo, and actual service is the real number it does carry. The implications of this concept are vital in comparisons between different transportation modes. For example, a commuter bus may be full in one direction, taking people to work or shopping, but may return nearly empty to complete the loop of its route. Its potential is there to carry a full passenger load on the return trip, but this is, practically speaking, impossible. Thus, although it consumes fuel for the complete loop, it actually provides transportation for fewer than the maximum rated passenger-miles. The same holds true for, say, a delivery truck, which leaves the warehouse full and returns empty. The ratio of actual service rendered vs potential service is called the "load factor" and must be used in connection with an energy analysis.

Load factors also hold for private vehicles, as exemplified by a passenger car rated for 6 seats and carrying only the driver having a load factor of 1/6, whereas motorcycles, usually considered as single-seaters in spite of the extra-long seat and foot pegs for a passenger, may actually be given a load factor of 2.0, when a passenger is carried.

4. Certain goods lend themselves naturally to specific modes of transportation. Perishable cargo lends itself to air transport, but iron ore is seldom shipped in this fashion. Natural gas and pipelines go together, but appliances are transported by rail and truck. Cargo density and fragility also become an important factor in determining which mode of transportation is practical. A commonly used unit of goods transport is the "ton-mile," depicting the movement of one ton of freight the distance of one mile, but it is important to specify the type of cargo, to avoid misleading generalizations about the relative efficiency of various transportation modes. For example, a supertanker may use less energy per ton-mile than a truck, but this would hold true for oil or bulk cargo, not for transporting eggs.

5. Other aspects of transportation service (such as time value, hours of available service, and the temporal and spatial availability of access and egress) are also important in the analysis of modal alternatives. Unless equivalent transportation service occurs in the alternatives, the analysis is less than rational.

6. Certain items may be used either as fuel or as structural material. Wood is an obvious example. In the case of roadway and airport construction, asphalt, a major constituent, falls in this category. Because, generally speaking, these materials are not "consumed" when used in construction, their inherent thermal energy is potentially available for future use, i.e., highways act as reservoirs of asphalt. It is important, however, to consider the practicality of extracting this material for further use. If this extraction is judged impractical, then the thermal energy of the material should be charged against the construction project. (The authors support the viewpoint that asphalt, once used on pavements, cannot be reclaimed practically for use as fuel.)

7. The ease with which materials lend themselves to recycling can be important in an energy analysis. Both portland cement concrete (PCC) and asphaltic concrete (AC) pavements can be recycled. Although both become aggregate during the process, much of the asphaltic binder in the AC can also be recycled by heating and fluxing whereas the portland cement in the PCC cannot. This property may be very important in an analysis of a pavement type.

The Technical Approach

An energy analysis, although containing many elements of art, does lend itself to the technical approach. This approach is based on due consideration of the physical laws of thermodynamics and on empirical data obtained by research and experimentation.

The first law of thermodynamics establishes the definite convertibility of mechanical work to and from energy, and the second law establishes the concept of entropy, in which energy, once expended, cannot be fully recovered. This leads to the concept of efficiency, which is a measure of the energy output of a process (say, an engine) vs the energy input required to run the process. For example, a typical petroleum-fueled electric power plant requires three units of energy input (in the form of fuel) for every one unit of energy it produces, the rest being lost mostly in the form of heat at the stack, and in mechanical and transmission losses. Such a system is said to have an efficiency of 0.33(8,9,18). The over-all efficiency of various systems plays an important part in the energy analysis.

The Process Approach

Empirical data provide estimates of the "energy worth" of items such as fuels; the energy consumed by vehicles; the energy required to produce various materials or finished products; the energy consumed in maintenance and repair of transportation facilities; and the actual "load factors" inherent in various transportation systems. These empirical values, or "energy factors," are in the process of being established and refined, and they incorporate various "reasonable assumptions." Typical approaches to data collection are, for example, obtaining statistics of throughput of a steel-producing plant, and the amount of energy consumed (in the form of fuel and/or electicity) to run the process. This would be followed with similar studies of ore-mining operations and transport, the end result being a figure for the total energy that went into producing a steel product. On a smaller scale, the energy inherent in, say, an automobile tire would be measured by obtaining statistics of throughput of a tire producing plant, along with the amount of energy consumed to run the process. This would be followed with similar studies of the energy required to grow natural rubber (or produce synthetic material) and to ship this raw material to the tire plant. Another process approach to measuring this energy would be obtaining the thermal energy of rubber, as reported by steam-producing plants that use old tires as fuel. This is followed by measurement of the amount of tread rubber worn off, to the point of replacement, and by investigating the percentage of tires that are retreaded and the energy associated with this process. The end result is a figure of energy consumed per mile driven. Tire wear values reported in Appendix A are based on the thermal energy approach, for which data were available. The manufacture energy of tires is not included, and thus could lead to erroneous values if the thermal energy is not substantially higher than the manufacture energy, thus "masking" its effect.

The inherent drawback of the process approach in the development of energy factors is that it requires considerable data collection and calculations, and that it is difficult to define an end-point to the study of the various input elements. Does one consider, for example, the energy consumed by workers commuting to the tire-making factory? This last problem has been mitigated through use of the techniques of "sensitivity analysis," discussed later in this chapter.

The Input-Output (I/O) Approach

A technique, developed for the field of economics, is available, which cross-relates all the goods and services required as input to the U.S. economy in order to produce another good or service. This I/O matrix does not deal directly with quantities of goods or services, but with their costs, in terms of dollars. The energy inherent in a product is presented in terms of the dollar costs of fuels bought or sold to create a dollar's worth of this product. Thus, given the estimated cost of, say, a highway project, one can determine the quantity of energy that will be consumed in its construction by multiplying the cost times the "Btu-per-dollar" factor available from I/O data. The simplicity of this approach, together with the availability of voluminous I/O data has contributed to its popularity.

One drawback of this approach is that I/O data are based on inadequate government statistics, which may require an 8- to 10-year time lag between the actual expenditure and its publication in the I/O system, necessitating the use of inflationary factors, which may vary from one good or service to the other.

The main drawback, however, is that I/O uses the cost of the energy of fuels as an input, and this cost varies considerably from region to region. Electricity costs may be three times higher in one region of the U.S. than in another, but an I/O analysis would not consider the energy used, which is the same regardless of the region, but the dollar cost of that energy, which is significantly different.

Additional Sources

Statistics provide data for actual passengers or freight transported by various systems, allowing estimates of "load factors;" i.e., actual service rendered vs potential service capability of a system.

Direct fuel consumption of vehicles is field- and laboratory-measured under actual or simulated conditions. These values are then used in conjunction with studies of the actual mix of various vehicle sizes and other characteristics to produce direct energy consumption figures for a "composite" vehicle that represents the statistical average of the "fleet on the road."

ENERGY FACTORS

An important part of this study has been the collection and presentation of available energy factors that have been established by the various methods listed in the following. The actual values are presented in Appendix A (the "Energy Factor Handbook"), and brief amplifying remarks, keyed to each of these values, are presented in Appendix B ("Commentary on the Energy Factor Handbook"). Appendix C is a bibliography keyed to the same values as Appendices A and B.

Appendices A and B are intended for users familiar with the subject; therefore, detailed discussion has been omitted from them and is, instead, presented in the following.

Fuels

Transportation consumes a variety of substances as fuels. Approximately 96% of these fuels are derived from petroleum(1). The direct thermal energy inherent in these fuels can be measured in the laboratory. Published values vary by ±15% due to the differing chemistry of natural deposits, refining techniques, and precision of laboratory measurements. Indirect energy expended in drilling, transporting, and refining petroleum fuels has not been identified adequately. Estimates suggest its magnitude to be between 10% and 20% of the thermal energy of ready-to-use fuels, and to vary with the type of distillate. Faced with this degree of precision, the authors have opted to report "default" values of petrochemical fuel energy, which are, in fact, estimates of thermal potential that do not, in theory, include indirect energy but may be considered as doing so for practical purposes.

Nonpetroleum-derived fuels are being considered for expanding roles in transportation. Again, the direct thermal energy inherent in these fuels can be measured in the laboratory, but insufficient information is available as to the quantity of indirect energy required to produce and store them. Indications suggest that the indirect energy may be of substantial magnitude. For example hydrogen, a prime candidate for use as a clean, portable fuel of the future, not only requires indirect energy to produce, but storage is a problem: as a pressurized gas in heavy; large containers (which require energy to manufacture); as a supercold liquid (which must constantly leak in order to maintain temperature), or absorbed in special compounds, from which the gas is released upon demand (still at the experimental stage). The indirect energy associated with nonpetroleum fuels has not been identified, thus the values reported herein represent the direct thermal energy only.

TABLE 1.
ENERGY OF SELECTED FUELS

Fuel	Energy per Unit
Ammonia (liquid)	6.25×10^4 Btu/gal
Coal	1.07×10^4 Btu/lb
Ethanol	8.93×10^4 Btu/gal
Hydrogen (liquid)	3.21×10^4 Btu/gal
Natural gas	1.00×10^3 Btu/ft^3
Gasoline	1.25×10^5 Btu/gal
Jet fuel	1.23×10^5 Btu/gal
Oil, diesel	1.39×10^5 Btu/gal
Oil, bunker C	1.54×10^5 Btu/gal
Oil, crude (Calif.)	1.38×10^5 Btu/gal
Wood	8.90×10^3 Btu/lb

Special consideration is due electricity, which is used as fuel. Electricity requires indirect energy input to a power plant in the form of petroleum, natural gas, coal, hydraulic pressure, nuclear reaction, or geothermal taps (wind, wave, and solar power are still experimental). The majority of electric power plants use petroleum and natural gas fuels, and their efficiency when transmission losses are included is 0.33. It is thus important, when discussing electricity, to clarify whether the energy units presented refer to the quantity of electrical energy used by a vehicle or system (reflected in the utility bill) or the equivalent energy consumed to produce this quantity of usable electricity (a figure three times greater). Transportation energy analyses must consider the total energy consumed to provide a given service, thus should use the larger figure.

Materials and Construction

Transportation requires use of manufactured goods for construction and operation of systems. The list of materials is endless, and ranges from aluminum carburetors to concrete structures to dynamite for blasting. None of these materials is found ready-to-use in nature; energy must be expended to refine the raw materials and transport them to the point of use. Some materials or finished products require considerably more energy to produce than others and studies are being conducted to estimate the quantity of this energy. Roadway-related transportation has been the best-explored mode to date. For example, energy values for roadway pavements, presented in Table 2, are based on typical quantities of materials that make up the structural section. The values include the energy required to produce each material (such as aggregates and asphalt), to heat and combine them, and to transport the mix, and, finally, the energy consumed by equipment (such as paversand rollers) to place them and create the final product.

TABLE 2.
ENERGY CONSUMED FOR PAVEMENTS IN-PLACE

Section	Energy per Unit*
Flexible section (AC surface):	
Mainline traffic design	8.05×10^9 Btu/ln-mi
Moderate traffic design	5.84×10^9 Btu/ln-mi
Shoulder 10 ft wide	4.87×10^9 Btu/mi
Rigid section (PCC surface):	
Mainline traffic design	6.72×10^9 Btu/ln-mi
Moderate traffic design	5.77×10^9 Btu/ln-mi

*Includes the thermal energy of the asphalt binder.

Wearout, replacement, and routine maintenance must be considered in an energy analysis, together with realistic "useful lives" of projects. Although it is possible for, say, a concrete bridge to provide service for 100 years, new alignment or widening requirements for a roadway may render the bridge obsolete in 20 years. Maintenance-related data are scarce and require further investigation.

Transportation Modes

Transportation of passengers or cargo is accomplished by various modes, each unique in its energy consumption characteristics. This study addresses all major modes in current use by modern society (except walking, bicycling, or use of pack animals). These modes have been classified into six general types, as follows:

1. Roadway transportation.
2. Rail transportation.
3. Personal rapid transit.
4. Air transportation.
5. Marine transportation.
6. Pipeline transportation.

The energy characteristics of each transportation type are described in the following discussion.

1. Roadway Transportation Modes. - Roadway vehicles include motorcycles, passenger cars, vans, trucks, and buses. Their power plants, with insignificant exceptions, use either gasoline or diesel fuel, the latter usually found only in very heavy-duty trucks and in a great number of large buses. The role of diesel fuel in vehicle power plants is expected to increase in the future, however.

Fuel consumption characteristics vary for each vehicle, but statistical information on sales, registrations, fuel consumption tests, and related information by the Environmental Protection Agency, the Federal Highway Administration, and others, allows postulation of "composite" vehicles by type. These "composite" vehicles represent a statistical average of the actual fleet on the road in terms of their fuel consumption. Detailed data on fuel consumption of composite vehicles are presented in Appendix A. For passenger cars, this "composite" vehicle changes slightly each year, due to older cars being driven less and eventually removed from service, while new, more fuel-efficient cars take to the road. Figure 4 shows the predicted change in the fuel economy of the "composite" private car through the year 2000.

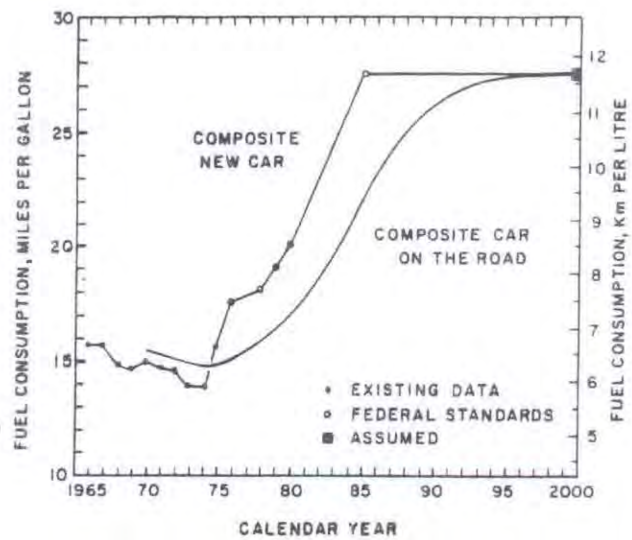


Fig. 4. Fuel consumption rates of composite passenger cars (weighted EPA: 45% rural cycle, 55% urban cycle).

Factors that influence fuel consumption of roadway vehicles may be classified as vehicle-related and facility/traffic-related. Major vehicle-related factors include engine size, fuel type, gross vehicle weight, and speed. Another important factor is the case of "cold starts." Engines and drive trains achieve their best efficiency when warmed to operating temperatures, and thus consume more fuel when cold. Lesser factors under this category include driver behavior, state of engine tune, tire type and pressure, and aerodynamics.

Major facility/traffic-related factors are roadway grade (vertical alignment), because more energy is required to climb than to travel on a level road, and the acceleration/decelerations/idling necessitated by dense traffic and/or traffic signals. Another important factor is the effect of substandard pavements, which extract a fuel penalty due to tire slippage and/or speed changes. Lesser factors include roadway curvature (horizontal alignment), altitude, and meteorological conditions. The last two are usually omitted from an analysis except in special cases (for ice and snow effects see Claffey (10).

From the data available, roadway vehicles were categorized as passenger cars, trucks, and buses. Motorcycles are not included due to insufficient data.

Passenger cars as defined herein include not only sedans, but also other lightweight 2-axle vehicles having a gross vehicle weight (GVW) under 8,000 lb (3,629 kg). Statistics(11) indicate that 99.8% of 2-axle, 4-tire vehicles have a GVW under 8,000 lb. This category includes nearly all pickup trucks and vans(12), which, although having a cargo-carrying potential, in practice are seldom heavily loaded. Fuel used is almost exclusively gasoline(12). Figure 5 shows the fuel consumption of the 1974 composite car at various speeds.

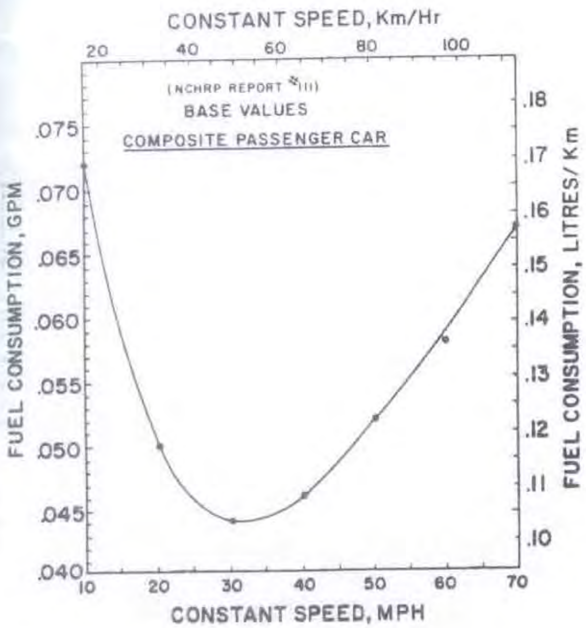


Fig. 5. Fuel consumption of composite passenger car on the road, at constant speeds. (base year = 1974)

Trucks are separated into two major subcategories: Two-axle vehicles having 6 or more tires, and tractor-semitrailer vehicles.

Two-axle, 6-tire vehicles represent light to heavy-duty carriers having a GVW between 8,000 and 16,000 lb (3,629 and 7,257 kg)(13). Statistics indicate that 95.3% of two-axle, 6-tire trucks exceed 10,000 lb (4,536 kg) GVW(11). This category includes a substantial percentage of all dump trucks, tankers, log bunk, transit mix and refrigerator trucks(12). Fuel used is 95% gasoline and 5% diesel(12). Figure 6 shows the fuel consumption of this type of vehicle at various speeds.

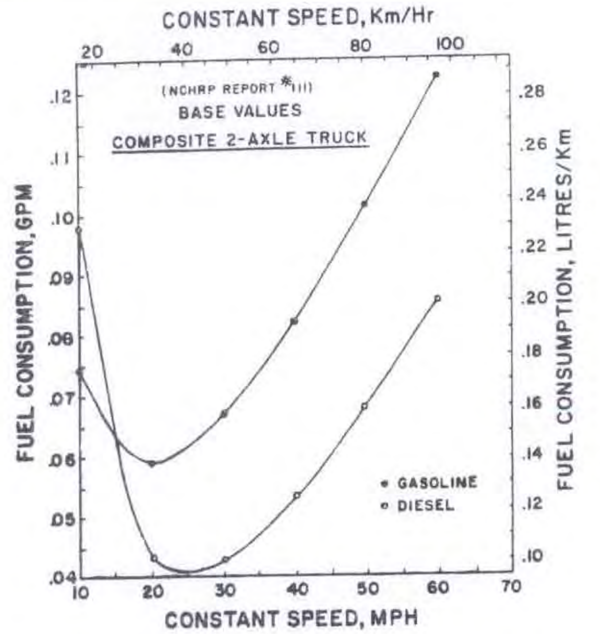


Fig. 6. Fuel consumption of composite 2-axle, 6-tire truck.

Tractor-semitrailer trucks represent heavy-duty multi-axle carriers exceeding 16,000 lb (7,257 kg) GVW. Fuel consumption data are based primarily on vehicles having a GVW between 40,000 and 50,000 lb (18,144 and 22,680 kg)(13). Fuel used is estimated as 65% gasoline, 35% diesel(13). Figure 7 shows the fuel consumption of this type of vehicle at various speeds.

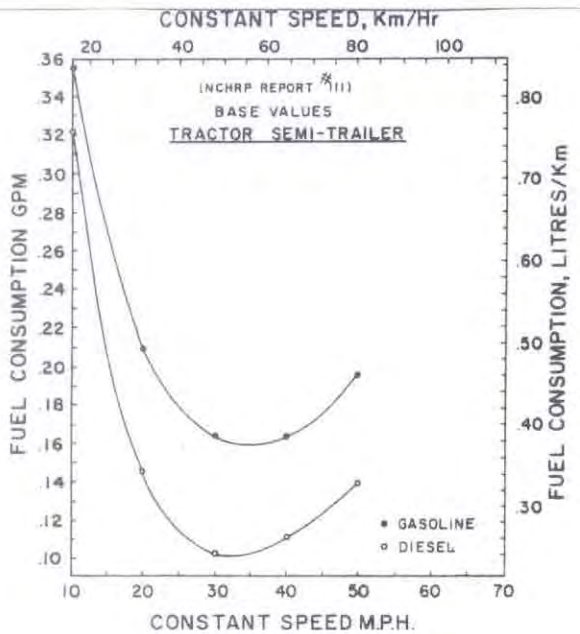


Fig. 7. Fuel consumption of composite tractor-semitrailer truck from 40,000 to 50,000 lb GVW.

Buses provide mass transit service for passengers between cities, within cities, or for school children. Weights and seating capacities vary. Fuels include gasoline, diesel, liquid propane, and electricity. There have been no recent tests of fuel consumption characteristics vs speed and grade for transit buses, previous tests having been made with an obsolescent vehicle(13). A computer model has been developed, describing fuel consumption characteristics vs speed and grade for intercity buses(14). Fleet statistics are available from various sources on the over all fuel consumption rates expected under actual service conditions. City transit bus fuel consumption is affected by the frequency of stops made in the route, and this factor must be considered in an energy analysis when sufficient information is available. Figure 8 gives the fuel consumption vs stop frequency of transit buses.

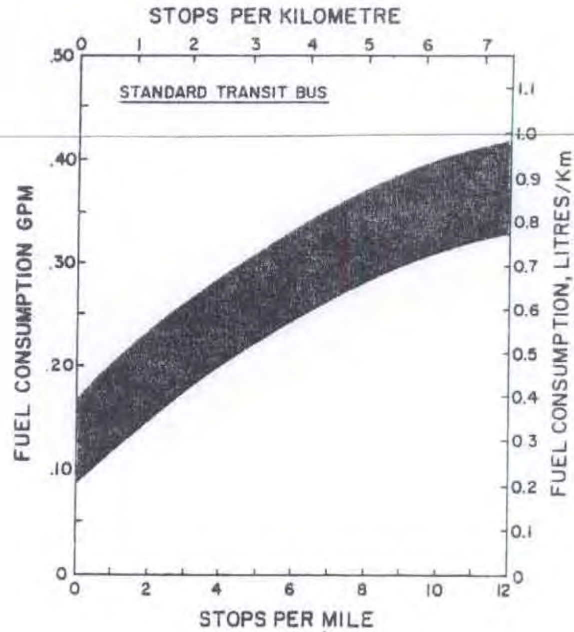


Fig. 8. Diesel fuel consumed vs bus stop frequency.

In general, it is worth commenting that most of the detailed data on fuel consumption vs speed and grade are based on obsolescent vehicles (1964-68 model cars, 1962-65 2-axle trucks, a 1960 tractor-semi-trailer and a 1960 transit bus)(13). Work of a similar nature(80) has been recently conducted on 1970-1974 model cars by the same author, and interested readers are urged to review this lastest study.

The indirect energy consumption associated with roadway vehicles includes vehicle-related and system-related items. Vehicle-related items include the actual wear out and replacement of the vehicle itself, which requires estimates of its service life in terms of miles driven; wear out of component parts such as tires, and routine maintenance and replacement of lubricants. Possible salvage energy may also be considered. System-related items include construction and maintenance of roads, bridges, etc., as well as support facilities such as parking lots, service stations, and garages. Attempts have been made to estimate the energy equivalent of items such as vehicle insurance(15). This is correct in principle, but the energy impact is so small as to have no effect on the precision of the analysis.

Information on indirect energy of vehicles is based on studies of the various materials incorporated within a finished vehicle (i.e., steel sheet, aluminum, copper, rubber, plastics, etc.) the energy required to produce each material, and the energy required to form and assemble the finished product(16,17). This is combined with estimates of the service life(18,19,20), and the energy consumed in routine maintenance(13,21,22).

Information on system-related indirect energy is based on several limited studies of construction materials(23,24,25) and operations(19,26,27), and on maintenance functions. This is combined with estimates of service life and the energy required for other operating requirements of the roadway system, such as illumination, signals, and landscaping. A substantial part of the data presented on roadway construction has been developed by the authors.

2. Rail Transportation Modes. - Fixed rail vehicles are trains and rail mass transit units. In addition, many personal rapid transit (PRT) and group rapid transit (GRT) vehicles operate on rails or special tracks. These are discussed separately.

Trains carry passengers or cargo, seldom both. Their power plants consist primarily of diesel-fueled engines, which run generators to supply electric drive motors (hence their designation: "diesel-electric"). Some trains are powered directly by electricity from either overhead wires or a third rail arrangement. Gas turbines are also used on some routes.

Fuel consumption characteristics vary and are influenced by three major factors: speed, gross weight, and terrain (grades) (28). Additional factors include delays or slowdowns due to the number of trains using a given route and track condition (the number and length of sections requiring slowdowns). In the case of commuter trains, the frequency of stops also becomes an important factor. Inasmuch as trains are designed to serve specific routes, the power plants are designed to meet the specific requirements of the routes. Passenger trains are usually composed of a standard number of units and weigh essentially the same whether empty or full. Thus, given speed and terrain, designers provide the appropriate power plant.

Freight trains vary as to number of units, gross weight, route and speed, so the power must be custom-fitted to each train as it is assembled at the yards. At that point, an estimate of the "gross trailing weight" is made and the appropriate number and size of locomotives is assigned to perform the task. Where required along the route, additional locomotives are temporarily attached to help climb steep grades. Locomotives are rated according to their maximum horsepower and weight is usually expressed in tons (2,000 lb)(29).

The railroad industry has conducted studies to aid in conservation of fuel(29). Through these and other studies (28,30), information as to fuel consumption rates of locomotives has become available, as well as computer models that report fuel consumption of trains over specific routes, at various speeds and various horsepower-to-weight ratios. Table 3, condensed from Appendix A, presents the fuel consumption rate per rated passenger (per seat) of selected trains.

TABLE 3.
DIESEL FUEL CONSUMPTION OF SELECTED TRAINS

Route	Distance (mi)	Propulsion Type	Fuel Consumed (gal/seat-mi)
Seattle-Havre	903	Diesel-elec.	0.009
Atlanta-Wash.	633	Diesel-elec.	0.012
New York-Wash.	284	Gas turbine	0.010
Chicago-St. Louis	277	Electric	0.013*

*Equivalent diesel fuel.

Studies also reported on various rail mass transit systems provide information as to their fuel consumption characteristics, the rated passenger capacity, speed, and weight(5,18,28,29,30,31,46,64,84). Table 4, condensed from Appendix A, presents the characteristics of selected rail mass transit systems.

TABLE 4.
CHARACTERISTICS AND ENERGY CONSUMPTION OF SELECTED MASS TRANSIT SYSTEMS

System	Seats [Standing] per car	Rated (hp/seat)	Wt/seat (Tons)	Energy Consumed (Btu/seat-mi)
Lindenwold	84	7.6	0.39	N.A.
Toronto	83 [N.A.]	1.9	0.35	860
San Francisco	72 [72]	7.4	0.40	850
Philadelphia	56 [N.A.]	5.8	0.43	1075
Cleveland	54 [N.A.]	3.4	0.51	686
Chicago	51 [N.A.]	3.4	0.41	952
New York	47 [N.A.]	7.3	0.84	1208

Estimates have been made of the indirect energy required for vehicle(16) and guideway construction(17,19). However, the energy requirements for operation and maintenance facilities have not been adequately identified.

3. Personal and Group Rapid Transit Modes. - Personal and group rapid transit systems are usually included under the labels "PRT" and "GRT," respectively. These transportation systems are in a state of research and development, and each operational system is unique in concept and design. The common features of existing operational systems are as follows:

° PRT systems provide passenger transportation in small vehicles, each carrying a few occupants, for short distances. Typical locations are airport terminal connections and amusement park rides.

° Nearly all systems are powered by electricity, using a.c. or d.c. motors, and travel on pneumatic tires on various guideway configurations, most of which are made of concrete.

° Data on direct and indirect energy consumption by PRT systems are scarce, and are expected to vary substantially from one system to the other.

° Many PRT/GRT systems are in an experimental or preliminary stage of design and/or development.

It is apparent that transportation energy characteristics must be individually analyzed for each proposed PRT/GRT system.

4. Air Transportation Modes. - Commercial air transportation systems provide service for passengers and cargo between airports. Due to safety and noise considerations, new airports are situated a considerable distance from population centers and are usually served by ground transportation (highways), and, occasionally, helicopters. The energy consumed by these feeder services must be charged to air transportation in an energy analysis. Jet aircraft use kerosene or naptha-type fuel, and piston-powered aircraft use aviation gasoline. Approximately 23% of the total U.S. aviation fuel is consumed by the military(28).

Aircraft operations may be divided into five distinct phases, each having its unique fuel consumption rate. These phases are:

1. Taxi-idle, usually the lowest consumption rate, which aircraft use from the airport terminal to the beginning of the runway.

2. Takeoff, always the highest consumption rate, when maximum power is applied to accelerate the aircraft to flying speed and lift it from the ground.

3. Climbout, where slightly less than maximum power is used from liftoff until an altitude of 3,000 ft (914 m) is reached.

4. Cruise, the normal steady-state fuel consumption of an aircraft. This phase covers the ascent from 3,000 ft to the cruising altitude, the actual cruise at a constant speed at that altitude, and the descent to 3,000 ft near the end of the trip. Cruising speed and altitude are regulated by airlines, the Federal Aviation Administration, or both, and play an important role in the fuel consumption rate(32,33).

5. Approach and land, from 3,000-ft altitude to touchdown, where the power is slightly increased or reduced from that used in the cruise mode, depending on the type of aircraft and its flying characteristics.

Fuel consumed in a specific trip may thus be estimated by the summation of the fuel consumed in all five modes, given the aircraft type, cruise speed, and distanc traveled. Typical times spent in each phase are given in Appendix A, along with fuel consumption characteristics(65,66,67) It is important to note that computation o fuel consumed while cruising must consider the length of the actual flight path, rather than the great circle distance between two airports. Airline statistics usually give great circle (i.e., shortest distance) mileage, but routes follow specified flight corridors that increase the trip length. Figure 9 shows typical fuel consumption rates of commercial aircraft in normal use. Due to scheduling problems and policy, the most efficient aircraft size is not always assigned to th appropriate route.

Most commercial airlines operate aircraft that carry both passengers and cargo. Some aircraft are convertible to carry either passengers or cargo. Thus, it is difficult to obtain specific data on fuel consumption for freight operations. It has been estimated that freight-only operations consume approximately 1% of the total aviation fuel consumed (including military use), so this lack of data does not constitute a major gap in the information available on air transportation.

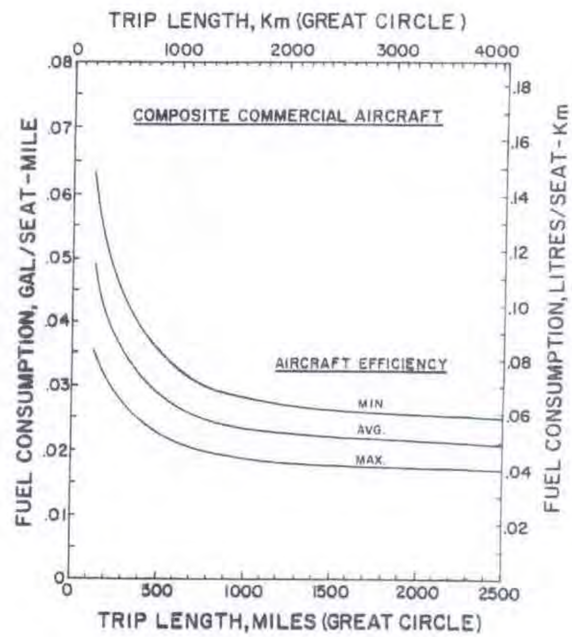


Fig. 9. Influence of trip length on jet fuel consumption of composite commercial passenger airplane.

Studies have been conducted to determine the indirect energy expended to manufacture certain commercial aircraft, as well as to obtain estimates of their expected service life, in terms of total distance traveled. The estimated values are between 78 and 170 Btu per seat-mile for commercial jet aircraft. However, the indirect energy consumed in maintenance, routine replacement of parts, etc., has not been adequately identified. One study(22) measured the total fuel purchased by commercial airlines, including aircraft fuel plus utilities and HVAC for operation of offices, terminals, etc. The same study added 40% to this figure for estimated maintenance functions.

Airports require special facilities and equipment for their operation, and the energy consumed by ground facilities and operations has not been identified. Construction of runways, taxiways, parking aprons, terminal buildings, hangars, etc., has not been adequately studied, because major airports are unique and each would be a case for special analysis.

A study of a general aviation airport of 200-aircraft capacity(19) has provided a value for construction-related indirect energy, which totals 6.66×10^{10} Btu. General aviation airports usually serve small single- and twin-engine aircraft, and should be distinguished from commercial airports used by airlines; the latter are considerably larger in size and complexity.

5. Marine Transportation Modes. - Marine transportation systems may be classified into three broad categories: Ferryboats, inland and coastal vessels, and deep-sea vessels.

Ferryboats provide transit of passengers and/or vehicles across narrow bodies of water to islands or peninsulas where the shore route is excessively long, and where bridges are impractical or overcrowded. They also provide service along a coastal route where seaborne travel is more convenient than the shore route. Typically, these vessels consume diesel fuel and many are designed and built for service on a specific route. Their consumption characteristics are influenced by their size and speed(34,35,36). A secondary factor is the consumption of fuel (at idle) while loading/unloading, but this is insignificant except in special cases.

As with roadway design, the number and size of vessels serving a particular route is determined by the peak traffic they handle. This results in a portion of some fleets being idle except for a few busy days every year (typically weekends and long holidays in summer)(34). Other fleets, whose primary service is to commuters, run fuller schedules.

Inland and coastal transportation is provided by ships, barge-tug combinations, and specially designed ore carriers on the Great Lakes. Inland vessel fuel consumption is affected by river currents (upstream and downstream). Details on these vessels were not readily available. Statistical studies have determined values for energy consumed vs actual service rendered for the entire system. These values are presented in Appendix A.

Deep-sea vessels transport passengers or cargo, seldom both. Two types of powerplants are used: Steamships, which comprise the vast majority, are powered by steam turbines that consume bunker C fuel oil; and motor ships, powered by diesel engines. Sails and nuclear reactors are also in use, but the number of vessels involved is insignificant. Gas turbines are increasingly being used in smaller ships, especially patrol craft.

Merchant vessels are usually designed and built for specific service; thus, their size, deadweight, cruise speed, and range are the known factors that determine the type and power of the engines, expressed in terms of shaft horsepower. Relatively simple empirical equations have been developed for cruise fuel consumption based on the rated shaft horsepower and engine type (steam turbine or diesel). These equations have been incorporated in computerized files by the U.S. Maritime Administration to provide fuel consumption estimates for each vessel under U.S. registry(37). The equations provide consumption rates in terms of long (2,240 lb) tons per day, as follows:

For steam turbines:
Shaft hp x 0.005571 = Bunker C use

For motor ships:
Shaft hp x 0.003313 = Diesel fuel use

More complex equations on fuel consumption have also been published(38).

Operational activities of vessels are governed by the service they provide (i.e., the amount of time spent at sea, in port, or in dockyards) and thus cannot be generalized, especially in the case of inland transportation, ferryboats, etc. However, typical operations of deep-sea vessels are 280 days at sea, 60 days in port and 20 to 25 days for scheduled maintenance. Tankers, bulk cargo, and container ships spend less time in port than general cargo ships because the nature of their cargo allows faster load/unloading(37).

The indirect energy consumed in shipbuilding and maintenance is difficult to measure. Studies have been conducted to determine the energy consumed by shipyards, and output in terms of tonnage of new vessels built and ship repairs accomplished, but as yet the two shipyard functions have not been distinguished from each other in terms of what proportion of energy is consumed by each.

Useful lives of vessels vary, depending on economics, and a typical figure for newly constructed deep-sea vessels is 25 years, as opposed to 20 years for vessels built circa 1960(37). Information on useful lives of inland vessels or ferryboats is not available.

All vessels require shore facilities (terminals, loading equipment, warehouses, drydocks, and the like), which require considerable indirect energy to build and maintain, but this energy consumption has not been identified. Additional amounts of energy are expended in creating and maintaining safe navigation channels, breakwaters, levees, lightships and lighthouses, operating the Coast Guard, etc. The quantity of this indirect energy has not been fully identified, but a sense for its magnitude may be obtained by statistics indicating that annual dredging of U.S. waterways totals 300 million cu yd (228 million m^3) of material(39).

6. Pipeline Transportation. - Pipeline systems consist of lines of piping with associated valves, pumps, etc. They are used for the transportation of fluids in various forms, such as natural gas, steam, water, crude and refined oil, and chemicals. An additional service is the transportation of solids by grinding them and mixing with a liquid (usually water) to create a slurry that is then pumped through. Coal and some ores are transported in this fashion.

Pipes are manufactured from a variety of materials, the most predominant being steel, iron, and concrete. Pumps are electric powered and are designed for the expected load, along with additional standby units. A study of the direct energy associated with pipelines has provided data on the energy consumed vs service rendered of U.S. pipelines but details were not readily available. Energy consumption of pipelines is influenced by the velocity and viscosity of the fluid, diameter of pipe, general route profile, and type and size of pumping stations. The material of which pipe is made is also a factor, both in its frictional characteristics and in the energy required for its manufacture. The indirect energy to manufacture, emplace, and maintain these systems has not been identified.

Energy vs Dollar Costs

In the early planning stages of most projects, cost estimates are made. Because these cost figures are available long before detailed information as to materials quantities, etc., the capability of estimating energy consumption through use of dollar costs is attractive. Studies have been conducted to pursue this conversion of dollars to Btu (40,41,42), and the first two have been discussed under "The Input-Output Approach" earlier in this chapter. These conversion factors vary, depending on the project type. The breakdown of the costs varies as to the fractions allocated for materials, transportation, operations, salaries, etc. Another important point for consideration is the changing value of inflating currency, which necessitates converting future project costs into constant dollars with the study date serving as the base year. This conversion may be performed through use of inflation factors available through government publications. In many cases, professional estimators can provide inflation factors for specific operations within the transportation sector. As an aid, general values for constant-dollar conversion factors are presented in Appendix A.

Ideally, cost-based analyses (Btu/$) and materials/quantities-based analyses (Btu/lb, etc.) should result in the same value of energy for a project. This is not the case, however, and the two values may differ by a significant amount. Energy estimates based on costs are quick and convenient, and provide a crude figure for most projects, but this method is obviously more indirect than the materials/quantities approach.

PROCEDURES FOR CONDUCTING ENERGY ANALYSES

Each energy analysis is unique to the transportation system or mode being studied. Achievement of meaningful results requires that an individual study be performed for each case or alternative under consideration with careful selection of appropriate data and use of the corresponding energy factors. It is important that the study be correctly planned at the outset.

Planning an Energy Study

The purpose of an energy study is to predict the effect a proposed action will have on the consumption of energy. Usually, an action is presented in the form of several proposed alternatives, which must be separately analyzed and then compared.

The extent to which an energy study will be useful in predicting impacts from the proposed action depends largely on how well the study is planned. Proper planning will provide a comprehensive approach that will yield sufficient data and information to adequately examine the ramifications of the proposed actions.

Several basic steps that are applicable to any technical study and should be covered in the preliminary planning stage are discussed in this section. These are: (1) determine the need for a study, (2) decide on the appropriate level of effort, (3) list the general objectives of the study, (4) select the parameters to be studied, (5) locate and designate sources for the data.

1. Determining the Need. - Some important factors in determining the need, or necessity, for conducting an energy analysis are the following:

(a) Mandatory requirements through regulations. Numerous and ever-increasing governmental regulations may require that energy be addressed at some point in the project development process. In California, for example, the State Environmental Quality Act requires an energy analysis to be conducted when an action would have a significant effect on energy.

(b) Public opinion. Have existing environmental groups shown concern over energy supply and expenditure aspects of the proposed action(s)? Have other citizens' groups formed to analyze or oppose the action(s) with regard to its energy aspects?

(c) Nature of the project. Are the mode, design, materials, operations, traffic, etc., of a transportation project energy intensive? Are there opportunities for energy conservation?

(d) Contact with public agencies. During initial contact regarding the project(s) with public agencies (such as the Environmental Protection Agency, the Federal Highway Administration, the Department of Energy, the State energy agency, the Maritime Commission, the Urban Mass Transportation Administration, the Federal Aviation Administration) has any indication of concern regarding energy expenditure been received?

(e) Existing problems in energy supply or distribution. Does available information indicate energy of fuel distribution problems in the region under study? Will the proposed action(s) overtax the system, on either a short- or long-term basis? Will the proposed action(s) alleviate or relieve the existing problems?

2. Deciding on the Level of Effort. - Once it has been decided that a study is necessary and clear objectives have been established, a decision on the appropriate level of effort needs to be made. It should involve the following considerations:

(a) What are the time constraints? Does the project schedule allow leeway in the energy study? When does the EIS process require the complete input?

(b) Are sufficient resources available? Is sufficient manpower available? Are personnel with proper expertise available? Is the necessary equipment on hand? Is sufficient financing available?

(c) In determining the need for a study, what did the nature of the project, public opinion, contact with other agencies, and existing problems indicate in terms of desirable depth of study?

(d) What is the availability of input information (design details, traffic counts and predictions, materials quantities, costs, etc.)?

3. Specifying General Objectives. - One or more clearly defined objectives should be developed in the study planning stage. These objectives give direction to the study and afford an opportunity for assessing progress and exercising control during the life of the study. They also generally define data needs and interact with decisions regarding the desirable level of effort for the study. Some typical study objectives are:

(a) Obtain an energy baseline against which to measure the effect of energy conservation strategies.
(b) Analyze a conservation strategy.
(c) Compare elements of a system.
(d) Compare design alternatives.
(e) Establish predicted energy availability.

It may be desirable, once the general objectives are defined and data sources are evaluated, to develop more specific objectives for various parts of the study. An example would be the comparison of several structural section designs for a highway.

4. Selecting Parameters. - The energy consumption parameters to be studied depend on the particular transportation mode. In general, they would include the direct fuel consumption characteristics of specific vehicles used, together with the various indirect energy considerations pertaining to each mode, as discussed earlier.

Also, service parameters must be studied. Transportation is a service, and the energy consumption values must be matched with this service. Typically, direct energy (fuel consumption) is obtained in terms of vehicle-miles, and each vehicle or group of vehicles has a rated capacity in terms of passengers or cargo. In practice, vehicles are seldom loaded to capacity 100 percent of the time. Thus, the actual service rendered is usually less than the potential service available, and this is accounted for in an analysis by the use of "load factors," which are the mathematical ratios of actual divided by potential service. Studies have been conducted to determine typical load factors for various modes of transport using statistical data. Specific studies should be conducted, however, for specific projects when conditions warrant such action.

5. Locating Data Sources. - Sources of data include published information (such as this report), statistics obtained through public and private sources, expert opinions obtained through correspondence or consultation with recognized authorities, or results obtained by direct experiment or original research. Inasmuch as an energy study may be challenged -- in or out of court -- it is vital that all data sources be clearly documented and presented in the appropriate section of the final document. Data that are conjectural in nature should be clearly labeled as such. Further discussion on data and evaluation of the sources is given in the following section under "Collection and Development of Required Data."

Conducting the Study

The manner in which a transportation energy study is conducted is a direct result of the objectives developed in the planning phase. In general, these studies may be classified as being in one or more of three broad categories: (1) System studies, in which a substantial part of an entire transportation system is affected (for example, creating a new rail mass transit system in an area, or initiating air passenger service between two communities); (2) Project studies, in which specific projects within an existing system are involved (for example, adding a new highway section to bypass a central business district, or building a new railway bridge); and (3) Operational improvements studies, in which methods of improving the energy efficiency of system operation are involved (for example, freeway ramp metering, or changing the cruising speed and schedule of ferryboats).

To further complicate the matter, a project in any one of the study categories may be in a different stage of development, such as planning or design.

Although each general category may call for a different level of analysis and input data, certain elements are basic to any analysis once the specific definitions of alternatives have been developed in the planning phase of the energy study. The following elements comprise a recommended study methodology:

1. Collect and develop data on:
   (a) Direct energy use.
   (b) Indirect energy use.
   (c) Service parameters.
2. Select or develop appropriate energy use factors.
3. Analyze data in terms of items 1 and 2.
4. Present a rational comparison of alternatives.

These study elements are discussed in the following and shown in block diagram form in Figure 10. Although the general tone of the discussion is directed at land surface transportation, the principles of analysis apply equally well to air, marine, and pipeline transportation.

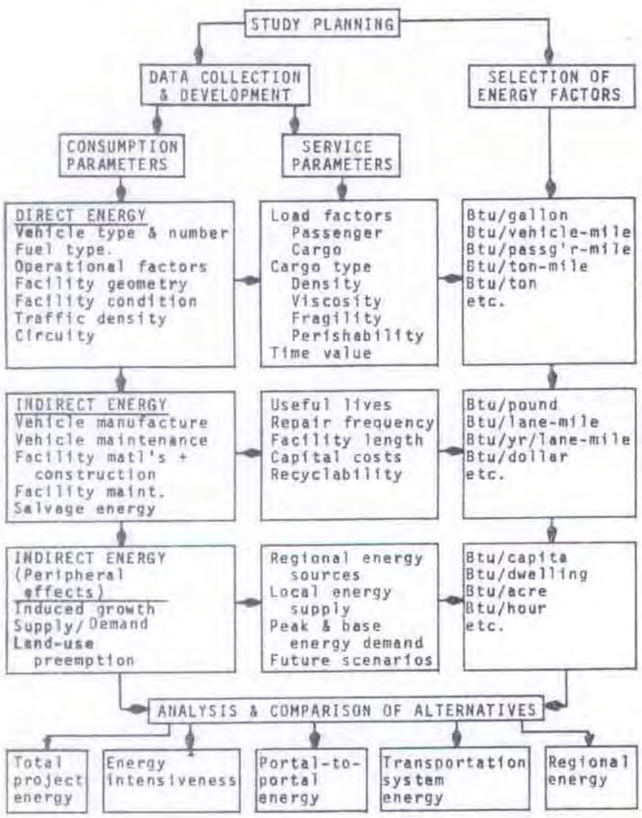


Fig. 10. Flow diagram: energy study methodology.

Collection and Development of Required Data. - These are functions of major importance, because data quality and detail have a direct effect on the final evaluation. The types of data required are statistics pertaining to direct and indirect energy consumption, and service parameters for the proposed alternatives. The detail required for an analysis at the planning stage will be far less than that required for a design stage, or project level, analysis. The accuracy, or validity, of the data has a direct relationship to the length of time between analysis and construction. The longer the intervening period, the more difficult it is to make good estimates. Hence, the level of detail should reflect the uncertainties involved in the analysis. The following hypothetical list (for roadways only) illustrates possible data categories for a fairly comprehensive project level analysis:

1. Direct Consumption

   (a) Traffic-related:
      (1) Year(s) of study.
      (2) Volume of traffic.
      (3) Speed.
      (4) Distance.
      (5) Composition of vehicle types.
      (6) Characteristics of traffic flow.
      (7) Cold-start effects.
      (8) Idling.

   (b) Facility-related:
      (1) Grade(s).
      (2) Curvature.
      (3) Pavement condition.
      (4) Stops (signs, signals, etc.).
      (5) Altitude.

2. Indirect Consumption

   (a) Vehicle manufacture:
      (1) Materials and quantities.
      (2) Manufacture energy.
      (3) Useful life.
      (4) Salvage energy.

   (b) Vehicle maintenance:
      (1) Routine wear and replacement.
      (2) Road-related wear.
      (3) Operation of repair facilities.
      (4) Fuel distribution.

   (c) Facility construction:
      (1) Quantity-oriented (when available).
         a. Excavation, backfill, dredging.
         b. Structures.
         c. Surface/pavements.
         d. Signs, lights, HVAC.
         e. Landscaping.
         f. Materials transport.
         g. Useful lives.

      (2) Cost-oriented($) (when quantities are not available).
         a. Date/constant dollar costs.
         b. Location (influence of hauling distance).
         c. Type of construction.
         d. Useful lives.

(d) Facility operation/ maintenance:
   (1) Quantity-oriented.
      a. Age of facility.
      b. Peripheral equipment.
      c. Surface/pavement type.
   (2) Cost-oriented($).

(e) Peripheral effects:
   (1) Change in land use with time.
   (2) Change in fuel source with time.
   (3) Change in local energy needs with time.
   (4) Future power plant sites.
   (5) Location of energy-related natural resources.

3. Service Parameters:

(a) Passengers:
   (1) Rated passenger-miles.
   (2) Load factors.
   (3) Effect on other modes.

(b) Cargo:
   (1) Type of cargo.
   (2) Rated ton-miles.
   (3) Load factor.
   (4) Effect on other modes.
   (5) Fragility.
   (6) Time value.

Often, required data will not be available in sufficient detail. Gaps in the data must be covered by reasonable estimates prior to proceeding further. An aid to determining the significance of possible inaccuracies in such an estimate is a sensitivity analysis. In this method, the original input estimate is changed by a large factor (say, doubled) and its effect in the final output of the study is noted. At the current state of the art, a sensitivity analysis producing less than 10 percent change in the final output indicates that inaccuracy in that particular input is not significant, and the original estimate is adequate for the purpose intended.

In collecting data for direct energy use, traffic data may present a problem, especially when the action being analyzed is one that introduces perturbations in the rest of the traffic network. Although traffic data for an existing situation may often be found from current measurements, data for a future situation will have to be developed. This will probably involve the exercise of a transportation or traffic model. At present, only a few models are constructed to give either an energy output or to be compatible with the data requirements of energy models (see Appendix G). Because traffic data requirements for energy analyses are similar to those for air quality, it is probable that many of the shortcomings in transportation models will be overcome in the near future.

Facility-related data for direct energy use (alignment, grades, etc.) are usually the easiest to acquire, using either direct measurement or as-built plans for existing facilities and preliminary engineering plans for proposed facilities.

Indirect data may be acquired from a variety of sources, including data in this report. Vehicle-related information (makes, models, weights, etc.) is often available in published statistics of transportation agencies, public or private. Facility-related indirect data are often available in preliminary studies that normally would precede an energy study. Construction dollar costs, structure lives, lighting, as well as types and quantities of materials, would be available, or could be estimated from project plans and specifications. Judgment should be exercised in selecting useful lives, used to prorate the manufacture or construction energy. This report and other literature may offer information and assist in filling gaps in the data.

Peripheral energy data (land use, energy availability, etc.) may be available from federal and local agencies that regulate utilities; regional planning boards; energy conservation administrations; and transportation planning departments within local and state transportation agencies. Because peripheral energy change may vary from removal of a few trees (in widening a mountain road) to attracting new population centers (in creating a new transportation corridor), selection of appropriate data sources is left to the judgment of the user.

Data relating to the transportation service being rendered may be available from agency statistics, operating schedules, field surveys, planning estimates, and other sources. Typically, a proposed set of alternatives would provide equal transportation service (but consume differing quantities of energy). In this case, the service data required can be minimal.

Selection or Development of Appropriate Energy Factors

Following the collection and development of data, appropriate energy factors are selected. These factors are available in Appendix A, the "Energy Factor Handbook." Direct energy factors (such as fuel consumptions in gallons per mile for a given grade) are combined with direct energy data (such as speed, grade, number of vehicles) to provide the necessary input to the analysis. Similarly, indirect energy factors (such as vehicle construction energy, useful life) are combined with indirect energy data (such as number of vehicles, mileage) for the analysis. The actual selection of the appropriate energy factors is demonstrated in the example problems in Appendix F.

Data analysis is normally a simple mathematical task, whose purpose is to obtain numerical values for the total energy consumed by each alternative to provide an equivalent transportation service. Because the service life of the vehicles and/or the system often would exceed the time period of interest in an analysis, this energy is prorated over the expected useful lives. It is thus practical to compute all values based on an "average year" representing the time period under study.

For purposes of discussion, the first two categories of transportation studies (system studies and project studies) may be considered jointly.

Direct energy analysis for system and project studies is made by one of two methods, depending on the detail of available data. Where detail is lacking, estimates may be made from over-all statistics obtained from agencies operating fleets of similar vehicles (or pipelines). Such statistics are presented under "Fuel Consumed in Normal Operations" in the Appendices. Where the quality of data permits, estimates should be based on the type and volume of vehicles involved and their fuel consumption characteristics. Given distance, speed, and other parameters affecting fuel consumption, estimates having better accuracy can be obtained. Baseline fuel consumption rates and their modifying parameters are presented in the Appendices. Because most analyses deal with future trends, the effect of changing efficiencies in vehicles (such as automobiles) must be accounted for.

Indirect energy is calculated by reducing the appropriate data to the same baseline, or average year, and summing their energy consumption values. This task is performed in the following manner:

1. The total energy consumed by vehicle manufacture is pro-rated according to the expected useful life (in terms of time or distance traveled). The appropriate fraction of the total is then charged to the alternative under study. Where applicable, the inherent salvage energy of the worn-out vehicle is prorated in the same manner, and a fraction is credited to the balance sheet being developed by the analysis.

2. Estimates of vehicle maintenance and associated facilities and operations are charged to the alternative under study.

3. If facilities must be constructed, estimates of the energy required are calculated by one of two methods, depending on the available data. Where details are limited, and only cost estimates are available, crude approximations are made, based on studies correlating project cost to energy. It should be kept in mind that dollar costs must be converted to base-year constant dollars through utilization of appropriate inflation factors, prior to computations involving Btu-per-dollar factors. Results of these studies are presented under "Energy Consumed vs Dollar Cost" in the Appendices. Where the quality of data permits, estimates should be based on the type of facilities, peripheral equipment, materials quantities and transport, and construction operations required to create the projects. The total energy consumed by facility construction is prorated according to the expected useful life (usually in terms of years), and the appropriate fraction is charged to the study. Salvage energy is considered, where applicable; however, this value is often insignificant, or may even be negative in nature, as in the case of nuclear waste from conventional fission plants, which must be stored and monitored for centuries. Dismantling and monitoring these plants at the end of their useful lives would also consume substantial energy.

4. Estimates of facility operations and maintenance energy are charged to the alternative under study.

5. The energy consumed or saved from the peripheral effects of a proposed action is charged to the alternative under study. The nature and magnitude of peripheral effects may not lend themselves to prorating over a given time period, and the resulting value of peripheral energy may be reported separately as a gross total. Examples of peripheral energy consideration are presented in Appendix F, problems 2 and 3.

6. All the direct and indirect energy consumptions for an average year are added (with the possible exception of peripheral energy) to provide a total annual consumption figure, which may then be compared with a similar analysis for a different alternative. Because the numerical values in the two most common units, Btu and joules, are often astronomical in magnitude it is recommended that these final totals be reduced into the more manageable and comprehensible unit of equivalent barrels of crude oil per day (a barrel containing the potential thermal energy of 5.80×10^6 Btu or 6.12×10^9 joules).

Service parameters are often given values, because system or project alternatives are being proposed to provide a given service. This service should be stated in terms of actual passenger-miles (km) or ton-miles (metric ton-km) of specified type(s) of cargo. These figures may be obtained by computing the value of rated passenger-miles or rated ton-miles involved, from information about the types of vehicles, their maximum rated capacity, and the distance they will travel. This rated service is then modified by appropriate load factors to obtain the actual service rendered. Where load factor pertaining to the specific circumstances under study cannot be obtained, guideline values are presented in Appendix A, Sec. 24.0. The time-value of service must also be considered. If the desired result of a set of alternatives is, say, to provide adequate peak-hour commuter service, not only the quantity but also the timing of this service becomes important.

Where applicable, the effect of an action on other modes of transportation should be calculated. This may be accomplished by estimating the change in existing traffic a proposal may foster (a new bridge may reduce ferryboat service) and an appropriate energy analysis should be conducted to compute the resulting effect.

The methods of analysis for operational improvements are very similar to those used for systems and projects. The significant difference lies in the nature of the data. Direct energy consumption may be computed in one of two ways, depending on the proposed action:

1. When the action involves only changes in operational methods (such as speed limits, signaling, schedules) the data used involve primarily existing equipment and technology. The emphasis is concentrated on computation of energy consumption of various conventional methods.

2. When the action involves new and innovative approaches, additional data must be obtained relating to their effect on energy, and as an example, the analysis would proceed as follows:

(a) Direct energy consumption may be computed based on data from improved vehicle power plants and their fuel consumption characteristics; improved or new types of fuel, or the switch from one fuel to another; and improved vehicle efficiency provided by mechanical, thermal, or aerodynamic design.

(b) Indirect energy related to the vehicles themselves may be computed based on data on altered vehicle design, materials, and construction, which may have a significant effect in the manufacture and salvage energy, as well as on the useful lives.

(c) Indirect energy related to the transportation facilities may be computed based on data on altered design, construction materials or construction techniques, which would have an effect on construction, maintenance, and useful lives.

(d) Peripheral energy and service rendered is computed in the same manner as in system or project analyses.

Comparison of alternatives follows the analyses of the various proposals. Comparisons should be based on one or more of the following criteria, depending on the nature of the study:

1. Total direct and indirect annual energy consumption by each alternative. This is a common basis of comparison in many cases, and the lowest value indicates the most energy-efficient alternative, if the alternatives provide the same transportation service. When alternatives differ by a small amount, the state of the art requires that this difference be considered as insignificant. Precisely what should be considered a "small" difference is a matter of experience and judgment; but for the benefit of those not familiar with energy comparisons, the researchers suggest that if two alternatives differ by 10 percent or less, this difference should not be considered significant.

Total energy concepts often are applicable also to design alternatives involving indirect energy such as pavements, bridges, culverts, etc. Such comparisons are valid only when the alternatives are comparable in terms of useful life and maintenance costs.

2. Energy intensiveness. Some alternatives are based on the provision of different levels of transportation service. To equate different levels of service to a common energy denominator, total energy must be divided by the number of units (people or tons of goods) transported to arrive at an energy intensity for comparison.

Service parameters can also be used to extend the energy intensity concept to the expenditure of indirect energy. This becomes necessary, for example, in the case of design alternatives that do not have comparable useful lives, physical dimensions, maintenance costs, etc. To provide equitable comparisons in these cases, total energy values may be divided, for example, by years of useful life and the length of facility and the yearly maintenance energy added in. Because this approach implies life-cycle analysis, recyclability or salvage value must be considered.

3. Portal-to-portal energy. Alternatives must be compared in terms of the total transportation service required for the trips that will be made. Invariably, a certain portion of most transport is performed by roadway vehicles (airport to city, etc.). Park-and-ride, or kiss-and-ride bus or rail transit systems require access and egress through the use of private cars, the energy consumption of which should be added to that of the main mode(s). Also, certain alternatives may be more circuitous than others in terms of the particular combination of line-haul and access/egress travel for certain trips. The final comparison should compare the energy consumed to provide portal-to-portal service.

4. Transportation system energy. This analysis examines the influence of a project or alternative on the present and future energy use within the entire transportation system. Items of concern are such things as changes in travel patterns that extend outside the project, patronage for the project that may have its source in a less efficient or a more efficient mode, and the possibility of fostering a mode that may reduce future options. Some alternatives, although more energy-intensive in their present form, may allow modification or conversion to a more efficient system at some future date, whereas the more immediately attractive alternative may not permit the same flexibility.

5. Regional energy. Placing a transportation project in the context of present and future regional energy supply and demand effectively integrates transportation energy uses with those of other sectors. It allows estimation of the peripheral energy use effects of the transportation system. Some typical elements that might be included in a regional energy analysis are:

(a) The timing of the energy expenditure. A "do-nothing" alternative does not require immediate consumption of large quantities of energy, whereas an energy-intensive construction project may consume enough energy in a short time period to create a strain on the energy supply of a region. On the other hand, near-term energy expenditures may be of less concern than those of ten years hence. At that time, deficit of payments, problems with foreign oil suppliers, and diminishing Alaskan production might mean more difficult times. This construction energy may be paid back by more efficient operation, and the time required for payback should be evaluated in a life-cycle analysis.

(b) The type of energy used by the facility and its present and future availability. Units of energy alone may obscure complications arising from use of scarce or energy-intensive fuels, or alternatives requiring heavy use of electricity may overtax local utilities during peak periods or seasons. Consequent energy shortages could, in turn, curtail transportation service.

(c) The transportation facility may induce growth. Although growth might occur in a particular sector of a given region without the existence of a proposed facility, the presence of the facility will normally accelerate land-use changes. The land-use changes are normally in the direction of greater energy use and must be evaluated in terms of regional supply and demand, as well as net impact on national reserves.

(d) The physical extent of the facility and its right-of-way preempts other uses of the land it occupies. In agricultural areas, or areas where natural ecosystems have high productivity, it may be necessary to account for the loss in bioenergy that otherwise would have been produced.

Other possibilities for peripheral effects exist in that the facility and the nature of the accompanying development might make recovery of a local fossil energy deposit uneconomical or reduce the options for siting nuclear power plants.

EXAMPLE STUDY

Each energy study is unique and does not require use of all the factors mentioned previously. A simple example problem, condensed from Appendix F, is presented in the following for illustrative purposes.

The following alternatives are proposed for a roadway transportation project:

Alternative 1. It is proposed to widen an existing major arterial roadway in an urban area, by the addition of two lanes. The section to be widened is within a right-of-way acquired several years previously, and there will be no physical encroachment on the community. The proposed widening will forestall congestion and allow free flowing traffic conditions, at 45 miles per hour. The total length of the project is 5.60 miles, with vertical alignment as follows: 2.2 miles have a grade of +1%, 1.6 miles are essentially level, and 1.8 miles have a grade of -3%, when viewed traveling upstation. Horizontal alignment is relatively straight, with negligible curvature. Cold starts are not a factor.

The predicted traffic between 1977, when the proposed widening will be opened to traffic, through the year 2000, will have an average daily traffic (ADT) of approximately 25,000 vehicles, counting both directions, of which 8% will be trucks having similar characteristics to "2-axle, 6-or-more tire trucks", and 6% will be trucks having similar characteristics to "tractor-semitrailer trucks". (Pickup trucks and small vans are considered as belonging to the category of passenger cars).

Total cost of the project, to be expended in 1976, will be $3,300,000, of which $66,000 will be spent for structures; $43,000 for landscaping; $15,000 for signals, lighting, and miscellaneous; and the remaining $3,176,000 on the roadway itself.

Alternative 2. It is proposed that no improvements are made in this area. (A "no-build" alternative.) The existing 4-lane, asphaltic concrete roadway will receive only normal maintenance. Future traffic predictions indicate the same ADT and vehicle mix as for Alternative 1. However, the heavy traffic expected during peak hours would affect the smooth flow of approximately 5,000 vehicles per day. Attempted speed of traffic will be 45 miles per hour. Alternative 2 will incur no construction costs.

Required: Perform an energy study, comparing the two alternatives from the energy point of view. (Note: Not all data required are available: state the assumptions made and used.)

ENERGY STUDY

This study projects the energy-related effects of two proposed alternatives in a transportation program. Both alternatives involve roadway transportation.

DESCRIPTION

An existing major arterial roadway in an urban area (give street name, route number, city, maps, etc., as required) does not have the capacity to carry the projected peak-hour traffic if future years. Congestion and slowdowns are expected to begin in 1976 and continue to increase. The (name the transportation agency) was aware of the predicted congestion, and has obtained sufficient right-of-way to allow a widening of the existing four-lane road when conditions warrant such action.

A decision must now be made whether or not to proceed with Alternative 1, which is to construct the widening, or with Alternative 2, which is to leave conditions as is (also known as a "no-build" alternative). One of the many factors that must be considered in making the decision is the energy-related effect of each alternative.

The average daily traffic projected between 1977 and 2000, is 25,000 vehicles per day, at a speed of 45 miles per hour. Alternative 1, the construction of two additional lanes, will allow smooth-flowing traffic without peak-hour congestion. The construction will cost a total of $3,300,000 and will be accomplished in 1976. Detailed data on design and materials quantities are not available at this preliminary stage. Alternative 2, the "no-build", will incur no construction expenditures, and will thus handle the projected traffic of 25,000 vehicles per day on the existing 5.6 miles of four-lane flexible (asphaltic concrete) pavement. These four lanes cannot, however, handle the projected peak-hour traffic smoothly, and it is estimated that an average of 5,000 vehicles will be involved in congested traffic daily, with the remaining 20,000 vehicles encountering no problems. Maintenance of the roadway will continue under both alternatives.

CONCLUSIONS

An energy analysis has been conducted in order to compare the two alternative projects under consideration.

Alternative 1, the construction of two additional lanes, will require a substantial one-time energy expenditure related to the construction materials, operations, and equipment in 1976. It will also require the normal maintenance of six lanes of flexible pavement, with its resulting energy consumption. Against this additional energy consumption must be balanced the fact that Alternative 1 will allow free-flowing traffic conditions, which will avoid increases in the fuel consumption of vehicles.

Alternative 2, the no construction ("no-build") alternative, will forego the energy consumption of the construction project, and will require maintenance of the existing four lanes only. Against this energy savings must be balanced the fact that Alternative 2 will cause traffic congestion that will increase the fuel consumption of a portion of the total vehicles operating on this road.

The following table provides the results of the energy analysis in terms of equivalent annual energy consumption by each alternative, averaged for the time period of 1977 through 2000. Construction energy and vehicle indirect energy values have been prorated according to estimated "useful lives," thus providing meaningful comparisons.

Energy Consumption, by Source	Equivalent Annual Consumption: Alternative 1 (Construction)	Alternative 2 (No-Build)
Direct (vehicle fuels)	3.06×10^{11} Btu	3.41×10^{11} Btu
Indirect, vehicles	2.52×10^{11} Btu	2.66×10^{11} Btu
Indirect, construction	2.04×10^{9} Btu	0
Indirect, maintenance	4.03×10^{9} Btu	2.69×10^{9} Btu
Peripheral effects	Nil	Nil
Total energy (annual avg.)	5.63×10^{11} Btu	6.10×10^{11} Btu
Total energy in terms of EQUIVALENT BARRELS OF OIL PER DAY:	266 Bbl	288 Bbl

At the current state of the art, the 8% difference between the energy consumption values of the two alternatives is too small to indicate that one is more energy-intensive than the other. It is concluded that the two alternatives will consume essentially the identical amount of energy, the initial construction expenditures being offset by reduced fuel consumption of vehicles.

Appended are the technical calculations of the energy analysis (see Appendix F).

REPORTING AN ENERGY STUDY

In the development of this research, energy was viewed in the nature of an environmental resource and subject to NEPA requirements. Although this may be moot, the type of technical study required by this viewpoint is comprehensive. Therefore, the technical document resulting from an energy study conducted, analyzed, and reported as described here can be considered as a technical environmental document. Fortunately, the procedures and data necessary to generate such a document are applicable to other purposes as well.

Content and format for various technical environmental impact documents are quite similar. Certain functions have to be performed by the document regardless of whether the study involves air quality, water quality, noise, or environmental resources such as energy.

The primary function of an environmental document is that of communication. Impact information has to be presented to two basically different groups of people, the technical and the nontechnical. The report must communicate equally with both groups. In the nontechnical sense, information must be in a form suitable for presentation at a public hearing, for use by executives and lay groups in decision making, and for incorporation into an EIS. From a technical standpoint, the document must fully support the EIS and must satisfy the needs of the technical reviewer, who wishes to assess the validity of the study and its compliance with environmental law.

To satisfy these two levels of need, the report is written in two parts. The second, or technical, part is written first. The first part is then written to summarize, in nontechnical language, the more important findings of the study. This summary can be presented, depending on the study objectives, in a form suitable for incorporation in an environmental impact statement.

In an energy report, particularly in the summary, the values reported should reflect the accuracy of the analysis. In many cases, equally competent authors offer energy use factors that differ widely. This might suggest that certain values should be reported as a possible range and not as a single value. In any case, reporting fractional values is never warranted. Because the Btu and the kilowatt-hour have little connotation of quantity in the experience of the average person, a more familiar term (such as equivalent barrels of oil) should be used in the report.

A report may be directed not only toward a broad category (system, project, or operational improvement) but also toward something more specific, such as a project phase (planning, design, construction, or operation and maintenance). A report may also present the results of a very restricted study, such as an energy analysis of several different pavement designs. It can be seen that the functions to be served by a report will vary widely depending on the objectives defined in the study phase. A relatively complete study might serve several of the following functions:

1. To describe existing transportation energy use as a baseline against which future energy changes can be evaluated.
2. To provide energy consumption and conservation input to the environmental impact statement.
3. To provide planners with energy consumption information that will enable logical trade-off analyses in system planning, mode selection, and corridor location.
4. To provide designers with energy consumption information that will enable logical trade-off analyses in geometric and structural design, volume and flow alternatives, and materials use.
5. To encourage and provide information for analysis of operations during construction to conserve energy.
6. To provide energy consumption information that will allow logical trade-off analyses during the maintenance and operation phase.
7. To provide an energy input to transportation system management measures.

Considering the various functions of a relatively comprehensive report, the following outline presents a basic and flexible format in which to present an energy study:

Nontechnical Portion (or Summary)
1. Introduction
2. Conclusions
3. Recommendations

Technical Portion
4. Background discussion
5. Data bank and contact description
6. Description of the analytical approach
7. Predictions of energy consumption and conservation
8. Planning information
9. Design information
10. Construction information
11. Maintenance and operation information
12. Continuing evaluation
13. Bibliography
14. Appendices

The following discussions are keyed to the foregoing outline:

1. The introduction should be a short narrative statement describing the existing situation, the need for the proposed improvement, and the location and extent of the various alternatives in sufficient detail to provide the reader with a mental picture of the work to be done. The project description must give the reader some indication as to the background behind the project, including public concerns, so that the reader fully understands the context and the transportation system into which the project fits. In particular, the project must be placed in the context of energy-related problems and constraints in the project region. Description of the background is best accomplished by abstracting Section 4.

2. Generally, the conclusions summarize Section 7. When an energy study is serving as technical input to an EIS, the conclusions should be structured as shown in the following. When the focus is on other objectives, the conclusions should reflect those objectives. Because most energy analyses are time dependent, the conclusions can be presented in the form of simple graphic trend lines and tabular summaries accompanied by a narrative which, in the case of an EIS-oriented study, ties directly to the following:

(a) The anticipated impact of the various alternatives on energy consumption and conservation. Direct energy use, by fuel type, and indirect energy should be shown. Both beneficial and adverse impacts should be discussed. Some possibilities are:

°Comparison of the energy use of the various alternatives in terms of total project energy, energy intensiveness, portal-to-portal energy, transportation system energy, or regional energy.

°Effects of the alternatives on local and regional energy supplies and on requirements for additional capacity.

°Energy requirements and energy use efficiencies of the alternatives for the various stages of construction, operation and maintenance, and removal (initial and life-cycle energy costs).

°Effects of the alternatives on peak- and base-period regional energy demands.

°Alternatives' compliance with existing energy regulations or standards.

°The effects of the alternatives on national energy resources.

For the no-build, or null, alternative, it is important to consider the indirect energy requirements for maintenance and operation in addition to the direct energy for operation.

(b) The unavoidable adverse effects of the alternatives on the energy resource. Unavoidable adverse effects might include such things as resource depletion and wasteful, inefficient or unnecessary consumption that cannot be mitigated.

(c) The effect of the various alternatives on the relationship between local short-term uses of the energy resource and the enhancement of long-term productivity. This effect may be expressed by examining the foreclosure of alternative land uses, future transportation alternatives, and other uses to which the project energy might be put. Life-cycle costs may be important.

(d) The irreversible and irretrievable commitments of the energy resource that would accompany the implementation of the various alternatives. These might consist of such things as preempting future opportunities for energy development or conservation, the use of fuel, and use of construction materials.

(e) Mitigation or energy conservation measures that might be part of implementing any of the various alternatives. These measures would be aimed at reducing wasteful, inefficient, and unnecessary energy consumption in all phases of the project. They would include any specialized machinery such as regenerative motors or flywheel storage, design features, pavement recycling at a future date, alternative fuels or energy systems, potential for reducing peak energy demand, and siting and orientation to reduce energy demand.

Other elements requiring discussion in this section might be the consistency of the various alternatives with regional and national energy goals and the consumption of energy by any growth or development resulting from the project.

3. Recommendations would not be written for inclusion in an EIS. This section would usually be written to summarize information presented in Sections 8 through 11. This information is an input to the various phases of a project and serves to identify opportunities for energy conservation and prevention of wasteful or inefficient consumption. For studies not concerned with an EIS input, the section might provide recommendations as to a preferred alternative action.

4. The background discussion provides information on the project in terms of its energy setting. Important things to discuss might include:

(a) Existing regional energy use patterns, in terms of fuel type used and temporal aspects.

(b) Regional energy supply and demand situation.

(c) Regional energy supply and demand associated with anticipated future land-use changes.

(d) Areas in the immediate project vicinity with energy potential, such as fossil fuel deposits or geothermal sources.

(e) Potential or proposed power plant sites in the immediate project vicinity.

(f) Expressed energy concerns of the public, local agencies, environmental groups, etc.

5. A data bank and contact description is necessary to satisfy regulatory agency reviewers. It also produces a "memory freshener" for study review in the future. Briefly, this section of the report provides a listing of productive and nonproductive data sources and contacts that were utilized in developing the energy study. A chronology should accompany the listing.

6. A description of the analytical approach is necessary for the technical reviewer. This provides an indication of the technical adequacy of the document. The approach should be discussed in sufficient detail to allow review of the important steps and show continuity in the analysis.

7. Predictions of energy consumption and conservation which developed from the analysis are presented in this section. These constitute the "results" of the study. Types of predictions to be made are dependent on the objectives of the study. Where the study is to serve as EIS input, the parameters discussed in Section 2 could serve as a framework.

8. If the objectives of the study are such that energy information is developed which may be of use in the planning phase of a project, it would be presented in this section for special attention by transportation planners. Even though the information may appear elsewhere in the report, this section allows a special orientation toward problems and opportunities in the planning phase.

9. Information for design input is often in the nature of impact mitigation, calling attention to materials and design parameters that offer energy economies or wasteful energy expenditures.

10. Construction information presented in this section can provide the construction engineer with the necessary insight to recognize possible energy conservation opportunities that may occur during the contractor's operations.

11. The maintenance and operation section is intended to carry the applicable results of an energy study on beyond the construction phase. An analysis may contain results that are predicated on certain types and frequencies of maintenance activities. Knowledge of the analysis may provide further opportunities to revise practices and promote conservation.

12. As energy conservation techniques become more important and are pursued in project development, many assumptions will be made about the newer and unproven approaches. To determine the worth of such techniques and assign more accurate values to them for use in analysis, feedback must occur. To enable the proper feedback, this section can provide a listing of those areas where more information is needed to refine the assumptions.

13. The bibliography provides a list of pertinent references for the reader. It should not duplicate Section 5.

14. Where necessary, calculations or other pertinent material may be appended to the report.

CHAPTER THREE

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

The current literature pertaining to transportation energy is staggering in amount and constantly growing. However, the quantity of hard numerical data and statistics, based on scientific research, is severely limited. A tendency exists for several publications, by different authors, to share the same data source.

The text has presented the following subjects:

1. An introduction to the current use of energy in transportation, and predictions of depletion of U.S. petroleum sources by the end of the 20th century or the early part of the 21st century.
2. A discussion of the theoretical considerations relating to the subject, including: the need to consider not only the fuel (direct energy) used to propel vehicles, but also the additional (indirect) energy required to manufacture and maintain vehicles, and to construct and maintain systems and facilities, as well as the induced energy change a project may have on a region.
3. A description of transportation vehicles and the parameters that affect their fuel consumption; and the parameters that affect the energy consumption of systems -- materials, dollar costs, etc.
4. Based on existing information, it is possible to conduct an energy-related analysis of transportation systems, projects, or operational improvements and compare proposed alternatives as to their energy efficiency. Recommended procedures for performing energy analyses and comparing alternatives are presented.
5. An effort has been made to separate the published original data from the veritable plethora of verbiage in the literature and assemble them in Appendix A as an "Energy Factor Handbook."

Transportation energy studies are still at an early stage of development, and published data estimates are subject to significant change as more research is conducted on the subject. Indeed, sources often present substantially different data for similar items. This is especially true of \$/Btu comparisons vs materials/Btu for transportation construction.

The best documentation is in the area of direct (propulsion) energy. Of the important segments of indirect energy, the field of facility maintenance is the least documented.

SUGGESTED RESEARCH

This report is based on a wide-ranging literature search. The various areas where data were found to be insufficient, unreliable, or even lacking, are reflected in the following suggestions for further research:

1. Energy required for road maintenance.
2. Energy required for pipeline construction, operation, and maintenance.
3. Energy required for airport construction, operation, and maintenance.
4. Energy required for vehicle maintenance (all types).
5. Fuel consumption characteristics of modern roadway vehicles.
6. Studies of alternative-fueled vehicles.

A further source of subjects for suggested research is Appendix A. Many of the items marked "N.A." (not available) may not have been thoroughly researched, or at least were not encountered in this effort.

REFERENCES

1. French, Alexander, "Measuring Energy Efficiency in Freight Transportation", Energy and Freight Movement, Transportation Research Board Session #52, pp 20-38, Jan. 1976.
2. "Environmental Impact Report - A Draft", Volume 3, California Transportation Plan, California DOT, July 1975.
3. "Energy Effects, Efficiencies and Prospects for Various Modes of Transportation", NCHRP Synthesis of Highway Practice 43, (1977).
4. "Potential for Energy Conservation in the United States: 1974-1978", National Petroleum Council, Sept. 1974.
5. Pollard, Hiatt, Rubin, "A Summary of Opportunities to Conserve Transportation Energy", (revised), U.S. Department of Transportation Report No. DOT-TSC-OST-75-22, August 1975.
6. A. S. Loebl et al, "Transportation Energy Conservation Data Book", Oak Ridge National Laboratory, Oct. 1976.
7. "Standard for Metric Practice", ASTM Designation E 380-76, American Society for Testing and Materials, Feb. 1976.
8. Chapman, Charlesworth, Baker, "Future Transport Fuels", Transport and Road Research Laboratory, Crowthorne, Berkshire, TRRL Supplementary Report 251.
9. Herendeen, Robert A., "The Energy Cost of Goods and Services", ORNL-NSF Environmental Program, Oak Ridge National Laboratory, October 1973.
10. Claffey, Paul J., "Passenger Car Fuel Consumption as Affected by Ice and Snow", Sponsored by the U.S. Department of Transportation Task Force on Application of Economic Analysis to Transportation Problems.
11. California Department of Transportation, "Heavy Vehicle Cost to State Highways in California", Sacramento, July 1976.
12. "State of California Department of Motor Vehicles Statistical Record on Motive Power Body Type and Weight Divisions for Automobiles, Motorcycles, Commercial Trucks and Trailers. Special 1973 Early Renewal Report. December 1 to December 31, 1972. Gross Report", Sacramento, California, Department of Motor Vehicles, 1972.
13. Claffey, Paul J., "Running Costs of Motor Vehicles As Affected by Road Design and Traffic", National Cooperative Highway Research Program Report 111, (1971).
14. Broderick, A. J. et al, "Effect of Variation of Speed Limits on Intercity Bus Fuel Consumption, Coach and Driver Utilization and Corporate Profitability", Report No. DOT-TSC-OST-75-4, U.S. DOT, Nov. 1975.
15. Transportation Systems Center, "Energy Primer Selected Transportation Topics", Technology Sharing, a program of the U.S. Department of Transportation. n.d. (Available from Office of Program Development, U.S. D.O.T., Transportation Systems Center, Kendall Square, Code 151, Cambridge, MA 02142).
16. Fels, Margaret Fulton, "Comparative Energy Costs of Urban Transportation Systems", Transportation Research, Vol. 9, pp 297-308, 1975.
17. Smylie, John, "Indirect Energy Consumption for Transportation Projects: Summary Outline", De Leuw, Cather and Company, October 1975.
18. U.S. Department of Transportation, "Characteristics of Urban Transportation Systems: A Handbook for Transportation Planners", May 1974.
19. Smylie, John, "Indirect Energy Consumption for Transportation Projects", De Leuw, Cather and Company, Los Angeles, California, October 21, 1975.
20. U.S. Department of Transportation, "Energy Impact Analysis Resource Information", Washington, D.C., June 1976.
21. Hirst, Eric, "Automobile Energy Requirements", American Society of Civil Engineers Proceedings 100 (TE4, No. 10909), November 1974, pp 815-26.
22. Herendeen, R. A., Sebald, Anthony, "The Dollar Energy and Employment Impacts of Air, Rail and Automobile Passenger Transportation", University of Illinois Center for Advanced Computation, (Document 96,) Sept. 1974.
23. Berry, R. Stephen and Fels, Margaret F., "The Energy Cost of Automobiles", Science and Public Affairs, December 1973.
24. The Asphalt Institute, "Energy Requirements for Roadway Pavements", College Park, Maryland, April 1975.
25. Lehner, Friedrich, "Light Rail and Rapid Transit," Transportation Research Board Special Report 161, pp 37-50.
26. "Fuel Usage Factors for Highway Construction", Transportation Research Board, Highway Research Circular, No. 158, July 1974.
27. Urban Goods Movement Demonstration Project Design Study, National Technical Information Service, No. PB-249 322, November 1975.
28. The Boeing Commercial Airplane Company, "Intercity Passenger Transportation Data: Energy Comparisons", Vol. 2, Seattle, Washington, May 1975.
29. Cetinich, J. N., "Fuel Efficiency Improvement in Rail Freight Transportation", U.S. Department of Transportation, Federal Railroad Administration, Report No. FRA-OR & D-76-136, December 1975.
30. Mays, R. A., Miller, M. P., Schott, G. J., "Intercity Freight Fuel Utilization at Low Package Densities - Airplanes, Express Trains and Trucks",

55th Annual Meeting of the Transportation Research Board, Session #52, Washington, D.C., January 20, 1976.
31. Sokolsky, S., "Energy Savings Resulting from Modal Shifts to Corridor Rail", the Aerospace Corporation, July 8, 1975.
32. Pilati, David A., "Airplane Energy Use and Conservation Strategies", Oak Ridge National Laboratory, ORNL-NSF-EP-69, 1975.
33. "Flight Operation Fuel Management Program", Braniff International Technical Performance, 1976.
34. Correspondence, 1976:
Mr. William G. Evans, Superintendent
Cape May-Lewes Ferry
The Delaware River and Bay Authority
Cape May, N.J. 08204
35. Correspondence, 1976
Mr. C. D. Byrne, Port Engineer
Washington State Ferries
Seattle Ferry Terminal
Seattle, Washington 98104
36. Correspondence and telephone discussions, 1976
Mr. William D. Stevens
Golden Gate Bridge & Highway Transportation District
Ferry Transit Division
P.O. Box 9000, Presidio Station
San Francisco, CA 94129
37. Correspondence and telephone discussions, 1976
Mr. T. J. Patterson, Jr., Western Region Director
Mr. Henry D. Ryan, Marine Surveyor
U.S. Maritime Administration
U.S. Dept. of Commerce
450 Golden Gate Ave.
San Francisco, CA 94102
38. Webb Institute of Naval Architecture, "Analysis of Marine Fuel Consumption and Sales", U.S. Department of Commerce, No. PB-246 602, August 1975.
39. Transportation Research Board, National Research Council, "Inland Waterway Transportation", Transportation Research Record 545, 1975.
40. Herendeen, Robert A. and Bullard III, Clark W., "Energy Cost of Goods and Services, 1963 and 1967", University of Illinois, Center for Advanced Computation, Document No. 140, November 1974.
41. Bullard, Clark W.; Penner, Peter S.; and Pilati, David A., "Energy Analysis Handbook", University of Illinois, Center for Advanced Computation, Document #214, October 1976.
42. "Guidelines for Estimating Fuel Requirements for Highway Construction Projects", Attachment to letter from California Dept. of Transportation Construction to all Transportation District Directors, March 5, 1974.
43. "Implicit Price Deflators", Survey of Current Business, Vol. 56, Bureau of Economic Analysis, January 1976.
44. "Manual of Steel Construction", (sixth edition) AISC, New York, New York, 1967.
45. Katsoulis, M., "Energy Impacts of Passenger Transportation", Roads and Transportation Association of Canada, Ottawa, March 1974.
46. Mascy, Alfred C. and Paullin, Robert L., "Transportation Vehicle Energy Intensities", (A Joint DOT/NASA Reference Paper) NASA TM X-62, 404, DOT-TST-13-74-1, June 1974.
47. California Energy Commission, "Quarterly Fuel and Energy Summary", Vol. 1, No. 4, fourth quarter 1975.
48. Uren, Lester Charles, "Petroleum Production Engineering", McGraw-Hill (3rd ed.), 1953.
49. Miner, Douglas F. and Seastone, John B. Handbook of Engineering Materials, (first edition) Wiley, New York, 1955.
50. Abraham, Herbert, Asphalts and Allied Substances, (sixth edition - in two volumes) Vol. 1, Van Nostrand, New York, 1961.
51. Portland Cement Association, "1974 Energy Report for U.S. Portland Cement Industry, Summary Analysis", Skokie, Illinois, May 1975.
52. Keyser, Carl A., Materials Science in Engineering, Merrill, Columbus, Ohio, 1968.
53. State of California Highway Transportation Agency, "Manual of Bridge Design Practice", (second edition), 1963.
54. Standard Plans, California Department of Transportation, March 1977.
55. U.S. Environmental Protection Agency, "Supplement No. 5 for Compilation of Air Pollutant Emission Factors", Second Edition, Research Triangle Park, North Carolina, December 1975.
56. Austin, T. C.; Michael, R. B.; Service, G. R., "Passenger Car Fuel Economy Trends Through 1976", Automobile Engineering Meeting, Detroit, Michigan, October 1975, Society of Automotive Engineers (SAE), Technical Report No. 750957.
57. Traffic Science Department, "The Influence of Vehicle Characteristics, Driver Behavior, and Ambient Temperature on Gasoline Consumption in Urban Traffic", Research Publication GMR-1950, Research Laboratories, General Motors Corporation, Warren, Michigan, January 20, 1976.
58. Transportation Research Board, "Transportation Programming, Economic Analysis, and Evaluation of Energy Constraints", Transportation Research Record 599, 1976.
59. U.S. Department of Transportation and U.S. Environmental Protection Agency, "Study of Potential for Motor Vehicle Fuel Economy Improvement", Truck and Bus Panel Report, Report No. 7 of Seven Panel Reports, January 10, 1975.
60. Correspondence with author, 1976:
Margaret F. Fels, "Appendix to Suburb-to-Suburb
Travel: Energy Time and Dollar Expenditures"
Center for Environmental Studies and Transportation Program, Princeton University.
61. Rensselaer Polytechnic Institute, "Mass Transit Technology: A Comprehensive Survey of Vehicular Hardware", U.S. Department of Commerce, No. PB-224 568, June 1973.

62. Correspondence, 1976
Mr. Thomas Buck, Manager, Public Affairs
Chicago Transit Authority
P.O. Box 3555
Chicago, Illinois 60654
63. Curry, James P., "Case Studies of Transit Energy and Air Pollution Impacts", De Leuw, Cather and Co., Washington, D.C., May 1976.
64. Healy, Timothy J., "Energy Requirement of the Bay Area Rapid Transit System", California Division of Transportation Planning, November 1973.
65. Airplane Energy - Federal Register, Volume 39, No. 102, Friday, May 24, 1974.
66. "Compilation of Air Pollutant Emission Factors", United States Environmental Protection Agency, Second Edition, Publication AP-42.
67. The Airplane Owner's & Pilot's Association "Pilot" March 1976.
68. U.S. Department of Transportation, "Energy Statistics: A Supplement to the Summary of National Transportation Statistics", Washington, D.C., August 1975.
69. U.S. Environmental Protection Agency, "Compilation of Air Pollutant Emission Factors", (second edition) Research Triangle Park, North Carolina, April 1973.
70. Baumgartner, J. P., "Energy Consumption of Rail, Road and Air Transport", Rail International, pp 22-29, January 1976.
71. Maddalon, Dal V., "Rating Aircraft on Energy", Astronautics & Aeronautics, pp 26-43, December 1974.
72. Hannon, Bruce, Puleo, F., "Transferring from Urban Cars to Buses; The Energy and Employment Impacts", University of Illinois Center for Advanced Computation, Document 98, April 1974.
73. Transportation Research Board, National Academy of Sciences, "Dual Mode Transportation", Special Report 170.
74. Office of Advance Planning, Planning and Research Division, "Energy and Transportation for the Future", Iowa Department of Transportation, Ames, Iowa.
75. Miller, M. P., "Energy Efficiency of Current Intercity Passenger Transportation Modes", Paper presented at the 3rd National Conference on Effects of Energy Constraints on Transportation Systems, Union College, Scenectady, N.Y., August 4, 1976.
76. Whittaker, R. H., "Communities and Ecosystems", (2nd Ed.), New York, Macmillan Publishing Co., 1975.
77. City of Los Angeles, "EIR Manual for Private Projects", 1975, Updated 1976.
78. Epps, Jon, "Energy Requirements Associated with Highway Maintenance and Rehabilitation", Paper presented at the 57th Annual Transportation Research Board Meeting, Jan. 16-20, 1978.
79. "A Report on the Problems and Possible Solutions to Disposing of or Recycling Used Tires", Transportation Laboratory, California Department of Transportation, Jan. 1975.
80. Claffey, Paul J., "Passenger Car Fuel Conservation", Prepared for Federal Highway Administration, Washington, D.C., PB-265 369, July 1976.
81. Congressional Budget Office, "Urban Transportation and Energy: The Potential Savings of Different Modes", December 1977.
82. T. Owen Carroll, Robert Nathans, Philip F. Palmedo, and Robert Stern, "The Planner's Energy Workbook - A Manual for Exploring Relationships Between Land Use and Energy Utilization", Brookhaven National Laboratory, June 1973.
83. Real Estate Research Corporation, "The Cost of Sprawl", April 1974.
84. Hopkins, John B., "Railroads and the Environment - Estimation of Fuel Consumption in Rail Transportation, prepared for the U.S. Dept. of Transportation, May 1975.

ADDITIONAL SOURCES CONSULTED

-1977-

Claffey, Paul J., "Passenger Car Fuel Conservation", Federal Highway Administration Report No. FHWA-PL-77009, January 1977.

Lave, C., "Negative Energy Impact of Modern Rail Systems", Science, Vol. 195, February 11, 1977.

"Data Base and Documentation for Estimating Emissions from Motor Vehicles in California", State of California Air Resources Board, May 1977.

"Background Paper, Urban Transportation and Energy: The Potential Savings of Different Modes", Congressional Budget Office, Congress of the United States, December 1977.

-1976-

UMTA Technical Study, "Recommended Level of Service Criteria Working Paper", CA-09-8001, Project II, Task D, January 9, 1976.

Pilkington, II, George B., "Effect of the Energy Crisis on Existing Design Standards", Transportation Research Board, Transportation Research Record No. 601, 1976, pp 53-55.

Mays, Miller, Schott, "Intercity Freight Fuel Utilization at Low Package Densities - Airplanes, Express Trains and Trucks", Washington, D.C., January 20, 1976.

Wachs, Martin, "Consumer Attitudes Toward Transit Service: An Interpretive Review", Journal of the American Institute of Planners, Vol. 42, No. 1, pp. 91-104, January 1976.

Daly, Herman E., "Energy Demand Forecasting: Prediction or Planning?", Journal of the American Institute of Planners, Vol. 42, No. 1, pp. 4-15, January 1976.

Curry, Richard F., "After the Otto, What?", American Motorist, p. 6, February 1976.

French, Alexander, "Transportation Energy Considerations", American Society of Civil Engineers Proceedings 102, pp. 27-37, February 1976.

Fuels and Materials Panel of the U.S. Department of Transportation Task Force on Motor Vehicle Goals Beyond 1980, "Fuels and Materials Resources for Automobiles in the 1980-1990 Decade", Washington, D.C., March 1976.

Millikin, Drosdat, Dean, "Transit Needs in Small California Communities, an Interim Report", DMT 013, California Department of Transportation, Sacramento, California, April 1976.

Curry, James P., DeLeuw, Cather & Company, "Case Studies of Transit Energy and Air Pollution Impacts", EPA-600/5-76-003, U.S. Environmental Protection Agency, May 1976.

Evans, Herman, Lam, "Multivariate Analysis of Traffic Factors Related to Fuel Consumption in Urban Driving", Transportation Science, Vol. 10, No. 2, pp. 205-215, May 1976.

Manager, U.S. General Services Administration Voluntary Truck and Bus Fuel Economy Program, "U.S. Government Interagency Commercial Vehicle Post-1980 Goals Study", Washington, D.C., May 1976.

"1974-1975 Annual Average Daily Truck Traffic on the California State Highway System", California Department of Transportation, Office of Traffic, June 1976.

Federal Highway Administration, "Lower Bituminous Mixing Temperatures", FHWA Notice N5080.52, June 9, 1976.

Federal Highway Administration, Incinearator Residue In Bituminous Base Construction", FHWA Bulletin FHWA-RD-76-12, June 28, 1976.

"Energy Effects, Efficiencies and Prospects for Various Modes of Transportation", NCHRP Synthesis of Highway Practice No. 43, July 1976.

California Energy Resources Conservation and Development Commission, Alternatives Implementation Division, Energy Systems Integration Office, "Draft Overview of Alternative Energy Technologies", October 7, 1976.

The American Association of State Highway & Transportation Officials, "Energy & Transportation", Birmingham, Alabama, November 16, 1976.

"1976 International Aerospace Specification Tables", Aviation Week & Space Technology, December 1976.

-1975-

U.S. Environmental Protection Agency, "Supplement No. 4 for Compilation of Air Pollutant Emission Factors - Second Edition", Research Triangle Park, North Carolina, January 1975.

Department of Transportation, Office of Highway Programming, Memorandum to Mr. Heinz Heckeroth, Assistant Director for Highways, Issue: Air pollution and energy use, File: AS.3.A, February 5, 1975.

Quintin Jr., W. P. and Eanes, T. S. "BART Progress Report", Society of Automotive Engineers, No. 750442, Detroit, Michigan, February 24-28, 1975.

Elms, Charles P., "New Transit Modes: Applicability and Current Status", Society of Automotive Engineers, No. 750214, Detroit, Michigan, February 24-28, 1975.

Penner, Peter S., "The Dollar, Energy and Labor Impacts of 1971 Motor Freight Transportation", University of Illinois Center for Advanced Computation Technical Memorandum No. 44, Revised March 1975.

The Asphalt Institute, "Energy Requirements for Roadway Pavements", MISC-75-3, College Park Maryland, April 1975.

UMTA Technical Study, "Potential Level of Service Criteria Working Paper", CA-09-8001, Project II, Task C, May 25, 1975.

Drosdat, Herbert and Kuehn, Thomas, "The Technologist and Public Policy", Chemtech, pp. 290-295, May 1975.

The Boeing Commercial Airplane Company, "Intercity Passenger Transportation Data: Service and Economic Comparisons", Vol. 1, May 1975.

Portland Cement Association, "Cement Industry Report Gains in Coal Conversion, Energy Efficiency", June 9, 1975.

Ross, Grisinger, Burris, "Outline of a Method of Estimating Transportation Energy Impacts", California Department of Transportation, District 07 Environmental Investigations, July 1975.

Leisher, L. L. and Schott, G. J., "Common Starting Point for Intercity Passenger Transportation Planning", Astronautics & Aeronautics, July/August 1975.

McMorris, Donn D., "Statement of American Trucking Association, Inc.", 1616 P Street, N.W., Washington, D.C., October 8, 1975.

Foster, C. R., "The National Asphalt Pavement Association's Energy Conservation Program", October 24, 1975.

Wade, Nicholas, "Nicholas Georgescu - Roegen: Entropy the Measure of Economic Man", Science, Vol. 190, pp. 447-450, October 31, 1975.

Sansom, Robert L., "Energy, Land Use and the Environment: The Impact on Transit", Transit Journal, pp. 6-20, November 1975.

Reed Jr., M. F., "The Price of Commuting", Traffic Engineering, pp. 41-42, December 1975.

U. S. Environmental Protection Agency, "Supplement No. 5 for Compilation of Air Pollutant Emission Factors - Second Edition", Research Triangle Park, North Carolina, December 1975.

"Cars in Operation", Automotive News, 1975 Almanac Issue, pg. 70, 1975.

Council on Environmental Quality, "MERES and the Evaluation of Energy Alternatives", pp 5-16, Washington, D.C., 1975.

"1975 International Aerospace Specification Tables", Aviation Week & Space Technology, 1975.

Transportation Research Board, "Strategies for Reducing Gasoline Consumption Through Improved Motor Vehicle Efficiency", Special Report 169, 1975.

Pilati, David A., "Conservation Options for Commercial Air Transport", Energy Systems and Policy, Vol. 1, No. 2, February 1975.

-1974-

Howard R. Ross Associates, "Energy Consumption of PRT Systems", Southern California Association of Governments, Los Angeles, California, March 15, 1974.

Norman, Colin, "Huge Resources Needed to Exploit Shale Oil", Energy Review, Nature Vol. 249, pp 704-706, June 21, 1974.

Lovins, Amory B., "The Case for Long-Term Planning", Bulletin of the Atomic Scientists, pp. 38-50, June 1974.

Mikolowsky, W. J., et al, "The Regional Impacts of Near-Term Transportation Alternatives: A Case Study of Los Angeles", The Rand Corporation, R-1524-SCAG, June 1974.

Goss, W. P., and McGowan, J. G., "Energy Requirements for Passenger Ground Transportation Systems", ASME Publication 73-ICT-24, New York, July 1974.

Healy, Timothy J., "The Energy Use of Public Transit Systems", California Department of Transportation, Division of Mass Transit, Santa Clara, August 1, 1974.

"Encourage Research on Improved Water Transport Vessels for Movement of People", Traffic Coordinating Council of the Metropolitan Transportation Commission, Hotel Claremont, Berkeley, California 94705, September 1974.

Hirst, Eric, "Automobile Energy Requirements", Transportation Engineering Journal, pp. 815-826, November 1974.

Healy, Timothy J., "Energy, Electric Power, and Man", San Francisco, Boyd and Fraser 1974.

-1973-

Hare, Charles T. and Springer, Karl J., "Exhaust Emissions from Uncontrolled Vehicles and Related Equipment Using Internal Combustion Engines, Part 2 - Outboard Motors", APTD-1491, January 1973.

Norco, Cirillo, Baldwin, Gudenas, "An Air Pollution Impact Methodology for Airports - Phase 1", APTD-1470, Environmental Protection Agency, January 1973.

Leach, Gerald, The Motor Car and Natural Resources, Organization for Economic Cooperation and Development, Paris 1973.

Austin, T. C. and Hellman, K. H., "Passenger Car Fuel Economy - Trends and Influencing Factors", Society of Automotive Engineers, Technical Paper No. 730790, Warrendale, PA., 1973.

-1972-

Lidsky, Lawrence M., "The Quest for Fusion Power", Technology Review, pp. 10-21, January 1972.

Lockheed Palo Alto Research Laboratory, "Pre-proposal: Characterization of Public Driving Pattern", LMSC D082110, February 12, 1972.

Highway Research Board, Traffic Flow Characteristics and Models - 7 Reports, Highway Research Record, No. 409, Washington, D.C., 1972.

-Prior to 1970-

Cross, Roy, A Handbook of Petroleum, Asphalt and Natural Gas, Bulletin No. 25, Kansas City Testing Laboratory, Kansas, MO, 1928.

APPENDIX A

ENERGY FACTOR HANDBOOK

ENERGY AND TRANSPORTATION SYSTEMS

INDEX

Section | Page

APPENDIX A

Energy Factor Handbook
List of Abbreviations

AC	asphaltic concrete
a.c.	alternating current
API	American Petroleum Institute
approx.	approximately
arr.	arrival
avg.	average
auto.	automatic
Btu	British thermal unit
C	degrees Celsius
CEQ	Council for Environmental Quality (U.S.)
cf	cubic feet
Co.	company
conc.	concrete
constr.	construction
corr.	corrugated
CTA	Chicago Transit Authority
cu. in.	cubic inches
d.c.	direct current
deg.	degrees
dep.	departure
DWT	deadweight
ea.	each
EIR	environmental impact report
EIS	environmental impact study
elec.	electric
EPA	Environamental Protection Agency
etc.	et cetera (and so forth)
expo.	exposition
F	degrees Fahrenheit
FAA	Federal Aviation Administration
fab.	fabricated
fig.	figure
F.O.B.	freight on board
ft	foot, feet
gal	gallon(s) (U.S. liquid)
gen.	general
GPM	gallons per mile (statute)
GVW	gross vehicle weight

hp	horsepower
hr	hour
HVAC	heating, ventilating, and air conditioning
i.e.	that is
instru.	instruments
kg	kilograms
km	kilometres
kw	kilowatt
KWH	kilowatt-hours
L.A.	Los Angeles
L.A.S.H.	lighter aboard ship
lb(s)	pound(s)
lf	lineal foot
lin-ft	lineal foot
lin-m	lineal metre
lit.	litre
ln	lane
lt.	light weight
m	metre
manuf.	manufacture
max.	maximum
mfg.	manufacturing
mi	mile
min.	minimum
misc.	miscellaneous
mm	millimetre(s)
MPH	miles per hour
M.S.	motorship
N.A.	not available
naut.	nautical
NCHRP	National Cooperative Highway Research Program
NEPA	National Environmental Protection Act
no.	number
non-met.	non-metallic
PA	Pennsylvania
pass.	passenger
PCC	portland cement concrete
pcf	pounds per cubic foot
plf	pounds per lineal foot
PRT	personal rapid transit

reinf.	reinforcement
R/R	railroad
R-T	rapid transit
sect.	section
sf	square foot
S.T.	steam turbine
std.	standard
S.T.O.L.	short take off and landing
T	ton
T-mile	ton-mile
transp.	transportation
TRB	Transportation Research Board
USA	United States of America
U.S.	United States
var.	varies, variable
veh.	vehicle
vs	versus
Wash.	Washington, D.C.
wt	weight
W.VA	West Virgina
yr	year

Symbols

#	number	<	less than
$	dollars	%	percent
>	greater than	$\pm$	plus or minus

1.0 PROPERTIES OF SELECTED FUELS

	Density	Thermal Energy
1.1 AMMONIA (liquid)	5.73 lb/gal	6.25×10^4 Btu/gal
	(0.69 kg/lit.)	(1.74×10^7 joules/lit.)
1.2 BUTANE (liquid)	N.A.	1.0×10^5 Btu/gal
		(2.8×10^7 joules/lit.)
1.3 COAL (composite, all grades)	78 pcf	1.07×10^4 Btu/lb
	(1250 kg/m^3)	(2.49×10^7 joules/kg)
1.3.1 Anthracite	97 pcf	1.44×10^4 Btu/lb
	(1554 kg/m^3)	(3.35×10^7 joules/kg)
1.3.2 Bituminous	84 pcf	1.28×10^4 Btu/lb
	(1346 kg/m^3)	(2.98×10^7 joules/kg)
1.3.3 Lignite	78 pcf	6.6×10^3 Btu/lb
	(1250 kg/m^3)	(1.5×10^7 joules/kg)
1.3.4 Subbituminous	N.A.	8.5×10^3 Btu/lb
		(2.0×10^7 joules/kg)
1.4 ETHANOL (ethyl alcohol)	8.02 lb/gal	8.93×10^4 Btu/gal
	(0.96 kg/lit.)	(2.49×10^7 joules/lit.)
1.5 GAS, NATURAL	0.038 pcf	1.0×10^3 Btu/cf

		(0.96 kg/lit.)	($2.49 \times 10^{[illegible]}$ joules/lit.)
1.5	<u>GAS, NATURAL</u>	0.038 pcf	1.0×10^{3} Btu/cf
		(0.609 kg/m^3)	(37.26×10^{6} joules/m^3)
1.6	<u>GASOLINE (automotive)</u>	5.57 lb/gal	1.25×10^{5} Btu/gal
		(0.67 kg/lit.)	(3.48×10^{7} joules/lit.)
1.7	<u>GASOLINE (aviation)</u>	5.57 lb/gal	1.08×10^{5} Btu/gal
		(0.67 kg/lit.)	(3.01×10^{7} joules/lit.)
1.8	<u>HYDRAZINE</u>	7.08 lb/gal	7.81×10^{4} Btu/gal
		(0.85 kg/lit.)	(2.18×10^{7} joules/lit.)
1.9	<u>HYDROGEN (liquid)</u>	1.67 lb/gal	3.21×10^{4} Btu/gal
		(0.20 kg/lit.)	(8.95×10^{6} joules/lit.)
1.10	<u>HYDROGEN+OXYGEN (liquids)</u>	4.32 lb/gal	2.19×10^{4} Btu/gal
		(0.52 kg/lit.)	(6.10×10^{6} joules/lit.)
1.11	<u>JET AIRCRAFT FUEL</u>	6.6 lb/gal	1.23×10^{5} Btu/gal
		(0.79 kg/lit.)	(3.42×10^{7} joules/lit.)
1.12	<u>KEROSENE</u>	6.71 lb/gal	1.35×10^{5} Btu/gal
		(0.80 kg/lit.)	(3.76×10^{7} joules/lit.)
1.13	<u>MAGNESIUM HYDRIDE</u>	7.20 lb/gal	5.12×10^{5} Btu/gal
		(0.86 kg/lit.)	(14.27×10^{7} joules/lit.)

1.14 METHANE (liquid)	5.61 lb/gal	7.81×10^{4} Btu/gal
	(0.67 kg/lit.)	(2.18×10^{7} joules/lit.)
1.15 METHANOL (methyl alcohol)	5.57 lb/gal	6.94×10^{4} Btu/gal
	(0.67 kg/lit.)	(1.93×10^{7} joules/lit.)
1.16 OIL, CRUDE		
1.16.1 Alaskan sources	N.A.	N.A.
1.16.2 California sources	7.88 lb/gal	1.38×10^{5} Btu/gal
	(0.95 kg/lit.)	(3.85×10^{7} joules/lit.)
1.16.3 Other USA sources	7.03 lb/gal	1.38×10^{5} Btu/gal
	(0.84 kg/lit.)	(3.85×10^{7} joules/lit.)
1.16.4 Outside USA sources	7.50 lb/gal	1.38×10^{5} Btu/gal
	(0.90 kg/lit.)	(3.85×10^{7} joules/lit.)
1.17 OIL, FUEL OIL		
1.17.1 No. 1 (API 42 deg.)	6.790 lb/gal	1.35×10^{5} Btu/gal
	(0.815 kg/lit.)	(3.76×10^{7} joules/lit.)
1.17.2 No. 2 Diesel (API 35 deg.)	7.076 lb/gal	1.39×10^{5} Btu/gal
	(0.849 kg/lit.)	(3.87×10^{7} joules/lit.)

1.17.3	No. 3 (API 28 deg.)	7.387 lb/gal (0.886 kg/lit.)	1.43×10^5 Btu/gal (3.99×10^7 joules/lit.)
1.17.4	No. 4 (API 20 deg.)	7.778 lb/gal (0.933 kg/lit.)	1.485×10^5 Btu/gal (4.14×10^7 joules/lit.)
1.17.5	No. 5 (API 14 deg.)	8.099 lb/gal (0.972 kg/lit.)	1.52×10^5 Btu/gal (4.24×10^7 joules/lit.)
1.17.6	No. 6 bunker C (API 10 deg.)	8.328 lb/gal (0.999 kg/lit.)	1.54×10^5 Btu/gal (4.29×10^7 joules/lit.)
1.18	<u>PROPANE (liquid)</u>	N.A.	9.70×10^4 Btu/gal (2.70×10^7 joules/lit.)
1.19	<u>SULFUR</u>	124 pcf (1987 kg/m^3)	4.0×10^3 Btu/lb (9.3×10^6 joules/kg)
1.20	<u>WOOD</u>		
1.20.1	Hardwoods	See Appendix B	8.6×10^3 Btu/lb (20.0×10^6 joules/kg)
1.20.2	Softwoods	See Appendix B	9.2×10^3 Btu/lb (21.40×10^6 joules/kg)
1.20.3	Resin	67 pcf (1074 kg/m^3)	1.74×10^3 Btu/lb (4.05×10^6 joules/kg)

2.0 PROPERTIES OF SELECTED MATERIALS

	Density	Energy to Produce
2.1 ALUMINUM		
2.1.1 Casting	165 pcf	$1.07x10^5$ Btu/lb
	(2644 kg/m^3)	($2.49x10^8$ joules/kg)
2.1.2 Rolled/forged	165 pcf	$1.25x10^5$ Btu/lb
	(2644 kg/m^3)	($2.91x10^8$ joules/kg)
2.1.3 Wire	165 pcf	N.A.
	(2644 kg/m^3)	
2.2 AGGREGATES		
2.2.1 Crushed gravels	100 pcf	$2.0x10^1$ Btu/lb
	(1602 kg/m^3)	($4.65x10^4$ joules/kg)
2.2.2 Crushed stone	95 pcf	$3.5x10^1$ Btu/lb
	(1522 kg/m^3)	($8.14x10^4$ joules/kg)
2.2.3 Uncrushed sands and gravels	100 pcf	$.75x10^1$ Btu/lb
	(1602 kg/m^3)	($1.74x10^4$ joules/kg)

2.3	ASPHALTS		
	2.3.1 Air-refined asphalts	8.2 lb/gal (0.98 kg/lit.)	N.A.
	2.3.2 Cutback asphalts	8.15 lb/gal (0.98 kg/lit.)	1.5×10^5 Btu/gal (4.18×10^7 joules/lit.)
	2.3.3 Emulsified (60% asphalt)	8.3 lb/gal (1.0 kg/lit.)	9.42×10^4 Btu/gal (2.63×10^7 joules/lit.)
2.4	BRASS	534 pcf (8556 kg/m^3)	N.A.
2.5	CEMENT, PORTLAND	90 pcf (1442 kg/m^3)	3.76×10^3 Btu/lb (8.74×10^6 joules/kg)
2.6	COPPER		
	2.6.1 Casting	556 pcf (8909 kg/m^3)	6.22×10^4 Btu/lb (14.47×10^7 joules/kg)
	2.6.2 Rolled	556 pcf (8909 kg/m^3)	6.40×10^4 Btu/lb (14.88×10^7 joules/kg)
	2.6.3 Wire	556 pcf (8909 kg/m^3)	5.31×10^4 Btu/lb (12.35×10^7 joules/kg)

2.7 <u>IRON, CAST</u>	450 pcf	$1.25x10^4$ Btu/lb
	(7210 kg/m^3)	($2.91x10^7$ joules/kg)
2.8 <u>LIME</u>	58 pcf	$3.0x10^3$ Btu/lb
	(929 kg/m^3)	($0.70x10^7$ joules/kg)
2.9 <u>MAGNESIUM, ALLOYS</u>	112 pcf	N.A.
	(1795 kg/m^2)	
2.10 <u>PLASTICS</u>		
2.10.1 Thermosetting	See Appendix B	N.A.
2.10.2 Thermoplastics	See Appendix B	N.A.
2.11 <u>RUBBER</u>		
2.11.1 Rubber goods (general)	94 pcf	$1.2x10^4$ Btu/lb
	(1506 kg/m^3)	($2.79x10^7$ Btu/kg)
2.11.2 Tires, new	29 lb each	$7.7x10^5$ Btu each
	(13 kg each)	($8.1x10^8$ joules each)
2.11.3 Tire, recapped	28.9 lb each	$2.0x10^5$ Btu each
	(13.1 kg each)	($2.1x10^8$ joules each)

2.12 STEEL, ALLOY

2.12.1 Prestressing tendons	See Appendix B	$3.2x10^4$ Btu/lb ($7.44x10^7$ joules/kg)
2.12.2 Various other products	490 pcf (7851 kg/m^3)	Add 5% to values of carbon steel

2.13 STEEL, CARBON

2.13.1 Automotive sheet	490 pcf	2.54×10^4 Btu/lb
	(7851 kg/m^3)	(5.91×10^7 joules/kg)
2.13.2 Bar reinforcing	490 pcf	2.64×10^4 Btu/lb
	(7851 kg/m^3)	(6.14×10^7 joules/kg)
2.13.3 Casting	490 pcf	2.33×10^4 Btu/lb
	(7851 kg/m^3)	(5.42×10^7 joules/kg)
2.13.4 Cold-rolled	490 pcf	2.64×10^4 Btu/lb
	(7851 kg/m^3)	(6.14×10^7 joules/kg)
2.13.5 Forging	490 pcf	3.80×10^4 Btu/lb
	(7851 kg/m^3)	(8.84×10^7 joules/kg)
2.13.6 Pipe	490 pcf	2.64×10^4 Btu/lb
	(7851 kg/m^3)	(6.14×10^7 joules/kg)
2.13.7 Rail, mainline R/R	38 plf	See 2.13.3
	(56 kg/m)	
2.13.8 Rail, light rail transit	33 plf	See 2.13.3
	(49 kg/m)	
2.13.9 Wire	490 pcf	3.06×10^4 Btu/lb
	(7851 kg/m^3)	(7.12×10^7 joules/kg)

2.14 STEEL, STAINLESS		
2.14.1 Cold-rolled	490 pcf	$3.94x10^4$ Btu/lb
	($7851\ kg/m^3$)	($9.16x10^7$ joules/kg)
2.14.2 Forging	490 pcf	$5.10x10^4$ Btu/lb
	($7851\ kg/m^3$)	($11.86x10^7$ joules/kg)
2.14.3 Pipe	490 pcf	$3.94x10^4$ Btu/lb
	($7851\ kg/m^3$)	($9.16x10^7$ joules/kg)
2.14.4 Wire	490 pcf	$4.36x10^4$ Btu/lb
	($7851\ kg/m^3$)	($10.14x10^7$ joules/kg)
2.15 WOOD		
2.16 ZINC		
2.16.1 Casting	440 pcf	$4.39x10^4$ Btu/lb
	($7050\ kg/m^3$)	($10.21x10^7$ joules/kg)
2.16.2 Rolled	440 pcf	$3.96x10^4$ Btu/lb
	($7050\ kg/m^3$)	($9.21x10^7$ joules/kg)

3.0 PROPERTIES OF SELECTED ROADWAY CONSTRUCTION

		Density	Energy Consumed
3.1	AGGREGATES		
3.1.1	Material F.O.B. plant	See Sec. 2.2	
3.1.2	On-job-site crushed gravels	See Sect. 2.2.1	7.3×10^{1} Btu/lb (1.7×10^{5} joules/kg)
3.1.3	On-job-site crushed stone	See Sect. 2.2.2	8.8×10^{1} Btu/lb (2.1×10^{5} joules/kg)
3.1.4	On-job-site uncrushed	See Sect. 2.2.3	6.0×10^{1} Btu/lb (1.4×10^{5} joules/kg)
3.2	BASE, CEMENT-TREATED		
3.2.1	Material F.O.B. plant	N.A.	2.3×10^{2} Btu/lb (5.4×10^{5} joules/kg)
3.2.2	Compacted in-place	135 pcf (2163 kg/m^3)	2.8×10^{2} Btu/lb (6.5×10^{5} joules/kg)
3.3	BASE, ASPHALT-TREATED		
3.3.1	Material F.O.B. plant	115 pcf (1843 kg/m^3)	1.05×10^{3} Btu/lb (2.44×10^{6} joules/kg)
3.3.2	Compacted in-place	120 pcf (1923 kg/m^3)	1.1×10^{3} Btu/lb (2.6×10^{6} joules/kg)

3.4	<u>BASE, LIME-TREATED</u>		
	3.4.1 Material F.O.B. plant	N.A.	$2.0x10^{2}$ Btu/lb ($4.6x10^{5}$ joules/kg)
	3.4.2 Compacted in-place	105 pcf (1682 kg/m^{3})	$2.6x10^{2}$ Btu/lb ($6.0x10^{5}$ joules/kg)
3.5	<u>CONCRETE, ASPHALTIC</u>		
	3.5.1 Material F.O.B. plant	120 pcf (1923 kg/m^{3})	$3.24x10^{3}$ Btu/lb ($7.54x10^{6}$ joules/kg)
	3.5.2 Pavements in-place	145 pcf (2323 kg/m^{3})	$3.24x10^{3}$ Btu/lb ($7.54x10^{6}$ joules/kg)
3.6	<u>CONCRETE, PORTLAND CEMENT</u>		
	3.6.1 Material F.O.B. plant	145 pcf (2323 kg/m^{3})	$9.42x10^{4}$ Btu/cf ($35.10x10^{8}$ joules/m^{3})
	3.6.2 Pavements in-place	145 pcf (2323 kg/m^{3})	$9.79x10^{4}$ Btu/cf ($36.48x10^{8}$ joules/m^{3})
	3.6.3 Structues in-place	145 pcf (2323 kg/m^{3})	$1.25x10^{5}$ Btu/cf ($46.58x10^{8}$ joules/m^{3})

3.7	EARTH, EXCAVATED		
3.7.1	Sediments, soft rock	120 pcf (1923 kg/m^3)	$2.19x10^3$ Btu/cf ($8.16x10^7$ joules/m^3)
3.7.2	Hard rock		N.A.
3.8	EARTH, FILL		
3.8.1	Material at borrow pit	See Sect. 3.7.1	
3.8.2	Hard rock, riprap		N.A.
3.9	STEEL, STRUCTURAL (bridges)		
3.9.1	Material F.O.B. plant	490 pcf (7851 kg/m^3)	$2.64x10^4$ Btu/lb ($6.14x10^7$ joules/kg)
3.9.2	Erected in-place	490 pcf (7851 kg/m^3)	$2.68x10^4$ Btu/lb ($6.23x10^7$ joules/kg)

4.0 ENERGY CONSUMED BY SELECTED CONSTRUCTION OPERATIONS

4.1 BACKFILLING	See Sect. 3.8.1
4.2 EXCAVATION	See Sect. 3.7.1
4.3 HAULING	
4.3.1 Asphalt, AC	3.3×10^3 Btu/T-mile (2.4×10^3 joules/kg-km)
4.3.2 Cement, concrete	2.6×10^3 Btu/T-mile (1.9×10^3 joules/kg-km)
4.3.3 Earth	N.A.
4.3.4 Fuels	2.2×10^3 Btu/T-mile (1.6×10^3 joules/kg-km)
4.3.5 Lumber	2.7×10^3 Btu/T-mile (2.0×10^3 joules/kg-km)
4.3.6 Metals	N.A.

4.4 PAVING	
4.4.1 AC, blade mixing	3.8 Btu/lb ($8.8x10^3$ joules/kg)
4.4.2 AC, travel plant mixing	1.5 Btu/lb ($3.5x10^3$ joules/kg)
4.4.3 Base, compacting	8.5 Btu/lb ($19.8x10^3$ joules/kg)
4.4.4 PCC	$1.95x10^2$ Btu/cf ($7.27x10^6$ joules/m^3)
4.5 PIPE LAYING	N.A.
4.6 SHIP CONSTRUCTION	See Sect. 21.1
4.7 STRUCTURE CONSTRUCTION	N.A.
4.8 TUNNELING	N.A.
4.9 WELDING	
4.9.1 Electric arc	$9.68x10^3$ Btu/hr ($10.21x10^6$ joules/hr)
4.9.2 Gas	N.A.

5.0 CONSTRUCTION OF ROADWAY STRUCTURES

5.1 BRIDGES

5.1.1 Bridges, automotive

5.1.1.1 Railing — 8.4×10^5 Btu/lf (2.9×10^9 joules/m)

5.1.1.2 Superstructure (excluding railing or sidewalks)

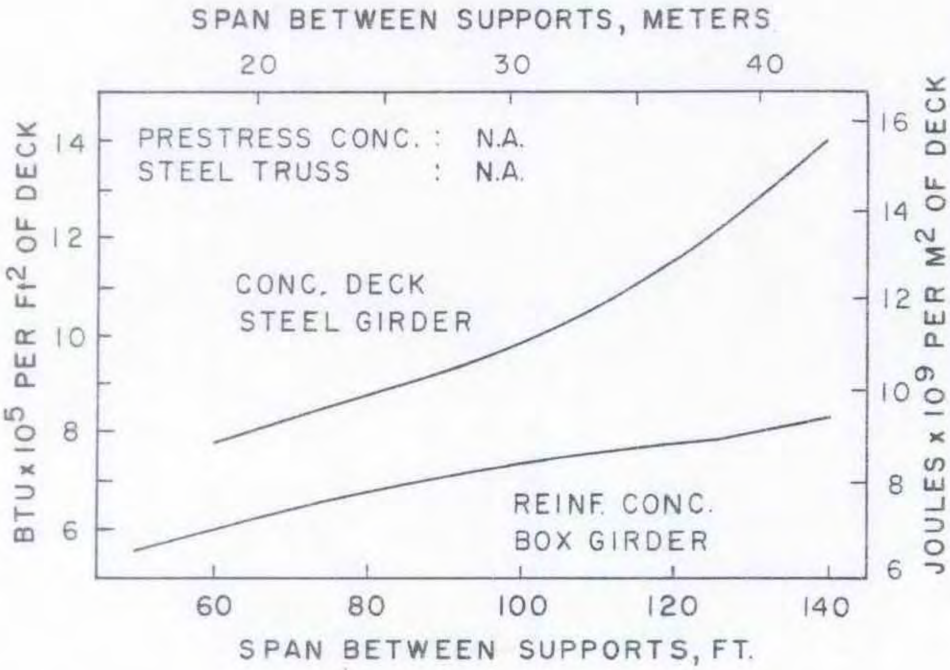


Fig. A1 Energy of bridge superstructure materials (Add 30% for placement energy).

5.1.1.3 Supports

5.1.1.3.1 Abutments

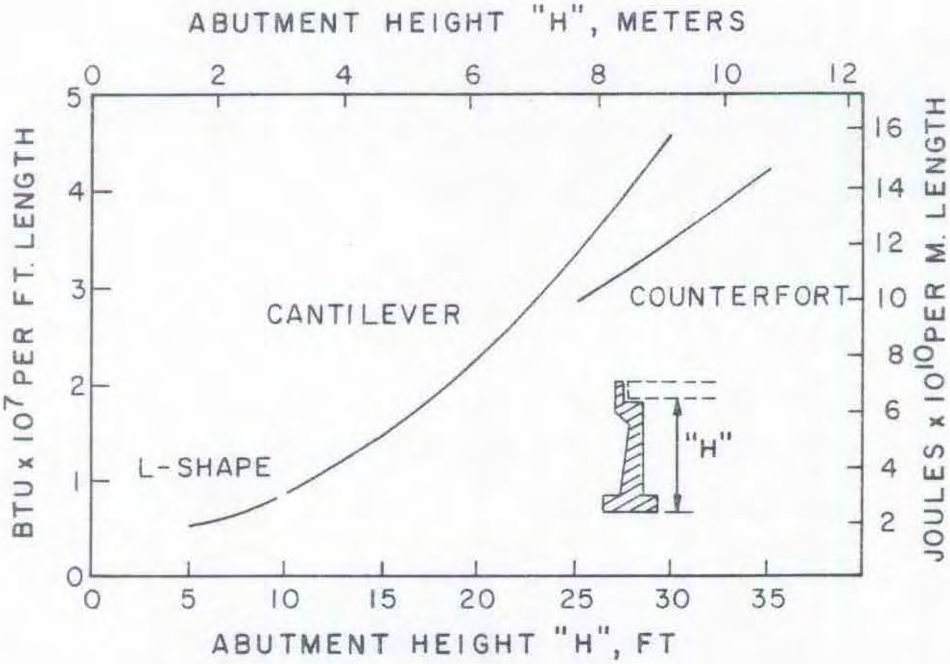


Fig. A2 Energy of bridge abutment materials (Add 30% for placement energy).

5.1.1.3.2 Column (per deck area) $1.0x10^{4}$ Btu/sf

($11.4x10^{7}$ joules/m^{2})

5.1.1.3.3 Endwalls-wingwalls (per bridge) $8.0x10^{7}$ Btu/ea.

($8.44x10^{10}$ joules/ea.

5.1.2 Bridges-pedestrian N.A.

5.1.3 Bridges-railroad

5.1.3.1 Prestressed concrete N.A.

5.1.3.2 Reinforced concrete

5.1.3.2.1 Single track (per bridge length) $3.7x10^{7}$ Btu/lin-ft

($1.3x10^{11}$ joules/m)

5.1.3.2.2 Double track (per bridge length) $6.4x10^{7}$ Btu/lin-ft

($2.2x10^{11}$ joules/m)

5.1.3.3 Steel N.A.

5.2 CULVERTS

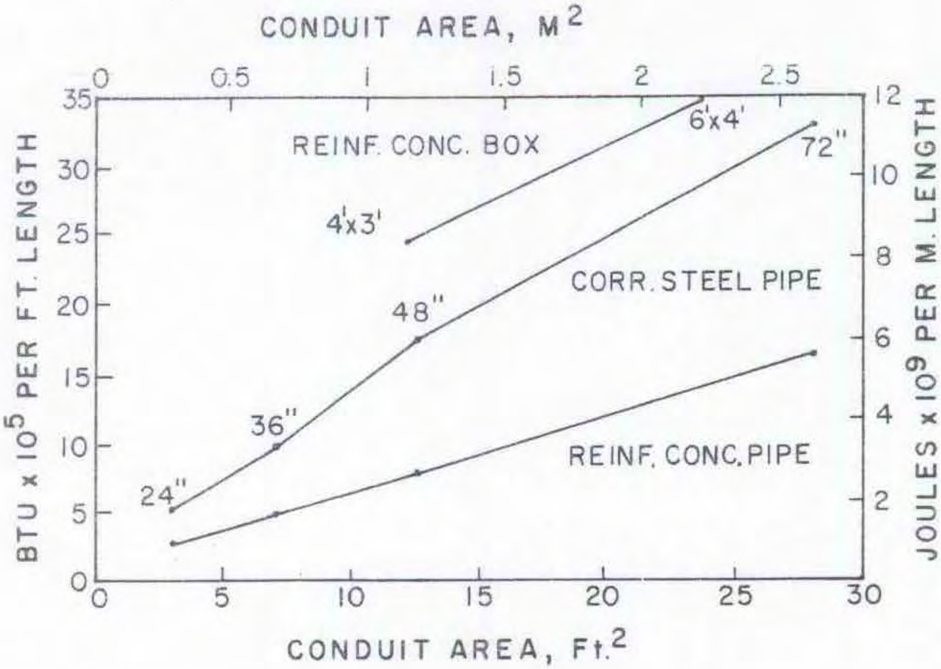


Fig. A3 Energy consumed for culverts in-place.

5.3	DRAINAGE STRUCTURES - General	
	5.3.1 Freeway rural (8-lane)	$3x10^9$ Btu/ln-mile ($2.0x10^{12}$ joules/ln-km)
	5.3.2 Freeway urban	N.A.
5.4	FENCING	
	5.4.1 Chain link	$1.74x10^5$ Btu/lin-ft ($6.02x10^8$ joules/m)
5.5	GUARDRAIL	
	5.5.1 Bridge - all concrete railing	$8.09x10^5$ Btu/lin-ft ($8.54x10^8$ joules/m)
	5.5.2 Bridge - concrete + steel railing	$8.63x10^5$ Btu/lin-ft ($9.11x10^8$ joules/m)
	5.5.3 Median barrier - all concrete	$7.0x10^5$ Btu/lin-ft ($24.2x10^8$ joules/m)
	5.5.4 Metal "W" beam + wood posts	$3.01x10^5$ Btu/lin-ft ($1.04x10^9$ joules/m)
	5.5.5 Metal "W" beam + steel posts	$5.90x10^5$ Btu/lin-ft ($2.04x10^9$ joules/m)
5.6	ILLUMINATION	See Appendix B

5.7 PAVEMENTS

5.7.1 Flexible Cross-section (AC surface)

5.7.1.1	Section designed for high truck traffic (mainline)	3.0×10^5 Btu/sf (3.4×10^9 joules/m^2)
5.7.1.2	Section designed for moderate truck traffic	2.0×10^5 Btu/sf (2.2×10^8 joules/m^2)
5.7.1.3	Shoulders	2.0×10^5 Btu/sf (2.2×10^8 joules/m^2)

5.7.2 Rigid Cross-section (PCC surface)

5.7.2.1	Section designed for high truck traffic (mainline)	1.06×10^5 Btu/sf (1.20×10^9 joules/m^2)
5.7.2.2	Section designed for moderate truck traffic	9.11×10^4 Btu/sf (10.34×10^8 joules/m^2)
5.7.2.3	Shoulder section	9.11×10^4 Btu/sf (10.34×10^8 joules/m^2)
5.7.2.4	Reinforcing steel	6.6×10^3 Btu/sf (7.5×10^7 joules/m^2)

5.8 RETAINING WALLS

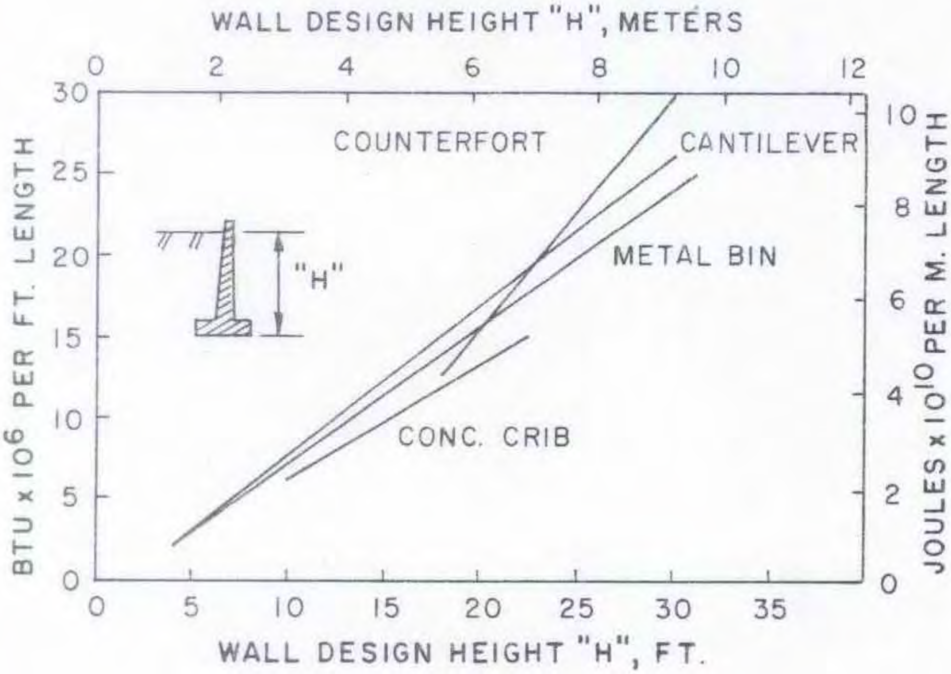


Fig. A4 Energy consumed for retaining walls in-place.

5.9	SIGNALS	See Commentary
5.10	SIGNS	
5.10.1	City streets	N.A.
5.10.2	Major arterials	N.A.
5.10.3	Freeway rural	1.0×10^9 Btu/ln-mile (6.6×10^{11} joules/ln-km)
5.10.4	Freeway urban	N.A.
5.11	UNDERGROUND CONSTRUCTION	
5.11.1	Cut-and-cover	N.A.
5.11.2	Tunneling	N.A.

6.0 ENERGY CONSUMED BY ROADWAY MAINTENANCE		
6.1 GENERAL HIGHWAY MAINTENANCE		
6.1.1 Flexible pavements	Annual	1.20×10^8 Btu/ln-mile (78.6×10^9 joules/ln-km)
6.1.2 Rigid pavements	Annual	4.0×10^7 Btu/ln-mile (26.2×10^9 joules/ln-km)
6.1.3 Structures		N.A.
6.2 SPECIFIC OPERATIONS		See Sect. 3.0

7.0 DIRECT FUEL CONSUMPTION OF PASSENGER CARS

7.1 FUEL CONSUMED AT CONSTANT SPEEDS

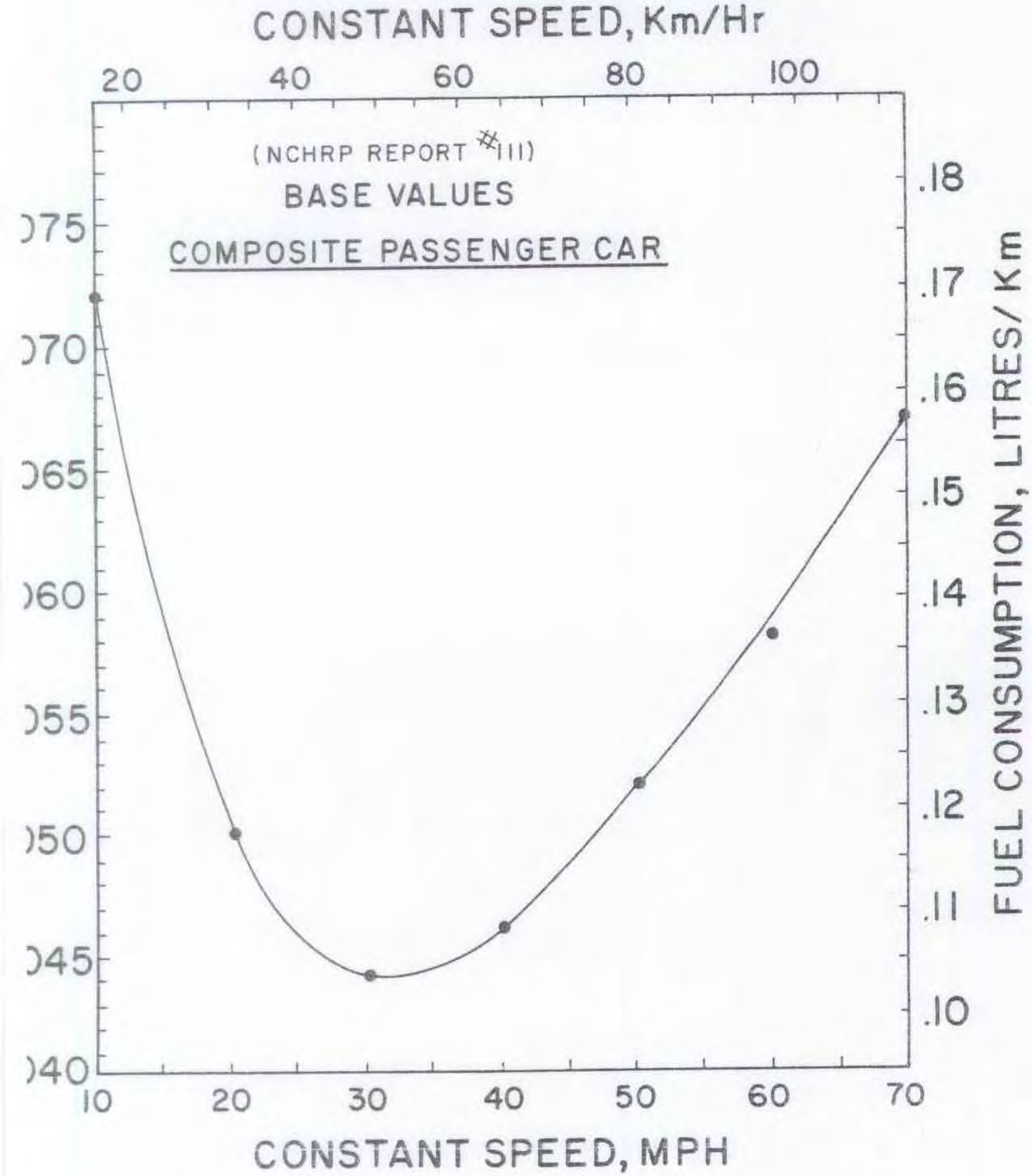


Fig. A5 Fuel consumption of composite passenger car on-the-road, at constant speeds. (Base year = 1974.)

7.1.1 Adjustment for Change in Fuel Economy by Year

(Multiply value from Fig. 5 x Factor 7.1.1 to obtain consumption rate for year under study.)

Year	Factor	Year	Factor	Year	Factor
1970	N.A.	1980	0.871	1990	0.565
1971	N.A.	1981	0.831	1991	0.556
1972	N.A.	1982	0.791	1992	0.550
1973	N.A.	1983	0.747	1993	0.546
1974	1.000	1984	0.748	1994	0.542
1975	1.000	1985	0.670	1995	0.540
1976	0.980	1986	0.638	1996	0.540
1977	0.955	1987	0.612	1997	0.540
1978	0.931	1988	0.592	1998	0.538
1979	0.902	1989	0.576	1999	0.538
				2000	0.538

7.1.2A Adjustment for Ascending Grades

(Multiply value from Fig. 5 x Factor 7.1.2A to obtain consumption rate for ascending grade)

Constant Speed MPH (km/hr)	Correction Factor 7.1.2A									
	Ascending Grade									
	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
10 (16)	1.11	1.21	1.33	1.43	1.56	1.68	1.83	1.99	2.22	2.49
15 (24)	1.14	1.30	1.42	1.58	1.72	1.88	2.08	2.28	2.55	2.84
20 (32)	1.16	1.40	1.52	1.72	1.88	2.08	2.32	2.56	2.88	3.20
25 (40)	1.16	1.38	1.54	1.75	1.93	2.13	2.41	2.69	3.01	3.35
30 (48)	1.16	1.36	1.55	1.77	1.98	2.18	2.50	2.82	3.14	3.50
35 (56)	1.16	1.36	1.54	1.74	1.94	2.14	2.46	2.76	3.09	3.44
40 (64)	1.17	1.35	1.52	1.70	1.89	2.09	2.41	2.70	3.04	3.39
45 (72)	1.15	1.35	1.49	1.65	1.84	2.04	2.34	2.60	2.92	3.26
50 (80)	1.13	1.35	1.46	1.60	1.79	2.00	2.27	2.50	2.79	3.12
55 (89)	1.14	1.33	1.46	1.60	1.78	1.96	2.22	2.44	2.70	3.02
60 (97)	1.16	1.31	1.45	1.60	1.76	1.93	2.17	2.38	2.62	2.93
65 (105)	1.14	1.28	1.42	1.56	1.71	1.88	2.09	2.30	2.52	2.81
70 (113)	1.12	1.25	1.39	1.52	1.66	1.82	2.01	2.21	2.42	2.69

7.1.2B Adjustment for Descending Grades

(Multiply value from Fig. 5 x Factor 7.1.2B to obtain consumption rate for descending grade)

Constant Speed MPH (km/hr)	Correction Factor 7.1.2B									
	Descending Grade									
	1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
10 (16)	.83	.62	.56	.56	.56	.56	.56	.56	.56	.56
15 (24)	.82	.58	.50	.49	.49	.49	.49	.49	.49	.49
20 (32)	.80	.54	.44	.42	.42	.42	.42	.42	.42	.42
25 (40)	.78	.52	.40	.37	.36	.36	.36	.36	.36	.36
30 (48)	.75	.50	.36	.32	.30	.30	.30	.30	.30	.30
35 (56)	.76	.52	.38	.31	.30	.28	.28	.28	.28	.28
40 (64)	.76	.54	.39	.30	.30	.26	.26	.26	.26	.26
45 (72)	.78	.56	.44	.35	.32	.26	.26	.22	.22	.22
50 (80)	.79	.58	.48	.40	.35	.27	.25	.19	.19	.19
55 (89)	.81	.60	.56	.46	.41	.32	.28	.22	.19	.16
60 (97)	.83	.62	.64	.52	.47	.38	.31	.24	.19	.14
65 (105)	.85	.67	.64	.55	.50	.42	.36	.28	.22	.16
70 (113)	.87	.72	.64	.58	.54	.46	.40	.33	.24	.19

7.1.3 Adjustment for Curvature of Road

(Multiply value from Fig. 5 x Factor 7.1.3 to obtain consumption rate for curved alignment)

Constant Speed MPH (km/hr)	Correction Factor 7.1.3 — Degree, [Radius, Ft.](Radius, m) of Curve										
	1	2	3	4	5	6	7	8	9	10	90
	[5730]	[2865]	[1910]	[1433]	[1146]	[955]	[819]	[717]	[637]	[574]	[71]
	(1746)	(873)	(582)	(437)	(349)	(291)	(250)	(218)	(194)	(175)	(22)
10 (16)	1.000	1.001	1.002	1.002	1.003	1.004	1.005	1.005	1.006	1.008	1.130
20 (32)	1.001	1.002	1.003	1.004	1.005	1.006	1.007	1.008	1.010	1.030	2.000
30 (48)	1.005	1.010	1.016	1.022	1.028	1.034	1.040	1.080	1.140	1.200	-
40 (64)	1.015	1.031	1.048	1.065	1.082	1.120	1.170	1.230	1.340	1.480	-
50 (80)	1.025	1.054	1.090	1.120	1.180	1.250	1.430	1.610	1.820	2.070	-
60 (97)	1.040	1.080	1.132	1.200	1.300	1.400	1.900	-	-	-	-
70 (113)	1.060	1.120	1.182	1.300	-	-	-	-	-	-	-

7.1.4 Adjustment for Substandard Road Surface

(Multiply value from Fig. 5 x Factor 7.1.4 to obtain consumption rate on roadway with given surface conditions)

Constant Speed MPH (km/hr)	Correction Factor 7.1.4 — Roadway Surface Condition: Badly broken and patched Asphalt	Dry well-packed Gravel	Loose Sand
10 (16)	1.01	1.09	1.23
20 (32)	1.05	1.13	1.28
30 (48)	1.20	1.26	1.40
40 (64)	1.34	1.56	1.73
50 (80)	1.50	1.70	2.00

Attempted Speed = 25 MPH (40 km/hr)

(Multiply value from Fig. 5 x Factor 7.1.5A to obtain consumption rate at given conditions)

Traffic Density	Correction Factor 7.1.5A										
	Frequency of Stops Per Mile (per km)										
	0	1	2	3	4	5	6	7	8	9	10
	(0)	(0.6)	(1.2)	(1.9)	(2.5)	(3.1)	(3.7)	(4.3)	(5.0)	(5.6)	(6.2)
Light	1.00	1.18	1.37	1.55	1.73	1.91	2.12	2.30	2.40	2.65	2.80
Moderate	1.00	1.22	1.41	1.60	1.78	1.97	2.20	2.37	2.56	2.75	2.94
Heavy	N.A.	1.26	1.47	1.74	1.95	2.16	2.39	2.55	2.70	2.91	3.17
Congested	N.A.	N.A.	N.A.	N.A.	2.21	2.44	2.68	2.85	2.98	3.18	3.39

Based on 6-lane central business district street with parking on both sides; with the following volumes of one-way vehicles per hour:

Light	0-40 vph	Heavy	240-280 vph
Moderate	120-160 vph	Congested	360-400 vph

7.1.5B Adjustment for Traffic Density on Highways and Expressways

(Multiply value from Fig. 5 x Factor 7.1.5B to obtain consumption rate at given conditions)

Attempted Speed MPH (km/hr)	Correction Factor 7.1.5B			
	Light Traffic	Moderate Traffic	Heavy Traffic	Congested Traffic
45 (72)	1.00	1.00	1.00	1.00
50 (80)	1.00	1.01	1.03	1.04
55 (89)	1.00	1.02	1.05	1.08
60 (97)	1.00	1.03	1.07	1.09

Based on 6-lane expressway, with the following volumes of one-way vehicles per hour:

Light	2400-2800 vph	Heavy	4400-4800 vph
Moderate	3200-3600 vph	Congested	5600-6000 vph

7.2 FUEL CONSUMED DURING SPEED CHANGES

Excess quantity of fuel consumed by slowing down and then accelerating back to the original speed:

Original Speed MPH (km/hr)	Excess gallons (litres) of fuel consumed — Amount of speed reduction MPH (km/hr) 10 (16)	20 (32)	30 (48)	40 (64)	50 (80)	60 (97)
20 (32)	.0032(.0121)	-	-	-	-	-
30 (48)	.0035(.0132)	.0062(.0235)	-	-	-	-
40 (64)	.0038(.0144)	.0068(.0257)	.0093(.0352)	-	-	-
50 (80)	.0042(.0159)	.0074(.0280)	.0106(.0401)	.0140(.0530)	-	-
60 (97)	.0046(.0174)	.0082(.0310)	.0120(.0454)	.0155(.0587)	.0190(.0719)	-
70 (113)	.0051(.0193)	.0090(.0341)	.0130(.0492)	.0167(.0632)	.0203(.0768)	.0243(.0920)

7.3 FUEL CONSUMED WHILE IDLING

7.3.1 Transmission in "Drive" : 0.63 gal/hr or 1.36 litres/hr

7.3.2 Transmission in "Neutral": 0.58 gal/hr or 2.20 litres/hr

7.4 FUEL CONSUMED DUE TO COLD STARTS

Figure A6 presents the ratio of fuel consumed to travel a given distance starting with a cold engine vs. the fuel consumed for the same trip starting with a fully warm engine. An engine is assumed cold after being off at ambient temperature for 8 hours or longer. For a trip of specified length, the total quantity of fuel consumed (as computed using sections 7.0-7.3) should be modified by the factor "relative fuel consumption rate" to account for cold start and ambient temperature. The factor for a fully warm engine start is 1.0.

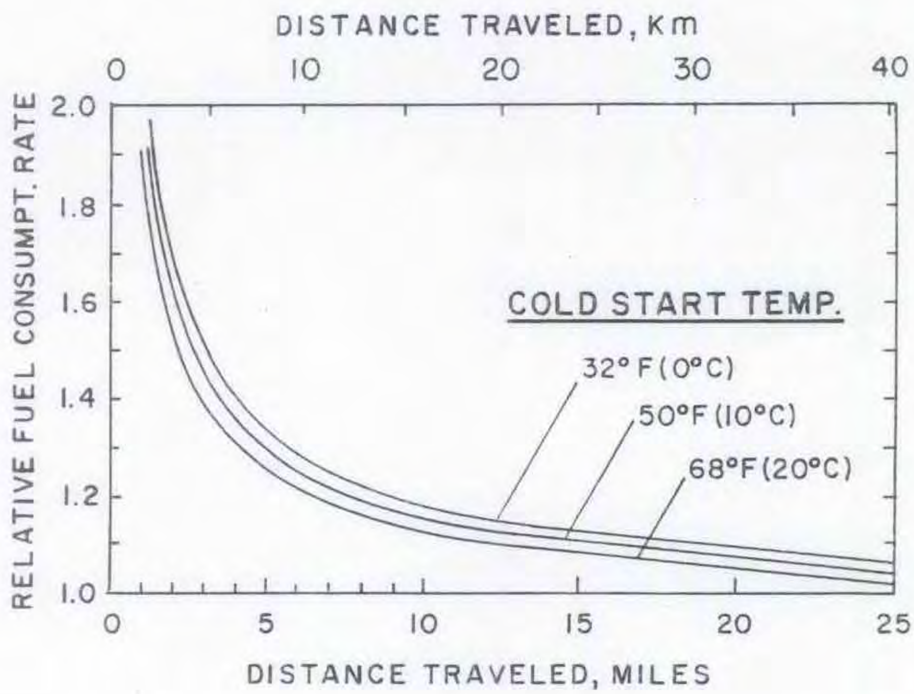


Fig. A6 Comparative fuel consumption of cold vs warm engines.

7.5 FUEL CONSUMED IN NORMAL USE

Fuel consumption for sales-weighted and mileage-weighted "Composite Car", representing the grand average of all passenger cars on-the-road is presented graphically in Figure A7, and tabulated in Table 7.5.1

Note: Figure A7 is the basis for Table 7.1.1, "Adjustment for Change in Fuel Economy by Year"

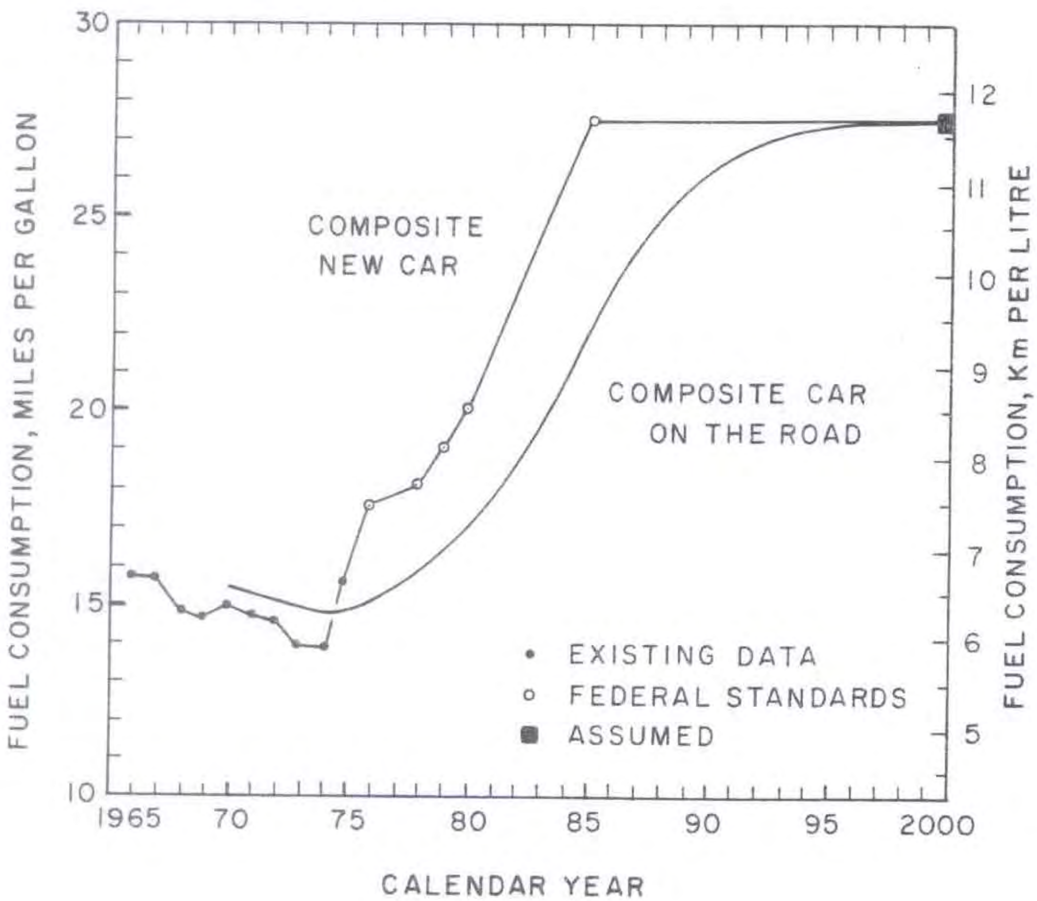


Fig. A7 Fuel consumption rates of composite passenger cars (weighted EPA: 45% rural cycle - 55% urban cycle).

7.5.1 Projected Fuel Consumption of Passenger Cars.

Composite passenger automobile operating on U.S. Roads based on 55% urban and 45% highway driving

Year	Miles per Gallon	Kilometres per litre
1977	15.5	6.59
1978	15.9	6.76
1979	16.4	6.97
1980	17.0	7.23
1981	17.8	7.57
1982	18.7	7.95
1983	19.8	8.42
1984	20.9	8.89
1985	22.1	9.40
1986	23.2	9.86
1987	24.2	10.29
1988	25.0	10.63
1989	25.7	10.93
1990	26.2	11.14
1991	26.6	11.31
1992	26.9	11.44
1993	27.1	11.52
1994	27.3	11.61
1995	27.4	11.65
2000	27.5	11.69

8.0 DIRECT FUEL CONSUMPTION OF TRUCKS

8.1 TWO-AXLE, SIX TIRE TRUCKS

8.1.1 Fuel Consumed at Constant Speeds

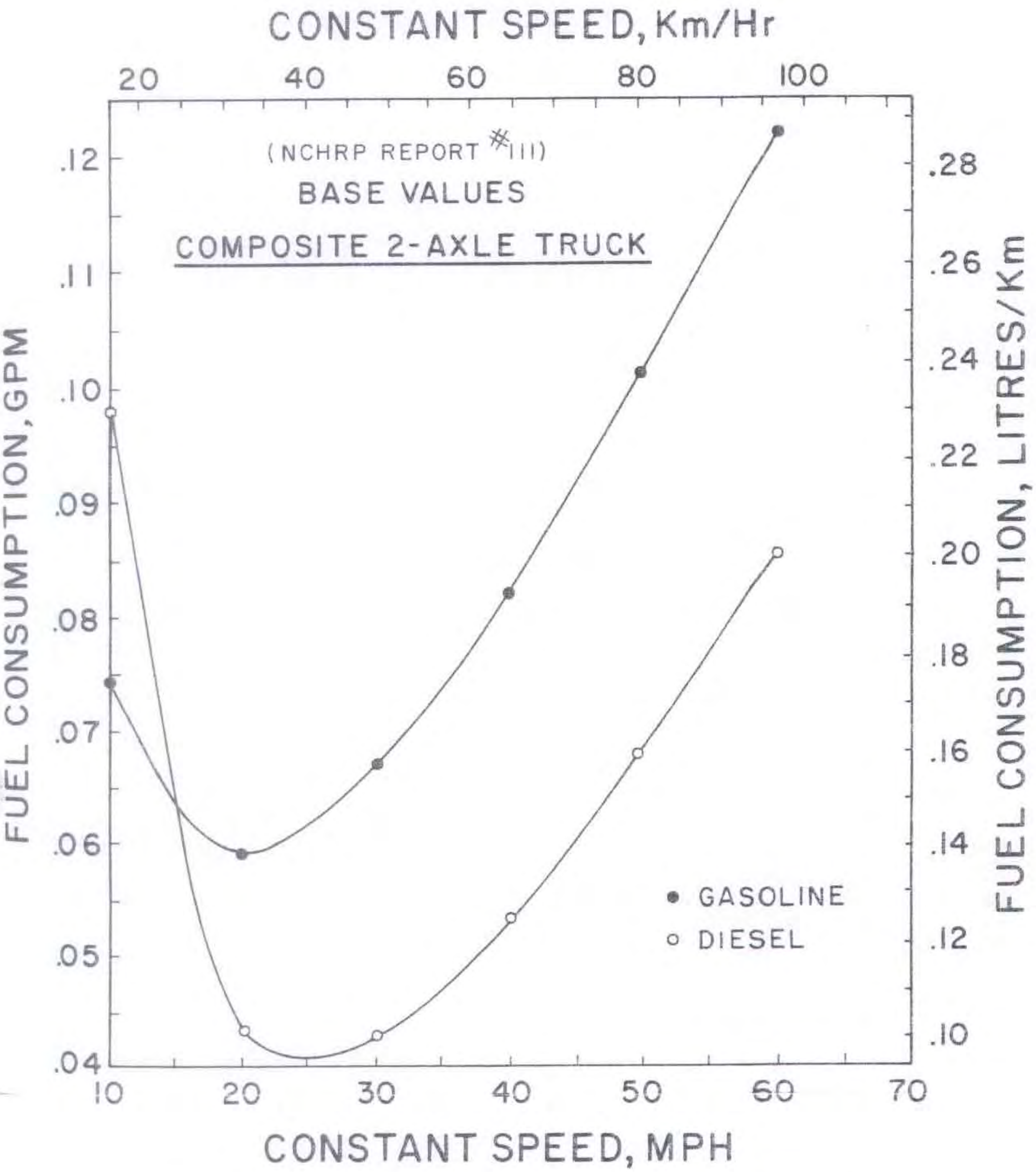


Fig. A8 Fuel consumption of composite 2-axle, 6-tire truck.

8.1.1.1 Adjustment for Ascending Grades

(Multiply Value from Figure 8 x factor 8.1.1.1A or 8.1.1.1B to obtain consumption rate on ascending grade)

Constant Speed MPH	(km/hr)	Correction Factor 8.1.1.1A (Gasoline fuel)									
		Ascending Grade									
		1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
10	(16)	1.27	1.62	1.93	2.36	2.64	3.04	3.45	3.91	4.38	4.82
20	(32)	1.36	1.90	2.37	2.83	3.22	3.63	4.21	5.00	5.83	6.68
30	(48)	1.40	1.81	2.24	2.70	3.07	3.46	4.00	4.55	-	-
40	(64)	1.37	1.72	2.11	2.56	2.78	-	-	-	-	-
50	(80)	1.29	1.57	1.92	-	-	-	-	-	-	-
60	(97)	1.23	-	-	-	-	-	-	-	-	-

Constant Speed MPH	(km/hr)	Correction Factor 8.1.1.1B (Diesel fuel)									
		Ascending Grade									
		1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
10	(16)	1.07	1.15	1.32	1.49	1.73	2.03	2.26	2.66	2.96	3.29
20	(32)	1.54	2.08	2.54	3.10	3.64	4.42	5.22	6.16	7.50	-
30	(48)	1.48	2.00	2.53	3.25	3.95	4.87	6.17	-	-	-
40	(64)	1.47	1.93	N.A.	-	-	-	-	-	-	-
50	(80)	N.A.	N.A.	-	-	-	-	-	-	-	-

8.1.1.2 Adjustment for Descending Grades

(Multiply value from Figure 8 x factor 8.1.1.2A or 8.1.1.2B to obtain consumption rate on descending grade)

Constant Speed MPH (km/hr)		Correction Factor 8.1.1.2A (Gasoline fuel)									
		Descending Grade									
		1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
10	(16)	0.86	0.74	0.72	0.69	0.69	0.69	0.69	0.69	0.69	0.69
20	(32)	0.83	0.66	0.58	0.51	0.51	0.51	0.51	0.51	0.51	0.51
30	(48)	0.81	0.61	0.51	0.40	0.39	0.37	0.37	0.36	0.36	0.36
40	(64)	0.87	0.62	0.50	0.39	0.35	0.30	0.28	0.26	0.24	0.24
50	(80)	0.89	0.71	0.57	0.45	0.38	0.31	0.25	0.20	0.20	0.20
60	(97)	0.90	0.74	0.61	0.51	0.43	0.35	0.29	0.20	0.16	0.16

Correction Factor 8.1.1.2B (Diesel fuel)

Descending Grade

Not available; authors suggest use of Table 8.1.1.2A

8.1.1.3 Adjustment for Curvature of Road

(Multiply value from Figure 8 x factor 8.1.1.3 to obtain consumption rate on curved roadway)

Constant Speed MPH	(km/hr)	Correction Factor 8.1.1.3 — Degree, [Radius, Ft.], (Radius, m) of Curve										
		1	2	3	4	5	6	7	8	9	10	30
		[5730]	[2865]	[1910]	[1433]	[1146]	[955]	[819]	[717]	[637]	[574]	[193]
		(1746)	(873)	(582)	(437)	(349)	(291)	(250)	(218)	(194)	(175)	(59)
10	(16)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
20	(32)	1.00	1.00	1.00	1.00	1.02	1.03	1.04	1.05	1.06	1.08	1.18
30	(48)	1.00	1.00	1.00	1.01	1.03	1.05	1.09	1.13	1.17	1.21	2.00
40	(64)	1.00	1.00	1.01	1.04	1.09	1.14	1.20	1.26	1.32	1.43	N.A.
50	(80)	1.01	1.02	1.06	1.13	1.23	1.33	1.43	1.53	-	-	-
60	(97)	1.02	1.05	1.10	1.15	-	-	-	-	-	-	-

8.1.1.4 Adjustment for Substandard Road Surface

(Multiply value from Figure 8 x factor 8.1.1.4 to obtain consumption rate on roadway with given surface condition)

Constant Speed MPH (km/hr)	Correction Factor 8.1.1.4 — Roadway surface condition: Badly Broken and Patched Asphalt	Dry Well-Packed Gravel	Loose Sand
10 (16)	1.03	1.24	1.46
20 (32)	1.06	1.28	1.62
30 (48)	1.07	1.45	2.16
40 (64)	1.08	1.58	2.46
50 (80)	1.20	1.69	–

8.1.1.5A Adjustment for Traffic Density on Urban Streets and Arterials

(Attempted speed = 25 MPH)

(Multiply value from Figure 8, speed circa 25 mph, x factor 8.1.1.5A to obtain consumption rate under given conditions.)

Traffic Density	Correction Factor 8.1.1.5A										
	Frequency of Stops Per Mile (per km)										
	0 (0)	1 (0.6)	2 (1.2)	3 (1.9)	4 (2.5)	5 (3.1)	6 (3.7)	7 (4.3)	8 (5.0)	9 (5.6)	10 (6.2)
Light	1.00	1.30	1.60	1.84	2.20	2.50	2.80	3.10	3.40	3.70	4.00
Moderate	1.00	1.30	1.62	1.84	2.21	2.50	2.80	3.10	3.41	3.70	4.00
Heavy	1.00	1.34	1.66	1.89	2.25	2.54	2.83	3.13	3.43	3.74	4.00
Heavily congested	N.A.	N.A.	N.A.	1.93	2.33	2.63	2.91	3.19	3.50	3.81	4.12

Based on 6-lane central business district street with parking on both sides; with the following volumes of one-way vehicles per hour:

Light	0-40 vph	Heavy	240-280 vph
Moderate	120-160 vph	Congested	360-400 vph

8.1.1.5B Adjustment for Traffic Density on Highways and Expressways

(Multiply value from Figure 8 x factor 8.1.1.5B to obtain consumption rate under given traffic conditions.)

Attempted Speed MPH (km/hr)	Correction Factor 8.1.1.5B			
	Light Traffic	Moderate Traffic	Heavy Traffic	Congested Traffic
45 (72)	1.00	1.00	1.00	1.00
50 (80)	1.00	1.00	1.03	1.03

Based on 6-lane expressway, with the following volumes of one-way vehicles per hour:

Light	2400-2800 vph	Heavy	4400-4800 vph
Moderate	3200-3600 vph	Congested	5600-6000 vph

8.1.2 FUEL CONSUMED DURING SPEED CHANGES

Excess quantity of fuel consumed by slowing down and the accelerating back to the original speed:

Original Speed MPH (km/hr)	Excess Gallons (litres) Consumed (Gasoline Fuel)				
	Amount of Speed Reduction, MPH (km/hr)				
	10 (16)	20 (32)	30 (48)	40 (64)	50 (80)
20 (32)	.0073 (.0276)	.0097 (.0367)	-	-	-
30 (48)	.0080 (.0303)	.0148 (.0560)	.0173 (.0655)	-	-
40 (64)	.0096 (.0363)	.0167 (.0632)	.0226 (.0843)	.0242 (.0916)	-
50 (80)	.0110 (.0416)	.0168 (.0636)	.0226 (.0843)	.0266 (.1007)	.0270 (.1022)

Original Speed MPH (km/hr)	Excess Gallons (litres) Consumed (Diesel Fuel)				
	Amount of Speed Reduction, MPH (km/hr)				
	10 (16)	20 (32)	30 (48)	40 (64)	50 (80)
10 (16)	N.A.	-	-	-	-
20 (32)	.006 (.021)	.007 (.028)	-	-	-
30 (48)	.005 (.021)	.010 (.038)	.012 (.047)	-	-
40 (64)	.006 (.023)	.010 (.040)	.014 (.054)	.016 (.061)	-
50 (80)	.007 (.026)	.010 (.039)	.014 (.053)	.017 (.065)	.018 (.068)

8.1.3 FUEL CONSUMED WHILE IDLING

Engine Size/Fuel	Consumption Rate Gal/hr	(Litres/hr)
351 cu.in/gasoline	0.65	(2.46)
386 cu.in/gasoline	0.80	(3.03)
477 cu.in/diesel	0.38	(1.44)

8.1.4 FUEL CONSUMED DUE TO COLD STARTS

Not Available

8.1.5 FUEL CONSUMED IN NORMAL USE

Trip Type	Fuel Consumption, GPM (litres/km)	
	Gasoline Fuel	Diesel Fuel*
Local Urban	0.13 (0.31)	N.A.
Short Range (<200 miles)	0.13 (0.31)	N.A.
Cross-Country	0.13 (0.31)	N.A.

*Note: 95% of 2-axle, 6-tire trucks under 16,000 lb (7257 kg) GVW are powered by gasoline fuel, and 5% by diesel.

8.2 TRACTOR SEMI-TRAILER TRUCKS

8.2.1 Fuel Consumed at Constant Speeds

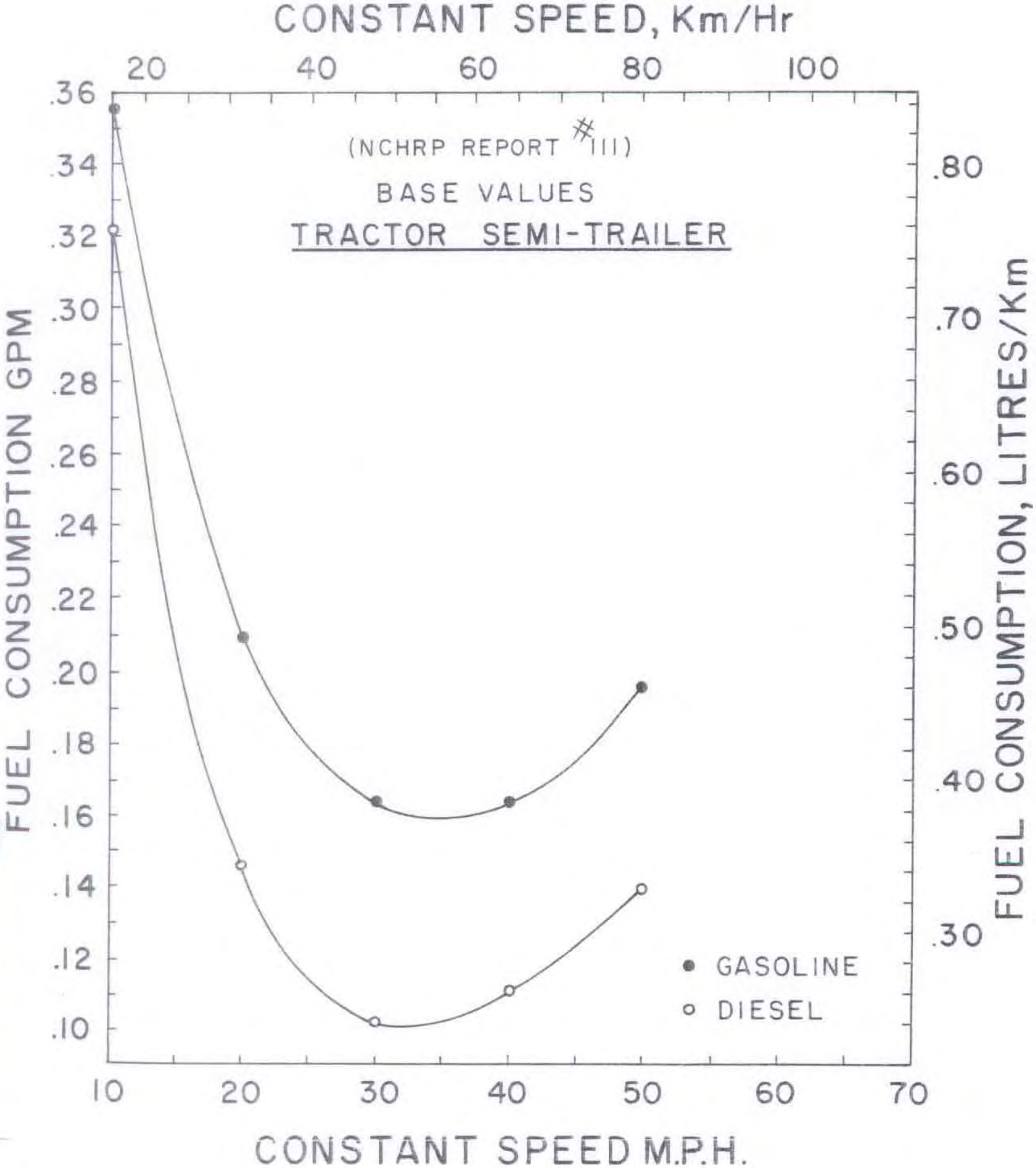


Fig. A9 Fuel consumption of composite tractor semi-trailer truck, 40,000-50,000 lb GVW.

8.2.1.1 Adjustment for Ascending Grades

(Multiply value from Figure 9 x factor 8.2.1.1A or 8.2.1.1B to obtain consumption rate on ascending grade)

Constant Speed MPH	(km/hr)	Correction Factor 8.2.1.1A (Gasoline Fuel) Ascending Grade									
		1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
10	(16)	1.14	1.34	1.52	1.73	2.07	2.42	2.89	3.37	3.77	4.20
20	(32)	1.39	1.75	2.22	2.67	3.29	3.91	-	-	-	-
30	(48)	1.54	2.09	2.89	3.77	4.88	-	-	-	-	-
40	(64)	1.69	2.39	3.44	-	-	-	-	-	-	-
50	(80)	1.76	2.49	-	-	-	-	-	-	-	-

Constant Speed MPH	(km/hr)	Correction Factor 8.2.1.1B (Diesel Fuel) Ascending Grade									
		1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
10	(16)	1.14	1.28	1.42	1.55	1.82	2.08	N.A.	N.A.	N.A.	N.A.
20	(32)	1.17	1.17	1.58	1.82	N.A.	N.A.	-	-	-	-
30	(48)	1.62	2.23	N.A.	N.A.	N.A.	-	-	-	-	-
40	(64)	1.64	2.27	N.A.	-	-	-	-	-	-	-
50	(80)	N.A.	N.A.	-	-	-	-	-	-	-	-

8.2.1.2 Adjustment for Descending Grades

(Multiply value from Figure 9 x factor 8.2.1.2A or 8.2.1.2B to obtain consumption rate on descending grade)

Constant Speed MPH (km/hr)		Correction Factor 8.2.1.2A (Gasoline Fuel) Descending Grade									
		1%	2%	3%	4%	5%	6%	7%	8%	9%	10%
10	(16)	0.70	0.41	0.37	0.34	0.34	0.34	0.34	0.34	0.34	0.34
20	(32)	0.67	0.33	0.30	0.26	0.26	0.26	0.26	0.26	0.26	0.26
30	(48)	0.70	0.40	0.32	0.24	0.24	0.24	0.24	0.24	0.24	0.24
40	(64)	0.79	0.56	0.40	0.25	0.25	0.25	0.25	0.25	0.25	0.25
50	(80)	0.84	0.67	0.49	0.21	0.21	0.21	0.21	0.21	0.21	0.21

Correction Factor 8.2.1.2B (Diesel Fuel)

Descending Grade

Not Available; authors suggest use of Correction Factor 8.2.1.2A

8.2.1.3 Adjustment for Curvature of Road

(Multiply value from Figure 9 x factor 8.2.1.3 to obtain consumption rate on curved roadway)

Constant Speed MPH	(km/hr)	Correction Factor 8.2.1.3 — Degree, [Radius, Ft.], (Radius, m.) of Curve										
		1 [5730] (1746)	2 [2865] (873)	3 [1910] (582)	4 [1433] (437)	5 [1146] (349)	6 [955] (291)	7 [819] (250)	8 [717] (218)	9 [637] (194)	10 [574] (175)	30 [193] (59)
10	(16)	1.00	1.00	1.00	1.00	1.01	1.01	1.01	1.02	1.03	1.04	1.05
20	(32)	1.00	1.01	1.01	1.01	1.02	1.04	1.07	1.10	1.12	1.13	1.30
30	(48)	1.00	1.01	1.01	1.02	1.04	1.08	1.15	1.22	1.28	1.34	2.00
40	(64)	1.01	1.01	1.02	1.02	-	-	-	-	-	-	-
50	(80)	1.01	1.01	1.02	1.02	-	-	-	-	-	-	-

8.2.1.4 Adjustment for Substandard Road Surface

(Multiply value from Figure 9 x factor 8.2.1.4 to obtain consumption rate on roadway with given surface condition)

Constant Speed MPH (km/hr)	Correction Factor 8.2.1.4 Roadway Surface Condition	
	Badly Broken and Patched Asphalt	Dry, Well-Packed Gravel
10 (16)	N.A.	1.07
20 (32)	N.A.	1.27
30 (48)	N.A.	1.59
40 (64)	N.A.	1.75

8.2.1.5 Adjustment for Traffic Density

8.2.1.5A Adjustment for Traffic Density on Urban Streets and Arterials.

(attempted speed = 25 MPH (40 km/hr)

(Multiply value from Figure 9 x factor 8.2.1.5A to obtain consumption rate at given conditions)

Traffic Density	Correction Factor 8.2.1.5A Frequency of Stops Per Mile (per km)										
	0 (0)	1 (0.6)	2 (1.2)	3 (1.9)	4 (2.5)	5 (3.1)	6 (3.7)	7 (4.3)	8 (5.0)	9 (5.6)	10 (6.2)
Light	1.00	1.39	1.78	2.18	2.57	2.96	3.35	3.75	4.14	4.53	4.93
Moderate	1.00	1.39	1.78	2.18	2.57	2.96	3.35	3.75	4.14	4.53	4.93
Heavy	1.00	N.A.	N.A.	N.A.	2.60	2.99	3.38	3.78	4.18	4.58	4.98
Congested	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	3.48	3.86	3.86	4.64	5.05

Based on 6-lane central business district street with parking on both sides; with the following volumes of one-way vehicles per hour:

Light	0-40 vph	Heavy	240-280 vph
Moderate	120-160 vph	Congested	360-400 vph

8.2.1.5B Adjustment for Traffic Density on Highways and Expressways.

(Multiply value from Figure 9 x factor 8.2.1.5B to obtain consumption rate at given conditions)

Attempted Speed MPH (km/hr)	Correction Factor 8.2.1.5B			
	Light Traffic	Moderate Traffic	Heavy Traffic	Congested Traffic
45 (72)	1.00	1.00	1.00	1.00
50 (80)	1.00	1.01	1.03	1.03

Based on 6-lane expressway, with the following volumes of one-way vehicles per hour:

Light	2400-2800 vph	Heavy	4400-4800 vph
Moderate	3200-3600 vph	Congested	5600-6000 vph

8.2.2 Fuel Consumed During Speed Changes

Excess quantity of fuel consumed by slowing down and then accelerating back to the original speed:

8.2.2A <u>Excess Gallons [Litres] Consumed (Gasoline Fuel)</u>

Original Speed MPH (km/hr)		Amount of Speed Reduction MPH (km/hr) 10 (16)	20 (32)	30 (48)	40 (64)	50 (80)
10	(16)	.015 [.057]	-	-	-	-
20	(32)	.040 [.151]	.047 [.178]	-	-	-
30	(48)	.040 [.151]	.065 [.246]	.085 [.322]	-	-
40	(64)	.050 [.189]	.077 [.291]	.110 [.416]	.133 [.503]	-
50	(80)	.065 [.246]	.107 [.405]	.157 [.594]	.227 [.859]	.205 [.776]

8.2.2B Excess Gallons [Litres] Consumed (Diesel Fuel)

Original Speed MPH (km/hr)	Amount of Speed Reduction MPH (km/hr) 10 (16)	20 (32)	30 (48)	40 (64)	50 (80)
10 (16)	N.A.	-	-	-	-
20 (32)	.030 [.115]	.036 [.135]	-	-	-
30 (48)	.027 [.103]	.044 [.165]	.061 [.232]	-	-
40 (64)	.032 [.121]	.049 [.184]	.069 [.262]	.089 [.337]	-
50 (80)	.041 [.155]	.066 [.251]	.097 [.368]	.148 [.559]	.137 [.520]

8.2.3 Fuel Consumed while Idling

Engine Size/Fuel	Consumption Rate Gal/hr	(Litres/hr)
386 cu in/Gasoline	0.80	(3.03)
503 cu in/Gasoline	0.79	(2.99)
501 cu in/Gasoline	0.89	(3.37)
672 cu in/Diesel	0.45	(1.70)

8.2.4 Fuel Consumed Due to Cold Starts

Not Available

8.2.5 Fuel Consumed in Normal Use

Trip Type	Fuel Consumption, GPM (Litres/km)	
	Gasoline Fuel	Diesel Fuel
Local Urban	0.20 (0.47)	0.18 (0.42)
Short Range (<200 miles)	0.20 (0.47)	0.18 (0.42)
Cross-Country	0.20 (0.47)	0.18 (0.42)

8.3 TRUCK FUEL CONSUMPTION BY GVW

8.3.1 Fuel Consumed in Normal Use by Gasoline Trucks

Trip Type	Fuel Consumption, GPM [Litres/km]					
	Gross Vehicle Weight, Thousand lbs (Thousand kg)					
	10-14 (4.5-6.4)	14-16 (6.4-7.3)	16-19.5 (7.3-8.8)	19.5-26 (8.8-11.8)	26-33 (11.8-15)	>33 (>15)
Local Urban	0.12 [0.28]	0.15 [0.35]	0.17 [0.41]	0.18 [0.41]	0.19 [0.44]	0.20 [0.48]
Short Range (<200 miles)	0.12 [0.27]	0.14 [0.33]	0.16 [0.39]	0.18 [0.41]	0.19 [0.44]	0.20 [0.48]
Cross Country	0.12 [0.28]	0.14 [0.33]	0.17 [0.39]	0.17 [0.39]	0.19 [0.44]	0.20 [0.48]

8.3.2 Fuel Consumed in Normal Use by Diesel Trucks

Trip Type	Fuel Consumption, GPM [Litres/km]		
	Gross Vehicle Weight, Thousand lbs (Thousand kg)		
	19.5-26 (8.8-11.8)	26-33 (11.8-15)	>33 (>15)
Local Urban	0.15 [0.35]	0.17 [0.40]	0.18 [0.42]
Short Range (<200 miles)	0.14 [0.33]	0.17 [0.40]	0.18 [0.42]
Cross Country	0.14 [0.33]	0.17 [0.40]	0.18 [0.42]

8.3.3 Relationship Between Load Capacity and GVW

Units: Thousand lbs (Thousand kg)

Capacity	GVW
10 (4.5)	15 (6.8)
25 (11.3)	40 (18.1)
30 (13.6)	45 (20.4)
40 (18.1)	58 (26.3)

8.4 FUEL CONSUMED IN NORMAL USE BY COMPOSITE TRUCK FLEET

Gasoline Fueled	0.18 GPM	[0.42 Litres/km]
Diesel Fueled	0.17 GPM	[0.40 Litres/km]

9.0 DIRECT FUEL CONSUMPTION OF BUSES

9.1 INTERCITY SERVICE

9.1.1 Fuel Consumed at Constant Speeds: N.A.

Constant Speed MPH (km/hr)	Fuel Consumption (Diesel Fuel) Gallons per Mile	(Litres per Kilometre)
50 (80)	.155	(.364)
55 (89)	.170	(.401)
60 (97)	.189	(.445)
65 (105)	.207	(.487)

9.1.1.1 Adjustment for Ascending Grades

(Multiply value from 9.1.1 x factor 9.1.1.1 to obtain consumption rate on ascending grade)

Constant Speed MPH (km/hr)	Correction Factor 9.1.1.1 Ascending Grade		
	1%	2%	3%
50 (80)	1.40	1.84	
55 (89)	1.38	Cannot Maintain Speed	
60 (97)	1.33		
65 (105)			

9.1.1.2 Adjustment for Descending Grade

(Multiply value from 9.1.1 x factor 9.1.1.2 to obtain consumption rate on descending grade)

Constant Speed MPH (km/hr)		Correction Factor 9.1.1.2 Descending Grade	
	-1%	-2%	-3%
50 (80)	.68	.33	Brakes Required
55 (89)	.70	.39	.06
60 (97)	.72	.44	.12
65 (105)	.74	.49	.20

9.1.2 Fuel Consumed in Normal Use:

0.167 GPM [0.393 Litres/km] Diesel Fuel

9.2 METROPOLITAN TRANSIT SERVICE

9.2.1 Fuel Consumed at Constant Speeds:

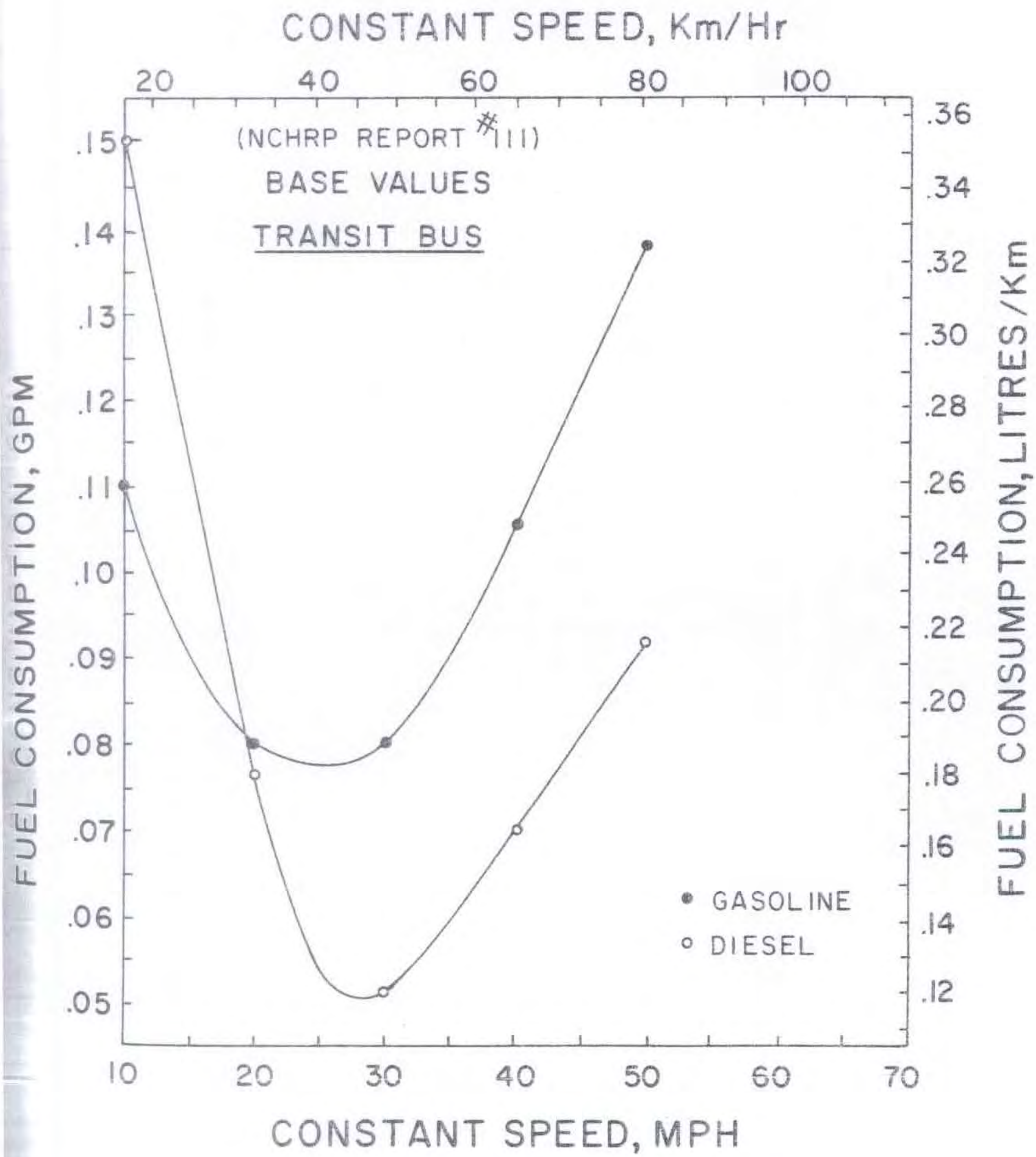


Fig. A10 Fuel consumption of transit bus.

9.2.1.1 Adjustment for Ascending Grades

(Multiply value from Figure 10 x factor 9.2.1.1A or 9.2.1.1B to obtain consumption rate on ascending grade)

Constant Speed MPH	(km/hr)	Correction Factor 9.2.1.1A (Gasoline Fuel) Ascending Grade 2%	4%	6%	8%	10%
10	(16)	1.36	1.63	1.73	1.52	1.38
20	(32)	2.09	2.76	2.94	2.57	-
30	(48)	2.86	4.03	4.38	-	-
40	(64)	3.58	5.15	-	-	-
50	(80)	4.44	6.31	-	-	-

Correction Factor 9.2.1.1B (Diesel Fuel)

Ascending Grade

Not Available

9.2.1.2 Adjustment for Descending Grades

(Multiply value from Figure 10 x factor 9.2.1.2A or 9.2.1.2B to obtain consumption rate on descending grade)

Constant Speed MPH (km/hr)		Correction Factor 9.2.1.2A (Gasoline Fuel)				
		Descending Grade				
		2%	4%	6%	8%	10%
10	(16)	0.54	0.54	0.54	0.54	0.54
20	(32)	0.56	0.53	0.52	0.52	0.52
30	(48)	0.54	0.43	0.45	0.45	0.45
40	(64)	0.52	0.37	0.29	0.29	0.29
50	(80)	N.A.	N.A.	N.A.	N.A.	N.A.

Correction Factor 9.2.1.2B (Diesel Fuel)

Descending Grade

Not Available

9.2.2 Fuel Consumed in Normal Use

9.2.2.1 Metropolitan Transit Operations (average vehicle):

Fuel Consumption: 0.257 GPM [.604 litres/km]

9.2.2.2 School Bus (var. seats) Gasoline:

Fuel Consumption: 0.135 GPM [.318 litres/km]

9.2.2.3 Minibus (10-13 seats) Diesel:

Fuel Consumption: 0.081 GPM [.191 litres/km]

9.2.2.4 Minibus (10-13 seats) Gasoline:

Fuel Consumption: 0.146 GPM [.343 litres/km]

9.2.2.5 Minibus (33 seats):

Fuel Consumption: N.A.

9.2.2.6 Standard (53 seats) Diesel:

Fuel Consumption: 0.234 GPM [.550 litres/km]

9.2.2.7 Standard (48 seats) Electric Trolley:

Fuel Consumption: 3.95 KWH/mile [2.45 KWH/km]

9.2.2.8 Standard (50 seats) Gasoline:

Fuel Consumption: N.A.

9.2.2.9 Standard (50 seats) Propane:

Fuel Consumption: 0.531 GPM [1.249 litres/km]

(equivalent 51500 Btu/mile)

9.2.3 Fuel Consumed vs. Bus Stop Frequency

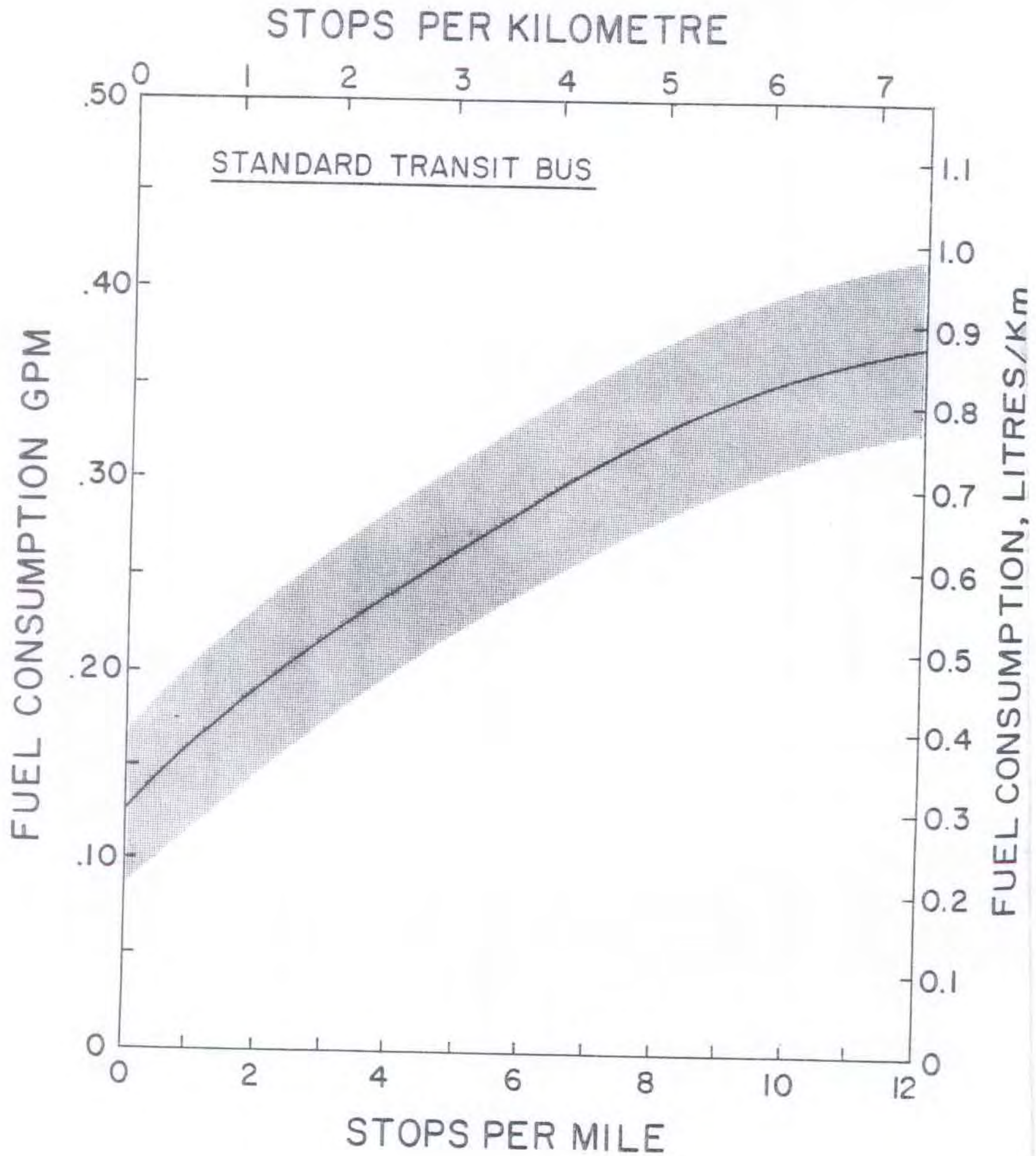


Fig. All Diesel fuel consumed vs bus stop frequency.

10.0 DIRECT FUEL CONSUMPTION OF TRAINS - General

10.1 FUEL CONSUMPTION PER THROTTLE POSITION

Diesel Fuel Consumption Rate: gallons per hour (litres per hour)

Diesel-Electric Locomotive	Throttle Position 8	7	6	5	4	3	2	1	Idle	Dynamic Brake
EMD SW1000-1000HP	60 (227)	50 (189)	40 (151)	31 (117)	22 (83)	13 (49)	6 (23)	5 (19)	3 (11)	-
EMD SW1500-1500HP	93 (352)	80 (303)	62 (235)	52 (197)	39 (148)	25 (95)	12 (45)	6 (23)	4 (15)	-
EMD GP/SD7-1500HP	93 (352)	75 (284)	60 (227)	46 (174)	34 (129)	23 (87)	14 (53)	6 (23)	4 (15)	-
EMD GP/SD9-1750HP	108 (409)	82 (310)	68 (257)	52 (197)	37 (140)	24 (91)	13 (49)	5 (19)	4 (15)	-
GE U18B-1800HP	103 (390)	85 (322)	72 (273)	56 (212)	42 (159)	24 (91)	16 (61)	11 (42)	4 (15)	20 (76)
EMD GP20-2000HP	116 (439)	86 (326)	69 (261)	55 (208)	42 (159)	28 (106)	14 (53)	6 (23)	4 (15)	-
EMD GP/SD38-2000HP	122 (462)	103 (390)	83 (314)	64 (242)	47 (178)	31 (117)	16 (61)	7 (26)	5 (19)	25 (95)
EMD GP30-2250HP	125 (473)	102 (386)	75 (284)	61 (231)	45 (170)	31 (117)	19 (72)	7 (26)	4 (15)	-

10.1 (Continued)

GE U23B,C-2300HP	112 (424)	92 (348)	81 (307)	64 (242)	48 (182)	27 (102)	17 (64)	12 (45)	4 (15)	20 (76)
EMD SD24-2400HP	144 (545)	106 (401)	81 (307)	61 (231)	44 (167)	30 (114)	18 (68)	6 (23)	3 (11)	-
EMD GP/SD35-2500HP	144 (545)	124 (469)	96 (363)	72 (273)	51 (193)	35 (132)	21 (79)	11 (42)	5 (19)	-
EMD.GP-SD40-3000HP	168 (636)	146 (553)	108 (409)	79 (299)	57 (216)	41 (155)	25 (95)	7 (26)	6 (23)	25 (95)
GE U30B,C-3000HP	149 (564)	127 (481)	102 (386)	81 (307)	62 (235)	34 (129)	22 (83)	16 (61)	5 (19)	26 (98)
GE U33B,C-3300HP	163 (617)	138 (522)	110 (416)	87 (329)	65 (246)	36 (136)	23 (87)	16 (61)	5 (19)	26 (98)
GE U36B,C-3600HP	177 (670)	150 (568)	119 (450)	94 (356)	69 (261)	39 (148)	24 (91)	16 (61)	5 (19)	26 (98)
EMD SD45-3600HP	194 (734)	172 (651)	127 (481)	92 (348)	68 (257)	48 (182)	28 (106)	10 (38)	6 (23)	25 (95)

10.2 TYPICAL DAILY LOCOMOTIVE OPERATION - Diesel Electric

Throttle Position	Delivered Horsepower	Operation (Hours)	Consumption Rate Gal/hr	(Litres/hr)
8	3100	3.6	168	(636)
7	2550	1.0	146	(553)
6	2000	1.0	108	(409)
5	1450	1.0	79	(299)
4	950	1.0	57	(216)
3	500	1.0	41	(155)
2	200	1.0	25	(95)
1	58	1.2	7.5	(28)
Idle	0	12.0	5.5	(21)
Dyn.Brake	-	1.2	25	(95)

10.3 HORSEPOWER REQUIREMENTS FOR ASCENDING GRADES

Additional horsepower required for gross elevation changes in the track.

Gross Elevation Change Feet/Mile	(Metres/km)	Additional Horsepower Required
0	(0)	21%
5	(0.95)	52%
10	(1.89)	82%
15	(2.84)	113%
20	(3.79)	144%
25	(4.73)	174%
30	(5.68)	205%
35	(6.63)	236%

10.4 FUEL CONSUMPTION PER HORSEPOWER-TO-WEIGHT RATIO

10.4.1 Relatively Level Territory — N.A.

10.4.2 Relatively Mountainous Territory

10.4.2.1 1.0 Horsepower/Trailing Gross Ton (.9 HP/Metric T)

Max. Speed MPH	(km/hr)	Avg. Speed MPH	(km/hr)	Diesel Fuel Consumption GPM	(Litres/km)
70	(113)	30.9	(49.7)	8.28	(19.48)
60	(97)	30.6	(49.2)	8.09	(19.03)
50	(80)	29.7	(47.9)	7.81	(18.37)
40	(64)	28.0	(45.1)	7.56	(17.78)

10.4.2.2 1.5 Horsepower/Trailing Gross Ton (1.4 HP/Metric T)

Max. Speed MPH	(km/hr)	Avg. Speed MPH	(km/hr)	Diesel Fuel Consumption GPM	(Litres/km)
70	(113)	37.6	(60.6)	9.33	(21.95)
60	(97)	37.2	(59.9)	8.88	(20.89)
50	(80)	35.6	(57.4)	8.43	(19.83)
40	(64)	32.5	(52.3)	8.06	(18.96)

10.4.2 (Continued)

10.4.2.3 3.0 Horsepower/Trailing Gross Ton (1.8 HP/Metric T)

70 (113)	47.0 (76.6)	10.42 (24.51)
60 (97)	44.3 (71.3)	9.72 (22.86)
50 (80)	40.3 (64.8)	9.08 (21.36)
40 (64)	35.6 (57.3)	8.53 (20.06)

10.4.2.4 4.0 Horsepower/Trailing Gross Ton (3.6 HP/Metric T)

70 (113)	49.8 (80.1)	12.28 (28.88)
60 (97)	46.3 (74.6)	10.91 (25.66)
50 (80)	41.4 (66.7)	9.77 (22.98)
40 (64)	36.0 (58.0)	9.08 (21.36)

10.4.2.5 5.0 Horsepower/Trailing Gross Ton (4.5 HP/Metric T)

70 (113)	N.A.	14.29 (33.61)
60 (97)	N.A.	11.9 (27.99)
50 (80)	N.A.	10.47 (24.63)
40 (64)	N.A.	9.92 (23.33)

10.4.2 (Continued)

10.4.2.6 6.0 Horsepower/Trailing Gross Ton (5.4 HP/Metric T)

70 (113)	51.8 (83.4)	16.62 (39.09)
60 (97)	47.5 (76.5)	13.74 (32.34)
50 (80)	42.1 (67.5)	12.10 (28.46)
40 (64)	36.0 (58.0)	11.36 (26.72)

10.4.2.7 8.0 Horsepower/Trailing Gross Ton (7.3 HP/Metric T)

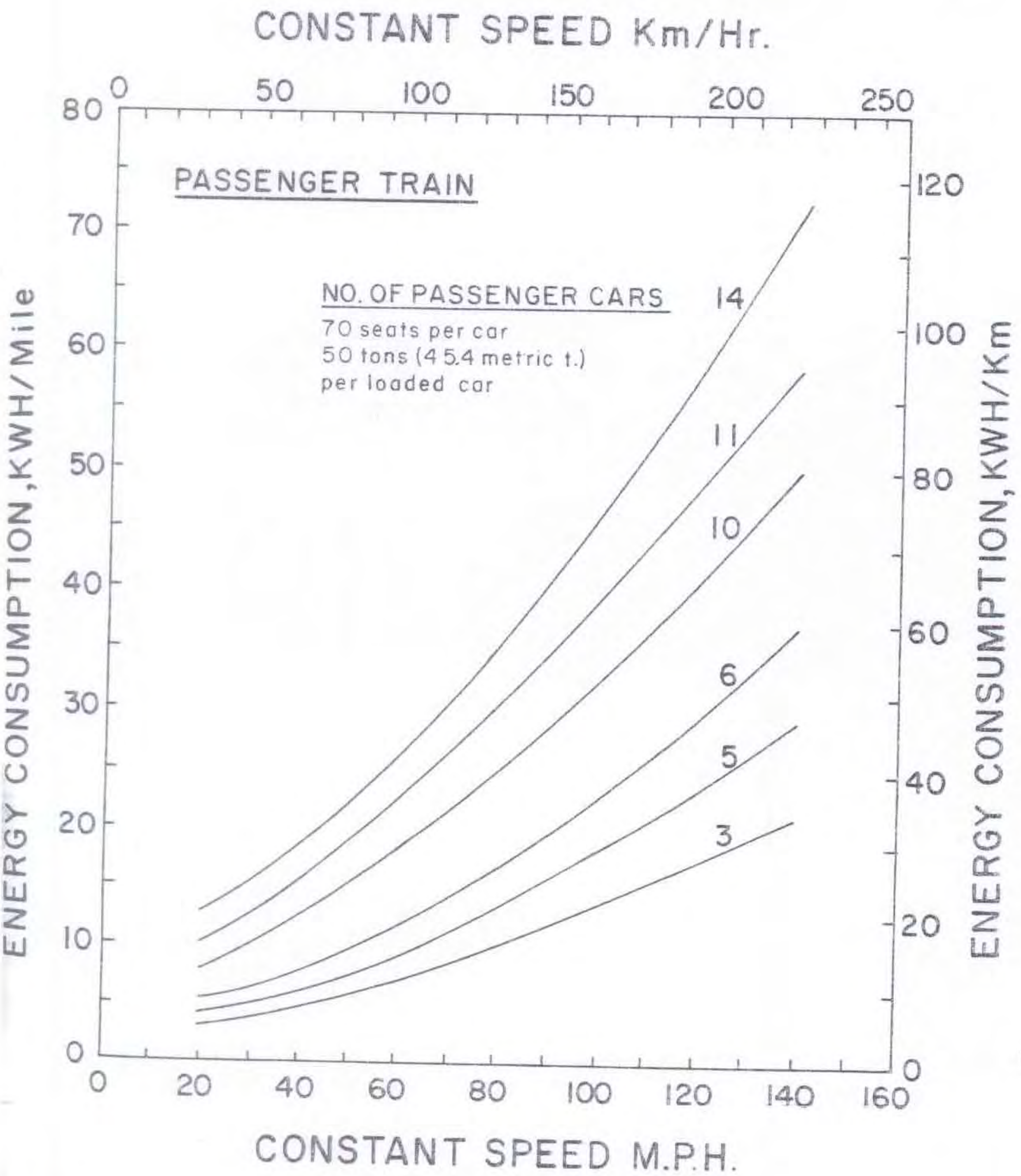
N.A.	N.A.	20.8 (48.98)

10.4.2.8 10.0 Horsepower/Trailing Gross Ton (9.1 HP/Metric T)

N.A.	N.A.	26.0 (61.16)

11.0 DIRECT FUEL CONSUMPTION OF PASSENGER TRAINS

11.1 FUEL CONSUMED AT CONSTANT SPEEDS



ig. A12 Energy consumption at constant speed - passenger train.

11.2 FUEL CONSUMPTION OF TRAINS - SHORT TRIPS

Electric energy 0.17 KWH/seat-mile (0.11 KWH/seat-km) [Diesel Fuel Equivalent = 0.013 gal/seat-mile (0.030 litre/seat-km)]

11.3 FUEL CONSUMPTION OF SELECTED TRAINS - LONG TRIPS - Diesel Fuel

Route	Distance Miles(km)	Propulsion Type	Gal/seat-mile (Lit/seat-km)	
Seattle-Havre	903 (1453)	Diesel-Elec.	.009	(.022)
Atlanta-Wash.	633 (1019)	Diesel-Elec.	.012	(.029)
New York-Wash.	284 (457)	Gas Turbine	.010	(.024)
Chicago-St. Louis	227 (365)	Electric	.013*	(.031)

*Equivalent diesel fuel

11.4 WEIGHT PER SEAT OF SELECTED TRAINS

Train Type	Gross Wt. Tons (Metric T)		No. of Seats	Gross Wt. per seat Tons	(Metric T)
Urban	39.5	(35.8)	50-60	0.72	(.65)
Intercity	525	(476)	382	1.37	(1.24)
Intercity	1000	(907)	1400	0.71	(.64)
Std.Diesel	600	(544)	360	1.67	(1.51)

12.0 DIRECT FUEL CONSUMPTION OF FREIGHT TRAINS

12.1 AVERAGE DISTRIBUTION OF GROSS TRAIN WEIGHT

Locomotive(s)	11%
Trailing Tare	49%
Net Freight	40%

12.2 CARGO WEIGHT DEPENDING ON COMMODITY SHIPPED

Commodity	Tons/car	(Metric T/car)
Average	54.1	(49.1)
Metallic Ores	77.3	(70.1)
Non-Met. Minerals	73.5	(66.7)
Coal	69.5	(63.1)
Petroleum	55.8	(50.6)
Farm Products	54.3	(49.3)
Wood Products	48.1	(43.6)
Food	38.6	(35.0)
Printed Matter	29.2	(26.5)
Machinery	27.9	(25.3)
Fab. Metal Products	27.4	(24.9)
Leather Products	24.5	(22.3)
Transp. Equipment	22.4	(20.3)
Textile Products	19.9	(18.1)
Instru., Photography	18.4	(16.7)
Apparel	18.1	(16.4)
Rubber or Plastic	16.4	(14.9)
Misc. Mfg. Goods	15.0	(13.6)
Electric Machinery	13.7	(12.4)
Furniture, Fixtures	9.2	(8.4)

12.3 FUEL CONSUMED IN NORMAL USE - Diesel

Gross Consumption:	0.0020 gal/Gross Ton-Mile	
	(0.0051 litres/Metric Ton-km)	
Net Consumption:	0.0049 gal/Net Ton-Mile	
	(0.0127 litres/Metric Ton-km)	

13.0 DIRECT FUEL CONSUMPTION OF RAIL MASS TRANSIT

13.1 FUEL CONSUMED IN NORMAL USE

Characteristics and Energy Consumption of Selected Systems

System	Seats [Standing] per car	Rated hp/Seat	wt/Seat Tons	(Metric T)	Energy Consumed** Btu/Seat-mi	(joules/Seat-km)
Std. Commuter	127 [123]	9.5	.47	(.43)	N.A.	(N.A.)
Lindenwold	84	7.6	.39	(.36)	N.A.	(N.A.)
Toronto	83 [N.A.]	1.9	.35	(.32)	860	(5.62×10^5)
San Francisco*	72 [72]	7.4	.40	(.36)	850	(5.62×10^5)
Philadelphia	56 [N.A.]	5.8	.43	(.39)	1075	(7.02×10^5)
Cleveland	54 [N.A.]	3.4	.51	(.46)	686	(4.54×10^5)
Chicago	51 [N.A.]	3.4	.41	(.38)	952	(6.26×10^5)
New York	47 [N.A.]	7.3	.84	(.76)	1208	(7.88×10^5)
Montreal	40 [120]	3.9	.75	(.68)	N.A.	(N.A.)
Tokyo "Alweg"	35 [65]	13.3	.39	(.35)	N.A.	(N.A.)

*BART System

**Standee capacity is not included in computations

14.0 PERSONAL RAPID TRANSIT (LIGHT MASS TRANSIT) FUEL CONSUMPTION

14.1 FUEL CONSUMED IN NORMAL USE

Not available

14.2 CHARACTERISTICS AND POWER RATING OF SELECTED OPERATIONAL SYSTEMS

System	Seats [Standing] per car	Rated hp/seat	wt/seat Tons (Metric T)	Avg. Speed MPH (km/hr)	Energy Consumption
N.Railbus (San Diego Zoo)	75	1.33	.13 (.11)	25 (40)	N.A.
Airtrans (Dallas Airport)	16 [24]	4.69	.34 (.31)	12 (19)	1.4 kw/veh-mi (.87 kw/veh-km)
Minirail (Montreal)	12	0.78	.05 (.05)	8 (13)	N.A.
K Monorail (Lancaster, PA)	12	0.42	N.A.	25 (40)	N.A.
Skybus (Tampa Airport)	12 [90]	8.33	1.06 (.96)	15 (24)	N.A.
Jetrail (Dallas Airport)	6 [4]	1.67	N.A.	30 (48)	N.A.

14.2 (Continued)

Peoplemover (Disneyland)	4		2.5	.08	(.07)	4	(6)	N.A.
ACT (Ford Motor Co.)	10	[20]	12.0	.64	(.58)	20	(32)	N.A.
StaRRcar (Morgantown, W.VA)	8	[13]	12.5	.43	(.39)	22	(35)	2 kw/veh-mi (1.2 kw/veh-km)
Speedwalk* (Moving sidewalk) (L.A. Airport)		[200±]	0.23*	30**	(44.6)**	1.4(2.25)		
Escalator* (Moving stairway)		[N.A.]	0.3*	N.A.		1.4(2.25)		N.A.

*Standees only in this system

**Values are: 30 plf (44.6 kg/m)

15.0 DIRECT FUEL CONSUMPTION OF PASSENGER AIRCRAFT

15.1 FUEL CONSUMED AT NORMAL OPERATING MODES

Estimated Fuel Consumption For Typical Operations - Jet Aircraft Fuel.

Aircraft Type	FUEL CONSUMPTION RATE GAL/hr (Lit/hr) Taxi-Idle	Take-off	Climb-out	Cruise	Approach Land	TIME IN MODE, HOURS Taxi - Idle Dep.	Arr.	Take-off	Climb-out	Approach Land
Jumbo	1053	10335	8677	3576	3154	.32	.12	.12	.04	.07
Jet	(3986)	(39122)	(32846)	(13537)	(11939)					
Long-Range	528	6567	5428	1879	2508	.32	.12	.12	.04	.07
Jet	(1999)	(24859)	(20547)	(7113)	(9494)					
Medium-	436	3980	3335	1136	1550	.32	.12	.12	.04	.07
Range Jet	(1650)	(15066)	(12624)	(4300)	(5867)					
Air Carrier	299	1450	1326	582	695	.32	.12	.01	.04	.08
Turboprop	(1132)	(5489)	(5019)	(2203)	(2631)					
S.T.O.L.	45	182	152	85	76	.32	.12	.01	.04	.08
Commercial	(170)	(689)	(575)	(322)	(288)					
Gen. Aviation	44	111	103	61	62	.32	.12	.01	.04	.08
Turboprop	(167)	(420)	(390)	(231)	(235)					
Gen. Aviation	1.2	7.3	7.3	7.1	3.2	.20	.07	.005	.08	.10
Piston*	(4.5)	(27.6)	(27.6)	(26.9)	(12.1)					

15.2 FUEL CONSUMED ASSUMING BEST CRUISING SPEED - Jet Aircraft Fuel

Aircraft Type	Approx. Seats	Best Cruise Speed MPH	(km/hr)	FUEL CONSUMPTION: Cruise Gal/Seat-Mile*	(Lit/Seat-km)	Non-Cruise** (per trip) Gal/Seat	(Lit/Seat)
Jumbo Jet	315	575	(925)	.020	(.047)	7.2	(27.3)
Long-Range Jet	140	565	(909)	.024	(.056)	10.1	(38.2)
Medium-Range Jet	90	565	(909)	.022	(.052)	10.1	(38.2)
Air Carrier Turboprop	85	360	(579)	.019	(.045)	3.0	(11.4)
S.T.O.L. Commercial	19	190	(306)	.028	(.066)	1.8	(6.8)
Gen.Aviation Turboprop	10	300	(483)	.020	(.047)	3.0	(11.4)
Gen.Aviation Piston	5	105	(169)	.023	(.054)***	0.3	(1.1)***

*Great Circle miles

**Non-Cruise mode includes: Taxi-Idle at both ends of trip, takeoff, climbout, and approach-landing.

***Aviation Gasoline Fuel

15.3 FUEL CONSUMED IN NORMAL OPERATIONS - Jet Aircraft Fuel

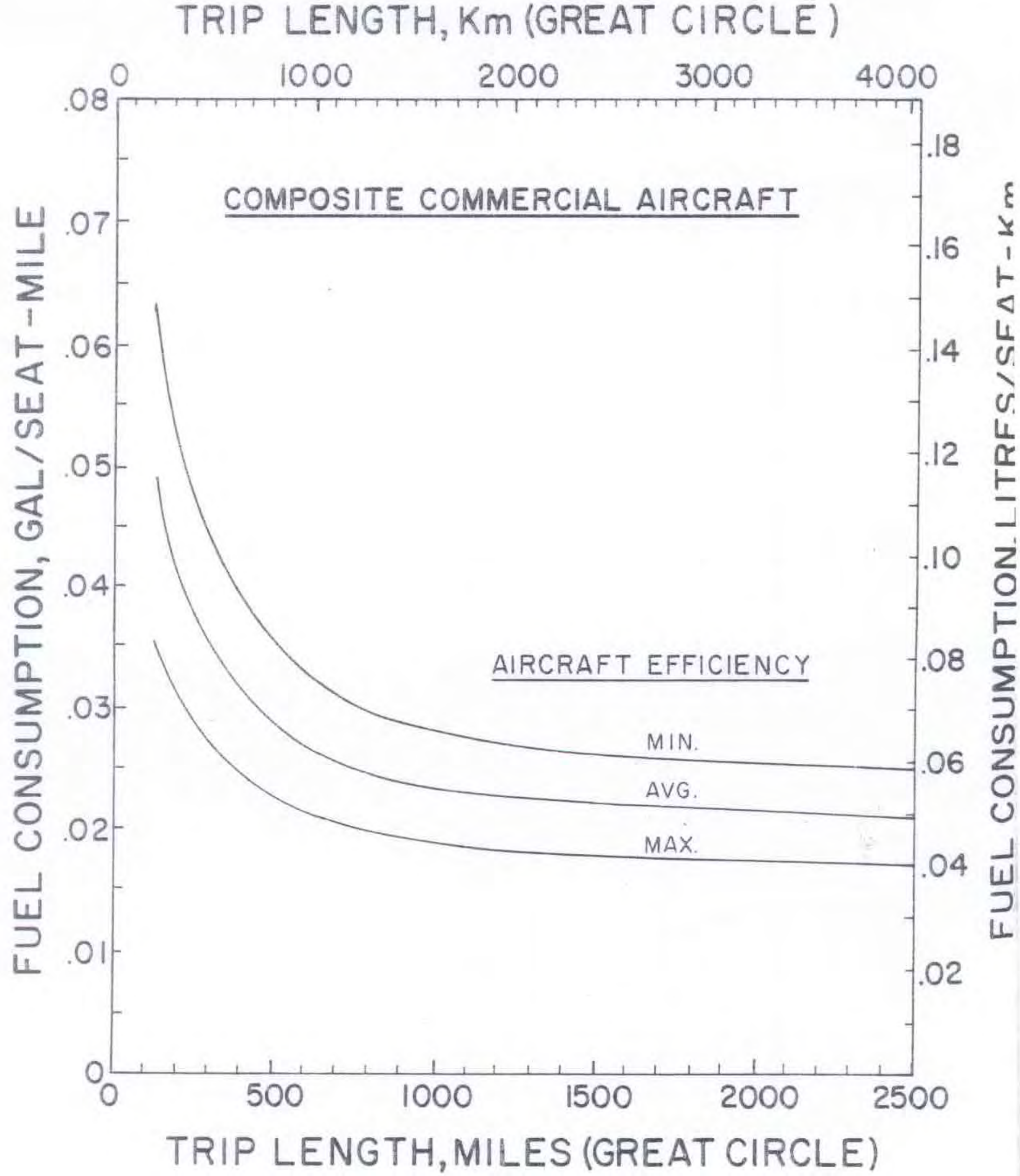


Fig. A13 Fuel consumption of composite commercial passenger airplane, as influenced by trip length.

16.0 DIRECT FUEL CONSUMPTION OF FREIGHT AIRCRAFT

16.1 CARGO-ONLY AIRCRAFT

Published values vary considerably. See Appendix B.

16.2 PASSENGER-CARGO AIRCRAFT (Lower Hold)

Published values vary considerably. See Appendix B.

17.0 DIRECT FUEL CONSUMPTION OF FERRY-BOATS

17.1 FUEL CONSUMPTION OF SELECTED FERRY-BOATS

System	Vessels in Service	Cruise Speed Knots*	Rated Passengers [Cars]	Fuel Consumption (Diesel) Gal/Rated Pass.-Mile** (Litres/Pass.-km)
Delaware-New Jersey; Cape May-Lewes Ferry	3 vessels, (identical, built 1974)	14	700 [100]	.022 (.052)
Washington State Ferries Fleet	6 large vessels, (built 1967-72)	18	2000-2500 [N.A.]	.006 (.014)
	+ 19 older vessels	vary	vary	N.A.
San Francisco Bay-Golden Gate Ferries	1 vessel	14	575	.005 (.012)
	+ 2 identical vessels 1976	22	700	.011 (.026)

*Knot: 1 nautical mile per hour = 1.151 statute miles per hour = 1.852 km/hr

**Statute miles.

18.0 DIRECT FUEL CONSUMPTION OF INLAND AND COASTAL VESSELS

18.1 FUEL CONSUMED IN NORMAL PASSENGER SERVICE

Fuel consumption (diesel fuel): .004 gal/pass.-mile

(.009 Litre/pass.-km)

18.2 FUEL CONSUMED IN NORMAL FREIGHT SERVICE

Fuel consumption: 509 Btu/T-mile

(3.03×10^5 joules/Metric T-km)

19.0 DIRECT FUEL CONSUMPTION OF MERCHANT SHIPS

19.1 CHARACTERISTICS OF U.S. FLAG MERCHANT SHIPS

Ship Type (No. of Ships)	Engine Type	Avg. Deadweight Long Tons	Avg. Speed Knots	Avg. Fuel Consumption Gal/Dwt. T-Mile (naut.)
Barge Carrier (6)	S.T.	43537	22.0	.00209
Bulk Carrier (1)	S.T.	13790	11.5	.00120
Bulk Carrier (1)	M.S.	13700	11.5	.00085
Chemical Tanker (1)	S.T.	35949	16.5	.00159
Combination (2)	S.T.	18049	17.0	.00201
Container (80)	S.T.	16627	20.2	.00381
Container (1)	M.S.	2294	16.0	.00427
Convertible (17)	S.T.	19705	22.2	.00382
Dry Bulk Carrier (9)	S.T.	22291	14.4	.00150
Dry Bulk Carrier (2)	M.S.	26724	15.0	.00101
General Cargo (157)	S.T.	13335	19.1	.00370
General Cargo (1)	M.S.	10206	15.5	.00135
L.A.S.H. (16)	S.T.	33407	21.9	.00283
Ore/Bulk/Oil (2)	S.T.	82160	16.5	.00111

19.1 (Continued)

Partial Container (1)	S.T.	14361	20.0	.00382
Passenger Vessel (6)	S.T.	8434	19.6	.00675
Petroleum Tanker (1)	S.T.	18635	15.0	.00172
Special Purpose Cargo (1)	S.T.	10380	15.0	.00266
Tanker (212)	S.T.	41659	16.1	.00156
Tanker (13)	M.S.	30860	16.2	.00108
Vehicle Carrier (8)	S.T.	14076	24.1	.00510
Fleet average (538)		27000	18.1	.00274

S.T. = Steam Turbine, using Bunker C Fuel Oil

M.S. = Motor Ship, using Diesel Fuel

Long Ton = 2240 lb (1016 kg)

Knot = 1 nautical mile per hour = 1.151 statute miles per hour = 1.852 km/hr

Gallon per Dwt. Ton-nautical mile = 2.315 Litres per Dwt. Metric Ton-km

19.2 FUEL CONSUMPTION IN-BERTH

Steam Turbine (Bunker C Fuel)	1900 Gal/day	(7200 Litres/day)
Motor Ship (Diesel Fuel)	660 Gal/day	(2500 Litres/day)

19.3 NORMAL OPERATING TIMETABLE

Average annual service timetable for merchant ships (non-passenger) is as follows:

At sea:	280 days
In port:	60 days
Scheduled maintenance:	25 days

20.0 DIRECT ENERGY CONSUMPTION OF PIPELINES

20.1 COAL SLURRY TRANSPORT

300 Btu/Ton-mile

(1.78×10^5 joules/Metric T-km)

20.2 NATURAL GAS TRANSPORT

2637 Btu/Ton-mile

(1.57×10^6 joules/Metric T-km)

20.3 OIL TRANSPORT

660 Btu/Ton-mile

(3.92×10^5 joules/Metric T-km)

21.0 INDIRECT - VEHICLE MANUFACTURING ENERGY

21.1 MANUFACTURE ENERGY CHARACTERISTICS OF SELECTED TRANSPORTATION VEHICLES

	Vehicle Type	Weight lbs(kg)	Rated Seats	Estimated Life Miles(km)	Manuf. Energy Btu/lb (joules/kg)	Manuf. Energy Btu/Seat-Mile (joules/Seat-km)
21.1.1	Car (Standard)	3500 (1588)	6	100,000 (160,900)	37500 ($8.72x10^7$)	219 ($1.43x10^5$)
21.1.2	Car (Compact)	2500 (1134)	4	100,000 (160,900)	41000 ($9.54x10^7$)	256 ($1.68x10^5$)
21.1.3	Truck (Van, Pickup)	5000 (2268)	-	100,000 (160,900)	54600 ($1.27x10^8$)	-
21.1.4	Truck (2 axle-6 tire)	10000 (4536)	-	200,000 (321,900)	58000 ($1.35x10^8$)	-
21.1.5	Truck (Semi-Trailer)	20000 (9072)	-	300,000 (482,800)	61400 ($1.43x10^8$)	-
21.1.6	Bus, Transit (Standard 40')	20000 (9072)	53	300,000 (482,800)	51200 ($1.19x10^8$)	64 ($4.19x10^4$)

21.1 (Continued)

21.1.7	Bus (Standard 35')	19000 (8618)	45	150,000 (241,400)	50200 ($1.17x10^8$)	141 ($9.23x10^4$)
21.1.8	Bus (Minibus)	7000 (3175)	13	100,000 (160,900)	N.A.	N.A.
21.1.9	Railroad (Locomotive)	See Appendix B	-	N.A.	N.A.	N.A.
21.1.10	Railroad Car (Commuter)	58250 (26401)	72	3,000,000 (4,800,000)	72000 ($1.67x10^8$)	19 ($1.24x10^4$)
21.1.11	Railroad Car (Cargo)	See Appendix B	-	N.A.	N.A.	-
21.1.12	PRT Car	3000-10000	Var	N.A.	61400-95600 ($1.43-2.22x10^8$)	N.A.
21.1.13	Aircraft (Commercial Jets)	See Appendix B Sect. 15.0		1,000,000 (1,610,000)	150500 ($3.50x10^8$)	78-170 ($5.11-11.1x10^4$)
21.1.14	Aircraft (Gen. Aviation Piston)	4000 (1814)	4	N.A.	170600 ($3.97x10^8$)	N.A.
21.1.15	Ships (Ferryboats)	Vary		N.A.	N.A.	N.A.

21.1 (continued

21.1.16	Ships (Merchant)	See Appendix B
2-.1.17	Pipelines	Not Available

22.0 INDIRECT - VEHICLE MAINTENANCE ENERGY

22.1 PASSENGER CARS

22.1.1

Normal Maintenance: 1400 Btu/veh-mile (9.18×10^5 joules/km)

For operations on gravel roads: 100% higher

For operations on unimproved earth roads: 500% higher

22.1.2

Average Travel Distance Before Repairs Are Necessary

Vehicle Part	Average Distance Miles	(km)
Oil Pump	109,000	(175,000)
Rear Axle	106,000	(171,000)
Radiator	76,000	(122,000)
Engine Block	70,000	(113,000)
Springs	68,000	(109,000)
Auto. Transmission	66,000	(106,000)
Brake System	54,000	(87,000)
Fuel Pump	52,000	(84,000)
Generator	52,000	(84,000)
Fan Belt	51,000	(82,000)
Carburetor	45,000	(72,000)
Universal Joints	44,000	(71,000)
Shock Absorbers	44,000	(71,000)
Water Pump	43,000	(69,000)
Exhaust	39,000	(63,000)
Sheet Metal	N.A.	

22.1.3 Tire Wear

22.1.3.1 New Tires, worn once and discarded:

Per Tire: 8.93×10^2 Btu/mile (5.85×10^5 joules/km)

22.1.3.2 New Tires, worn once (if 50% reclaimed and retreaded).

Per Tire: 5.80×10^2 Btu/mile (3.80×10^5 joules/km)

22.1.3.3 Retreaded Tires, worn once and discarded.

Per Tire: 1.33×10^1 Btu/mile (8.74×10^3 joules/km)

22.2 TRUCKS

Not available (see 22.1.1 for maintenance rate on unimproved roads).

22.3 BUSES

22.3.1 Normal Maintenance 13142 Btu/veh-mile (8.62×10^6 joules/km)

22.4 TRAINS

Energy consumption associated with maintenance has not been identified. Generally, 19 to 20% of available locomotives are in the shops for maintenance and repair at any given time. In addition, locomotives receive safety inspections every 24 hours and a one-hour routine inspection, lubrication and refuelling stop every 5 days.

22.5 PERSONAL RAPID TRANSIT

Not Available

22.6 AIRCRAFT

See Appendix B

22.7 SHIPS

Energy consumption associated with maintenance has not been adequately identified. (See Commentary Sect. 21.1.16.) Typical scheduled maintenance time totals 20-25 days per year for the average merchant vessel.

22.8 PIPELINES

Not Available

23.0 INDIRECT-SYSTEM CONSTRUCTION & MAINTENANCE ENERGY

23.1 ROADWAY FACILITIES

23.1.1 Roadway Construction

See Sections 3.0, 4.0, 5.0, 6.0

23.1.2 Roadway Maintenance

23.1.2.1 Fuel Consumed by Selected Equipment

Vehicle Type	Btu/hr	(joules/hr)
Front End Loader - 2 cu yd Diesel	$6.95x10^3$	($7.33x10^6$)
Front End Loader - 1.5 cu yd Gasoline	$5.00x10^3$	($5.28x10^6$)
Loader for Aggregates	$8.75x10^5$	($9.23x10^8$)
Front End Loader, Diesel	$2.22x10^5$	($2.34x10^8$)
Motor Grader - 23,000 lb Diesel	$6.95x10^3$	($7.33x10^6$)
Grader, Diesel	$3.75x10^5$	($3.96x10^8$)
Roller	$1.11x10^5$	($1.17x10^8$)
Striping Machine	$1.25x10^5$	($1.32x10^8$)
Hand Striping Machine	$6.25x10^4$	($6.59x10^7$)
Mower, Roadside	$1.25x10^5$	($1.32x10^8$)
Mower, Landscape	$4.68x10^4$	($4.94x10^7$)
Tractor, Farm Type	$3.75x10^5$	($3.96x10^8$)
Spreader, Self Propelled	$3.38x10^5$	($3.57x10^8$)
Broom, Mechanical	$1.25x10^5$	($1.32x10^8$)
Dozer, Track Type	$4.17x10^5$	($4.40x10^8$)
Crushing/Screening Plant	$6.95x10^5$	($7.33x10^8$)
Asphalt Paver	$6.26x10^5$	($6.60x10^8$)

23.1.2.2 Energy Consumed By Normal Maintenance Operations

23.1.2.2.1 Flexible Pavement (A.C.)

Annual: 1.2×10^{8} Btu/ln-mi

(7.87×10^{10} joules/ln-km)

23.1.2.2.2 Rigid Pavement (P.C.C.)

Annual: 4.0×10^{7} Btu/ln-mi

(2.62×10^{10} joules/ln-km)

23.2 RAILROAD FACILITIES (CONVENTIONAL)

23.2.1 Guideway Construction - Single Track

23.2.1.1 Aerial Structures

5.56×10^{10} Btu/mile (3.64×10^{13} joules/km)

23.2.1.2 At Grade (standard ties, ballast, etc.)

1.71×10^{10} Btu/mile (1.12×10^{13} joules/km)

23.2.1.3 At Grade (Concreted Track)

1.91×10^{10} Btu/mile (1.25×10^{13} joules/km)

23.2.1.4 Subway (Cut-and-Cover)

1.63×10^{11} Btu/mile (1.07×10^{14} joules/km)

23.2.1.5 Subway (Tunneling)

3.28×10^{11} Btu/mile (2.15×10^{14} joules/km)

23.2.2 Stations, Yards, Maintenance Facilities, etc. Not Available

23.3 RAIL MASS TRANSIT FACILITIES

23.3.1 Guideway Construction

See Values under Sect. 23.4.1

23.3.2 Stations, Yards, Maintenance Facilities, etc. See Appendix B

23.4 PERSONAL (LIGHT) RAPID TRANSIT FACILITIES

23.4.1 Guideway Construction

Energy required for guideway construction is estimated as being 34% to 68% of the values under section 23.2.1.

23.4.2 Stations, Yards, Maintenance Facilities, etc. Not Available

23.5 AIR TRANSPORTATION FACILITIES

23.5.1 Commercial Airport

Not Available

23.5.2 General Aviation Airport (Private, small aircraft).

Construction energy for 200 plane capacity:

6.66×10^{10} Btu (7.02×10^{13} joules)

23.6 MARINE TRANSPORTATION FACILITIES

Not Available

23.7 PIPELINE TRANSPORTATION FACILITIES

Not Available

24.0 LOAD FACTORS

24.1 CARGO-RELATED LOAD FACTORS

24.1.1	Road transport (trucks)		N.A.
24.1.2	Rail transport		
	24.1.2.1	All cars	57%
	24.1.2.2	Boxcars	67%
	24.1.2.3	Flatcars	69%
	24.1.2.4	Gondolas	54%
	24.1.2.5	Hoppers	50%
24.1.3	Air transport		
	24.1.3.1	Cargo-only aircraft	47%
	24.1.3.2	Passenger/cargo (lower hold)	41%
24.1.4	Marine transport		
	24.1.4.1	Ferryboats (vehicle transport)	40%
	24.1.4.2	Merchant vessels	N.A.
24.1.5	Pipeline transport		N.A.

24.2 PASSENGER-RELATED LOAD FACTORS

24.2.1 Passenger car

24.2.1.1	Intercity travel	37% - 43%
24.2.1.2	Urban travel	23% - 35%
24.2.1.3	Overall	37% - 48%

24.2.2 Bus

24.2.2.1	Intercity	41% - 43%
24.2.2.2	Urban	20% - 24%
24.2.2.3	School bus	38%

24.2.3 Rail (conventional and rapid rail transit)

24.2.3.1	Intercity	53%
24.2.3.2	Urban (commuter)	18% - 25%
24.2.3.3	Overall (conventional)	37% - 43%

24.2.4 Aircraft

24.2.4.1	Long trip	43% - 58%*
24.2.4.2	Short trip	25% - 46%
24.2.4.3	Overall	48% - 55%

*58% refers to International Trips

24.2.5 Marine

24.2.5.1	Ferryboats	26%
24.2.5.2	Passenger liners	N.A.

24.3 CIRCUITY

Ratio of actual route length to great circle distance between two points.

Great Circle Distance Miles	(km)	Circuity Ratio Car & Truck	Bus	Rail	R-T	Air	Marine
100	(161)	1.01-1.43	1.01-1.64	1.01-1.46	NA	1.74	NA
200	(322)	1.01-1.40	1.01-1.61	1.04-1.46	"	1.35	"
300	(483)	1.01-1.39	1.01-1.59	1.07-1.46	"	1.26	"
400	(644)	1.04-1.38	1.04-1.58	1.10-1.46	"	1.20	"
500	(805)	1.05-1.37	1.05-1.55	1.12-1.46	"	1.15	"
1000	(1609)	1.08-1.30	1.08-1.46	1.20-1.46	"	1.08	"
2000	(3219)	1.12-1.21	1.12-1.33	1.25-1.46	"	1.05	"

25.0 ENERGY CONSUMED VS. DOLLAR COST

25.1 CONSTANT-DOLLAR CONVERSION FACTORS

Year	Index	Year	Index
1965	74.32	1971	96.02
1966	76.36	1972	100.00
1967	79.02	1973	105.92
1968	82.57	1974	116.20
1969	86.72	1975	N.A.
1970	91.36	1976	N.A.

25.2 ENERGY/DOLLAR FOR ROADWAY CONSTRUCTION (1973-74 $)

		Btu/$	(joules/$)
25.2.1	Freeway construction		
25.2.1.1	New constr. - rural	5.76×10^4	(6.08×10^7)
25.2.1.2	New constr. - urban	4.62×10^4	(4.87×10^7)
25.2.1.3	Widen - rural	3.59×10^4	(3.79×10^7)
25.2.1.4	Widen - urban	2.05×10^4	(2.16×10^7)
25.2.2	Arterial roadway construction		
25.2.2.1	New constr. - rural	5.49×10^4	(5.79×10^7)
25.2.2.2	New constr. - urban	4.40×10^4	(4.64×10^7)
25.2.2.3	Widen - rural	3.86×10^4	(4.07×10^7)
25.2.2.4	Widen - urban	1.92×10^4	(2.03×10^7)
25.2.3	Structure construction		
25.2.3.1	Reinforced concrete box girder bridges	3.70×10^4	(3.90×10^7)
25.2.3.2	Concrete deck, steel girder bridges	4.00×10^4	(4.22×10^7)
25.2.4	Landscaping	1.03×10^4	(1.09×10^7)
25.2.5	Signals, illumination, misc.	9.70×10^3	(1.02×10^7)

25.3 ENERGY/DOLLAR FOR SELECTED PROJECTS (1967 $)

		Btu/$	(joules/$)
25.3.1	New construction, public utilities	8.97×10^{4}	(9.46×10^{7})
25.3.2	New construction, residence	6.21×10^{4}	(6.55×10^{7})
25.3.3	New construction, non-residence	7.57×10^{4}	(7.98×10^{7})
25.3.4	Maintenance constr., residential	5.60×10^{4}	(5.91×10^{7})
25.3.5	Maintenance constr., other	6.39×10^{4}	(6.74×10^{7})
25.3.6	Railroad construction	9.77×10^{4}	(1.03×10^{8})
25.3.7	Roadway (highway) new constr.	6.67×10^{4}	(7.03×10^{7})

25.4 ENERGY/DOLLAR FOR SELECTED MANUFACTURING (1967 $)

		Btu/$	(joules/$)
25.4.1	Concrete block	1.53×10^{5}	(1.61×10^{8})
25.4.2	Concrete products	1.17×10^{5}	(1.23×10^{8})
25.4.3	Construction machinery	7.49×10^{4}	(7.90×10^{7})
25.4.4	Conveyors	7.18×10^{4}	(7.57×10^{7})
25.4.5	Electrical equipment	7.24×10^{4}	(7.64×10^{7})
25.4.6	Elevators	6.52×10^{4}	(6.88×10^{7})
25.4.7	Heating equipment	7.85×10^{4}	(8.28×10^{7})

		Btu/$	(joules/$)
25.4.8	Hoists, cranes	7.40×10^4	(7.81×10^7)
25.4.9	Industrial controls	4.34×10^4	(4.53×10^7)
25.4.10	Locomotives	6.17×10^4	(6.51×10^7)
25.4.11	Pipe (metal)	8.16×10^4	(8.61×10^7)
25.4.12	Plastics	2.43×10^5	(2.56×10^8)
25.4.13	Power transmission equipment	6.60×10^4	(6.96×10^7)
25.4.14	Railroad and streetcars	1.24×10^5	(1.31×10^8)
25.4.15	Shipbuilding	7.22×10^4	(7.62×10^7)
25.4.16	Synthetic rubber	3.29×10^5	(3.47×10^8)
25.4.17	Transformers	8.27×10^4	(8.72×10^7)

25.5 ENERGY/DOLLAR FOR TRANSPORTATION (1967 $)

		Btu/$	(joules/$)
25.5.1	Passenger transport	N.A.	
25.5.2	Motor freight transport	5.81×10^4	(6.13×10^7)
25.5.3	Rail freight transport	N.A.	
25.5.4	Air transport	2.42×10^5	(2.55×10^8)

		Btu/$	(joules/$)
25.5.5	Marine transport	$2.81x10^5$	$(2.96x10^8)$
25.5.6	Pipeline transport	$1.17x10^5$	$(1.23x10^8)$

26.0 ENERGY PRODUCTION OF SELECTED NATURAL SYSTEMS

26.1 NET QUANTITY & ENERGY PRODUCTION

Ecosystem Type	Dry Quantity Production $lb/ft^2/yr$	$(kg/m^2/yr)$	Energy Production $Btu/ft^2/yr$	$(joules/m^2/yr)$
Tropical forest	.410	(2.000)	$3.13x10^3$	$(3.56x10^7)$
Temperate forest	.256	(1.250)	$1.96x10^3$	$(2.22x10^7)$
Boreal forest	.164	(.800)	$1.25x10^3$	$(1.42x10^7)$
Woodland and shrubland	.143	(.700)	$1.10x10^3$	$(1.24x10^7)$
Savanna	.184	(.900)	$1.41x10^3$	$(1.60x10^7)$
Temperate grassland	.123	(.600)	$9.39x10^2$	$(1.07x10^7)$
Tundra and alpine	.029	(.140)	$2.19x10^2$	$(2.49x10^6)$
Desert and semidesert	.008	(.040)	$6.26x10^1$	$(7.11x10^5)$
Cultivated land	.133	(.650)	$1.02x10^3$	$(1.16x10^7)$
Swamp and marsh	.410	(2.000)	$3.13x10^3$	$(3.56x10^7)$
Lake and stream	.051	(.250)	$4.14x10^2$	$(4.71x10^6)$
Total continental	.158	(.773)	$1.21x10^3$	$(1.37x10^7)$
Algal beds, reefs, estuaries	.369	(1.800)	$2.98x10^3$	$(3.39x10^7)$
Open ocean	.026	(.125)	$2.26x10^2$	$(2.56x10^6)$
Total marine	.031	(.152)	$2.74x10^2$	$(3.12x10^6)$
World total	.068	(.333)	$5.40x10^2$	$(6.13x10^6)$

26.2 GROSS QUANTITY PRODUCTION

Land systems:	2.7 x Net quantity production
Oceans:	1.5 x Net quantity production
World:	2.3 x Net quantity production

26.3 ENERGY CONTENT OF LIVING TISSUE

Type	Energy per Dry Weight Btu/lb	(joules/kg)
Land plants	7.64×10^3	(1.78×10^7)
Larger aquatic plants	8.09×10^3	(1.88×10^7)
Plankton	8.81×10^3	(2.05×10^7)
Animal tissue	8.99×10^3	(2.09×10^7)

27.0 ENERGY CONSUMED BY DWELLINGS

27.1 ELECTRICITY CONSUMPTION

Type of Dwelling	Annual Energy Consumed Per Area of Floor Space: Energy Delivered	Energy Consumed at Powerplant	
	KWH/ft^2	Btu/ft^2	(joules/m^2)
Residential			
All-electric, single-family residence	10.3	1.05×10^5	(1.20×10^9)
Single-family residence w/electric kitchen	5.4	5.53×10^4	(6.28×10^8)
Single-family residence w/gas appliances	4.8	4.91×10^4	(5.58×10^8)
All-electric apartment	7.0	7.17×10^4	(8.14×10^8)
Apartment w/electric kitchen	4.4	4.51×10^4	(5.12×10^8)
Apartment w/gas appliances	4.0	4.10×10^4	(4.65×10^8)
Non-Residential - General Categories			
Office and professional buildings	34.2	3.50×10^5	(3.98×10^9)
Warehouses	14.4	1.47×10^5	(1.67×10^9)
Retail outlets	47.8	4.89×10^5	(5.56×10^9)
Restaurants and cocktail lounges	76.9	7.87×10^5	(8.94×10^9)

27.1 (Continued)

Type of dwelling	KWH/ft^2	Btu/ft^2	($joules/m^2$)
Hotel and motels	26.0	$2.66x10^5$	($3.02x10^9$)
Service establishments	95.2	$9.75x10^5$	($1.11x10^{10}$)
Elementary schools	23.1	$2.37x10^5$	($2.69x10^9$)
High schools and colleges	38.8	$3.97x10^5$	($4.51x10^9$)
Hospital and convalescent facilities	100.7	$1.03x10^6$	($1.17x10^{10}$)
Churches	6.0	$6.14x10^4$	($6.98x10^8$)
Theaters and recreation	32.5	$3.33x10^5$	($3.78x10^9$)
Manufacturing/industrial	50.1	$5.13x10^5$	($5.83x10^9$)

27.2 NATURAL GAS CONSUMPTION

Type of Dwelling	Annual Energy Consumed per Dwelling Unit	
	Btu/unit	(joules/unit)
Residential		
Single family residences	$1.10x10^{8}$	$(1.16x10^{11})$
Multi-family, 4 or fewer units	$6.40x10^{7}$	$(6.75x10^{10})$
Multi-family, 5 or more units	$5.80x10^{7}$	$(6.12x10^{10})$
	Annual Energy Consumed per Area of Floor Space	
	Btu/ft^2	$(joules/m^2)$
Non-Residential		
Office	$4.20x10^{4}$	$(4.77x10^{8})$
Shopping center	$2.40x10^{5}$	$(2.73x10^{9})$
Hotel	$6.00x10^{5}$	$(6.81x10^{9})$
Industrial	$3.96x10^{4}$	$(4.50x10^{8})$

28.0 LAND USE ENERGY LEVELS

Land Use	Annual Consumption Btu/Acre	Annual Consumption (joules/km^2)
28.1 Agricultural	N.A.	
28.2 Industrial		
28.2.1 Chemicals	$1.37x10^{10}$	$(3.57x10^{15})$
28.2.2 Commercial	$1.20x10^{9}$	$(3.13x10^{14})$
28.2.3 Light industry	$3.40x10^{9}$	$(8.86x10^{14})$
28.2.4 Medium industry	$8.70x10^{9}$	$(2.27x10^{15})$
28.2.5 Mining, processing	$9.4x10^{9}$	$(2.45x10^{15})$
28.2.6 Paper	$1.37x10^{10}$	$(3.57x10^{15})$
28.3 Residential		
28.3.1 High density	$5.00x10^{8}$	$(1.30x10^{14})$
28.3.2 Planned mixed housing	$6.0x10^{8}$	$(1.56x10^{14})$
28.3.3 Urban sprawl	$8.0x10^{8}$	$(2.09x10^{14})$

APPENDIX B

COMMENTARY

ON

ENERGY FACTOR HANDBOOK

KEYED SECTIONS

The remarks and data in this Commentary are keyed by matching section numbers to the subjects in Appendix A, the Energy Factor Handbook. They contain amplifying remarks and explanations of the methods and sources used to obtain the data.

OMITTED SECTIONS

Sections for which no information or data were available are omitted in this Commentary. Main sections include "General Comments," which may contain all pertinent or available information on some subsections. These subsections are also omitted in this Commentary.

1.0 PROPERTIES OF SELECTED FUELS

General Comments:

Data presented are estimates of the potential thermal energy available in each fuel, if it could be consumed with 100% efficiency. Reported values of fuel energy vary by more than 15% between references.

Energy consumed in fuel production (mining, processing, transport, etc.) has not been adequately identified. Estimates for petroleum-derived fuels suggest that the energy consumed in their production is equivalent to 10%-20% of the fuels' thermal energy, depending on the distillate.

Some fuels require special handling, containers, maintaining nonambient storage temperatures, etc. Energy consumed to provide such hardware and special treatment has not been identified, but can be of substantial magnitude.

1.19 WOOD

Potential thermal energy of wood as a fuel varies with species and moisture content. Values vary by more than 20% between references.

Table B1. Properties of Selected Wood, Air Dry

Species	Density pcf	(kg/m^3)	Thermal Energy Btu/lb	(joules/kg)
Birch	41	(657)	7500	($1.74x10^7$)
Cherry	35	(561)	7900	($1.84x10^7$)
Fir, douglas	32	(513)	N.A.	
Hickory	51	(817)	7600	($1.77x10^7$)
Oak	46	(737)	7800	($1.81x10^7$)
Pine	31	(497)	8100	($1.88x10^7$)
Poplar	28	(449)	7700	($1.79x10^7$)

NOTE: In the United States, firewood is often sold by the "cord," a vague unit described generally as: tightly packed logs and pieces forming a "block" measuring 4 ft x 4 ft x 8 ft. Reported weights of one cord of particular species are as follows: Hickory, 4,500 lb; oak, 3,850 lb; pine, 2,000 lb, poplar, 2,350 lb. These estimates vary widely.

1.19.1 Hardwoods are defined as broad-leafed species (without reference to the actual strength of the wood itself).

1.19.2 Softwoods are defined as species having needle-like leaves.

1.19.3 Resin Values are based on samples from pine trees.

2.0 PROPERTIES OF SELECTED MATERIALS

The energy "worth" of these manufactured materials includes the energy consumed in mining, transporting, refining, molding or shaping, special treatments, and final transportation to the point of use. The claimed reliability of the published estimates varies from $\pm5\%$ to over $\pm50\%$ of the given energy value. The base values presented under section 2.0 are "best estimate" values for materials at the point of use, except in special cases where these materials must be transported over very long distances after manufacture. For such special cases, the energy consumed in transportation of the manufactured products should be added to the base values.

2.1 ALUMINUM

See Comment 2.0

2.2 AGGREGATES

2.2.1 Crushed gravels are defined here as natural sands and gravels that must be run through a crusher (for size reduction, gradation, obtaining rough surfaces and/or for meeting other requirements).

2.2.2 Crushed stone is defined here as an aggregate that must be quarried by drilling and shooting, then run through a crusher.

2.2.3 Uncrushed sands and gravels are defined here as aggregates that may be removed with little difficulty and require minimum processing.

2.3 ASPHALTS

Asphalts as well as wood are hydrocarbons, and thus possess potential energy as fuels. When used as construction materials, this energy becomes unavailable, since it cannot be extracted (economically) later. Thus, values for asphalts and wood include their thermal energy.

Energy required for the production of asphalts has been estimated at 2000 Btu/gal ($5.57x10^5$ joules/litre).

2.4 BRASS

See Comment 2.0

2.5 CEMENT-PORTLAND

The energy value given has appeared in publications of both the Portland Cement Association and the Asphalt Institute. As an aid, the following table is presented:

Table B2. Frequently Used Units of Cement:

Ton	2000 lbs (907 kg)	=	$7.57x10^6$ Btu ($7.99x10^9$ joules)
Barrel	376 lbs (171 kg)	=	$1.42x10^6$ Btu ($1.50x10^9$ joules)
Sack	94 lbs (43 kg)	=	$3.56x10^5$ Btu ($3.76x10^8$ joules)

2.6 COPPER — See Comment 2.0

2.7 IRON-CAST — See Comment 2.0

2.8 LIME

The energy value presented is provided by the National Lime Association.

2.9 MAGNESIUM-ALLOYS — See Comment 2.0

2.10 PLASTICS

The energy consumption associated with production and distribution of plastics has not been identified. Plastics have potential energy as fuels due to their hydrocarbon content.

2.10.1 Thermosetting plastics have densities between 68-128 pcf (1058-2051 kg/m^3) and include epoxies (adhesives) and polyesters (fiberglass, auto body parts).

2.10.2 Thermoplastics have densities between 59-125 pcf (945-2003 kg/m^3) and include ABS (auto dashboards); acrylics (aircraft windows, signs); polyamides (pipe, fuel containers); polyethylenes (bottles, construction sheets); and vinyls (wire insulation, tiles).

2.11 RUBBER

Rubber possesses potential energy as fuel. Data from specially designed steam-generating plants, using old tires as fuel, indicate a production of 8.05×10^3 Btu per lb of rubber consumed, at a reported overall plant efficiency of 66.7%. This indicates that the potential thermal energy of rubber is 1.2×10^4 Btu/lb (2.8×10^7 joules/kg). A typical standard passenger-car tire (size G78x15, 4 ply rating, Load Range B) weighs 29.0 lbs (13.15 kg) new, and loses 6.0 lbs (2.72 kg) of tread over its estimated life of 25,000 miles (40,234 km). If the worn tire is retreaded, an additional 2.8 lbs (1.27 kg) is removed by "buffing" and a new wide tread cap, weighing 8.5 lbs (3.86 kg) is added. (Caps vary in weight from 7.0 to 8.5 lbs for this size tire.) Estimated life of the retread is 15,000 miles (24140 km).

2.11.1 Value presented is based on the thermal potential of rubber. Energy consumed in product manufacturing has not been identified.

2.11.2 Value is based on the estimated 5 gallons of crude petroleum required for the materials and processes required to manufacture one new tire.

2.11.3 Value is based on the thermal energy of replacement rubber in the cap, plus a reported 0.40 gallons (1.5 litres) of No. 6 fuel oil per tire for curing heat, plus 25% additional indirect energy associated with retreading operations.

2.12 STEEL-ALLOY

2.12.1 Prestressing tendons primarily consist of stress-relieved 7-wire strands or solid bars.

Table B3. Properties of Prestressing Steel

Type	Diameter inches (mm)	Weight lb/ft (kg/m)	Energy Btu/lin-ft	(joules/lin-m)
Strand	1/4 (6.4)	.122 (.182)	8	(2.77×10^4)
"	3/8 (9.5)	.274 (.408)	18	(6.22×10^4)
"	1/2 (12.7)	.494 (.735)	32	(1.11×10^5)
Bar	3/4 (19.1)	1.50 (2.23)	99	(3.42×10^5)
"	1 (25.4)	2.67 (3.97)	175	(6.05×10^5)
"	1 1/4 (31.8)	4.17 (6.20)	274	(9.47×10^5)

2.12.2 Energy consumed in production of alloy steels has been estimated as being 5% higher than comparable carbon steel products.

2.13	STEEL-CARBON	See Comment 2.0
2.14	STEEL-STAINLESS	See Comment 2.0
2.15	WOOD	See Comment 2.0
		" " 2.3
2.16	ZINC	See Comment 2.0

3.0 PROPERTIES OF SELECTED ROADWAY CONSTRUCTION

General Comments:

Data presented under section 3.0 have been derived from a variety of sources, and represent the estimated energy consumed in the production, transportation, and final operations required to perform the desired construction. In-place energy values include the estimated fuel consumed by appropriate heavy equipment to perform the required operations (see also commentary Section 4.0).

4.0 ENERGY CONSUMED BY SELECTED CONSTRUCTION OPERATIONS

General Comments:

Information presented under section 4 is based on several sources and on the authors' estimates of the propulsion fuel required to operate various major equipment (trucks, pavers, graders, etc.) required for construction.

5.0 PROPERTIES OF ROADWAY STRUCTURES

General Comments:

Data presented under section 5.0 are based on estimates of energy consumed by operations and materials required to construct completed structures-in-place. Energy values used in computions have been derived from sections 2.0 and 3.0.

5.1 BRIDGES

Data under section 5.1 have been derived from California Department of Transportation statistics of materials quantities required for typical highway bridge designs.

5.2 CULVERTS

Data under section 5.2 have been derived from California Department of Transportation statistics of materials quantities required for typical highway designs. Energy consumed in unusual or excessive excavation and/or backfill is not included in the values.

5.3 DRAINAGE STRUCTURES - General

Data under section 5.3 are based on a study of several California highway construction projects and include the following (typical) quantities:

Steel Pipe: 8.64×10^{8} Btu/ln-mile (56.6×10^{10} joules/ln-km)

Concrete Pipe: 1.09×10^{8} Btu/ln-mile (7.1×10^{10} joules/ln-km)

Reinf. Concrete Box: One per mile, size 6ftx4ft (1.83mx1.22m)

5.4 FENCING

Value presented is based on California Department of Transportation standard specification chain link fence for right-of-way, height 6.5 ft (1.98 m) with posts spaced at 10 ft (3.05 m).

5.5 GUARDRAIL

Data are based on materials quantities from the California Department of Transportation standard specifications. Energy consumed for installation has not been identified.

5.5.4 Value presented is based on a single "W" shaped steel beam (1.91×10^5 Btu/ft, [6.60×10^8 joules/m]) on wood posts spaced at 6 ft 3 in (1.91 m).

5.5.5 Value presented is based on steel beam (see 5.5.4) on steel posts spaced at 6 ft 3 in (1.91 m).

5.6 ILLUMINATION

Energy consumed in manufacturing, placing, and maintenance of illumination and supports has not been identified. Standard mercury vapor lamps commonly used for street and highway illumination are rated at 400 watts, and together with ballast consume approximately 475 watts of electricity. High pressure sodium lamps rated 250 watts (313 watts total) are 30% brighter and have similar service lives.

5.7 PAVEMENTS

Data under section 5.7 are estimates of the energy consumed by operations and materials required to construct roadway pavements in-place. Typical structural cross-sections correspond to "Traffic Index" values of 13.5 (very high truck volume) and 10.0 (moderate truck volume).

5.8 RETAINING WALLS

Data under section 5.8 have been derived from materials quantities included in California Department of Transportation standard specifications for retaining walls.

5.9 SIGNALS

The energy consumption associated with production and distribution of signals has not been identified. A normal 3-color signal using standard 8 inch (0.20 m) diameter lenses uses 67 watt bulbs (California Department of Transportation uses special bulbs rated 90 watts). One or more interconnected signals require a single controller, whose estimated rating is 2 kilowatts. Some controllers require air conditioning equipment which consume additional electric power.

5.10 SIGNS

5.10.3 Data are based on a study of 8-lane highway sections, and include major sign-carrying structures spanning the road. Illumination structures are not included.

5.11 UNDERGROUND CONSTRUCTION

The energy consumption associated with major underground construction has not been identified. (See section 23.2 for estimated construction energy of railroad tunnels).

6.0 ENERGY CONSUMED BY ROADWAY MAINTENANCE

6.1 GENERAL HIGHWAY MAINTENANCE

Data presented under section 6.1 are based on materials quantities used to maintain and repair the highway system in the San Francisco Bay area in California. This section includes 3965 ln-miles (6381 ln-km) of flexible and 2022 ln-miles (3254 ln-km) of rigid pavement. Annual use of materials alone constitutes $86x10^6$ Btu per ln-mile ($56x10^9$ joules/ln-km) of flexible pavement and $20.5x10^6$ Btu per ln-mile ($13.4x10^9$ joules/ln-km) of rigid pavement. The remainder of the energy consumption is an estimate of the requirements for maintenance-related buildings, grounds, equipment and their fuels, and other indirect sources.

7.0 DIRECT FUEL CONSUMPTION OF PASSENGER CARS

General Comments:

Data presented under this section have been primarily extracted from NCHRP Report No. 111. Direct fuel consumption refers to the fuel (gasoline) required for propulsion of passenger cars. Values refer to the actual quantity of fuel pumped into the cars' tanks and do not account for fuel consumed indirectly for other purposes (such as maintenance and replacement). The research methods on which these values are based include the effect of standard and automatic transmissions and standard/power steering, brakes, etc. However, they do not account for additional fuel consumption due to major optional accessories (such as air conditioning).

Individual vehicles vary widely in size, weight, powertrain, and fuel type and consumption. The mix of the various types and models on-the-road has been identified through sales and vehicle registration figures. From this information, a "composite", or average car has been postulated whose performance matches that of the entire "fleet" on-the-road. This composite car changes slightly every year because older cars are driven less or are removed from service, while new ones with differing fuel economy begin using the road. This change is accounted for in this study.

The values presented reflect, as far as possible, the results of the U.S. Environmental Protection Agency (EPA) tests for exhaust emissions. While these tests are run on chassis dynamometers, as opposed to actual roadtesting, they represent a faithful effort at simulation of road driving conditions, the test methods are repeatable under controlled conditions, and compliance to the EPA standards is required by law.

7.1 The tables under section 7.1 are designed to permit the user to obtain base values of fuel consumption from Figure 5 and modify these values according to conditions by multiplying them by a series of "correction factors" reflecting each condition.

7.1.1 In order to project fuel consumption of the "composite" car to future years, correction is made for the changing fuel economy of this car depending on the year of study. This correction is based on the following parameters:

1. Sales-weighted mix of car size, weight, and fuel consumption for any model year. The consumption figures are either those published by the Environmental Protection Agency (EPA) or decreed by Federal law and are weighted at the ratio of: 45% EPA Highway Cycle consumption and 55% EPA Urban Cycle consumption.

Note: To verify the validity of using EPA cycle fuel consumption figures (variable speed) to correct NCHRP 111 fuel consumption figures (steady speed) an "NCHRP 111

Composite Car" was mathematically run through the EPA cycles, and the resulting 45% Highway-55% Urban consumption matched the EPA figures for the model years to the authors' satisfaction (within 0.5 MPG).

2. Ratio of ages of cars on-the-road (i.e. how many new cars, 1-year old, 2, 3, year old, etc., cars were on the road) for the particular year of study.

3. Respective fraction of the actual miles driven during the study year by cars depending on their age, as presented in Table 4.

Table B4. Fraction of Annual Car Travel According to Age

Model Year	% of Total Miles (km) Travelled	Model Year	% of Total Miles (km) Travelled
"Current"	11.2	7 yr. old	6.3
"Last Years"	14.3	8 " "	4.7
2 yr. old	13.0	9 " "	3.2
3 " "	12.1	10 " "	1.9
4 " "	10.8	11 " "	1.3
5 " "	9.4	Over 11 yr. old	3.9
6 " "	7.9		

7.4 FUEL CONSUMED DUE TO COLD STARTS

Cold engines consume substantially more fuel because of inefficient combustion and excessive friction. As the engines warm up, efficiency improves. "Cold and warm" efficiencies are relative terms and depend on the ambient temperature. Generally, an engine is considered fully warm after 20 to 40 miles of travel. At that time, the combustion chambers and all parts and lubricants are assumed to have reached operating temperature. An engine is considered fully cold after remaining inoperative at ambient temperatures for 8 or more hours.

Colder ambient temperatures reduce efficiency, lengthen the time required for warmup, and thus cause increased fuel consumption.

Figure A6 is based on study using 1974-75 model cars of all sizes, in urban commute traffic on level roads. Cars were parked outdoors for 8 hours or longer, and driven off after 30 seconds idling time.

7.5 FUEL CONSUMED IN NORMAL USE

The cars sold each year, when taken collectively, consume fuel at some "average" rate. this rate changes each year, depending on the sales-mix of car type and characteristics (size, weight, engine size, specific fuel consumption for each, etc.).

Data prior to 1976 have been obtained from sales statistics and EPA fuel consumption tests. From 1977 through 1985, the "average" consumption rate (EPA) is specified by public law #94-163 (12-22-75). The authors have assumed that: a) Federal standards will be met. b) The required 27.5 MPG (11.7 km/l) average will remain unchanged between 1985 and 2000. c) The fuel consumption of cars will remain constant as they get older. (This last assumption is expected to hold for the first 5 years ±). Consumption should increase as engines wear and become less efficient, but older cars are driven fewer miles, and thus, the increased consumption is not expected to significantly affect the total consumption when all cars on-the-road are considered.

Also see comment 7.1.1

8.0 DIRECT FUEL CONSUMPTION OF TRUCKS

General Comments

Trucks are defined, for the purpose of this report, as commercial (as opposed to recreational) vehicles used to transport goods, and having two or more axles and 6 or more tires.

A California study of registrations (1972) indicated that 99.8% of two-axle, 4 tire vehicles have gross vehicle weight (GVW) less than 8000 lb (3629 kg). These "light duty" vehicles include passenger cars, pickup trucks, panel trucks, and most vans. The same study indicated that 95.3% of two-or-more-axle, 6 or more tire vehicles have GVW more than 10,000 lbs (4536 kg). It is this latter group which is defined as trucks.

Fuels used in truck engines are almost exclusively gasoline or diesel. A study of California registrations (1972) indicated that trucks using other fuels (primarily Butane, Propane, or Electricity) comprised only 0.4% of the total. The ratio of gasoline to diesel trucks depends on the potential use and load of the vehicle. As an aid, the following information is offered:

Table B5. Proportion of Gasoline and Diesel Trucks

	Gross Vehicle Weight, thousand lbs (thousand kg)		
Fuel	Up to 15 (Up to 6.8)	40-45 (18.1-20.4)	58 (26.3)
Gasoline	95%	70%	50%
Diesel	5%	30%	50%

A study in Los Angeles County, California, indicated that 85% of trucks used gasoline, and 15% used diesel; and of the total truck-miles traveled, 78% were by gasoline and 22% by diesel trucks.

Direct fuel consumption refers to the fuel (gasoline or diesel) required for propulsion of fully loaded trucks. The values under section 8 represent the actual quantity of fuel pumped into the trucks' tanks and do not account for fuel consumed indirectly for other purposes (such as maintenance and replacement). The research methods used give consumption values for the highest (i.e. most economical) gear for each driving condition. Whether truck drivers operate their vehicles (i.e. choose gears) in the same manner has not been established, but it is assumed that this is the case.

Fuel consumption rates for trucks are assumed to remain constant for the remainder of the 20th century. This assumption is based on the following observations: a) Fuel type and fuel economy are not regulated at present nor in the foreseeable future. b) Gross vehicle weights and load capacities are regulated, and no significant changes are expected. Even if changes occur, they will be accompanied by proportionate changes in fuel consumption, and thus the fuel consumed vs. service rendered would remain constant. c) The research and development being performed on truck power plants is not expected to produce significant results, and new, more efficient trucks (which may show as much as 18% improvement in full economy) will represent a small fraction of the total miles driven. d) The effect of retrofit devices, such as radial tires and aerodynamic "deflectors", when subjected to systematic studies, show less than 5% improvement in fuel economy, and thus, even if installed in a large portion of trucks, would not cause significant changes in the overall consumption rates of the truck population.

8.1 TWO AXLE, SIX TIRE TRUCKS

Data presented under section 8.1 have been primarily extracted from NCHRP report #111. The composite truck represents a combination of 8000 lbs (3629 kg) and 16,000 lbs (7257 kg) Gross Vehicle Weight trucks, weighted on a 50% - 50% ratio.

Based on a U.S. census, (1972) 95% of two axle, 6 tire trucks use gasoline fuel; 5% use diesel fuel.

The tables under section 8.1 are designed to permit the user to obtain a base value of fuel consumption from Fig. 8 and modify this value according to conditions by multiplying it by a series of "correction factors" reflecting each condition.

8.2 TRACTOR SEMI-TRAILER TRUCKS

Data presented under section 8.2 have been primarily extrac- from NCHRP report #111. The composite truck represents a combination of 40,000 lbs (18144 kg) and 50,000 lbs (22680 kg) gross vehicle weight trucks, weighted on a 50%-50% ratio. Based on a U.S. census, (1972), it is estimated that this size "composite truck" would be 60% gasoline-fueled and 40% diesel-fueled.

8.3 TRUCK FUEL CONSUMPTION BY GVW

The trucking industry classifies trucks into 8 separate classes by gross vehicle weight. Classes 3 through 8 (GVW 9000 lbs [4082 kg] through 33,000 lbs [14,969 kg]) have been statistically studied and values of fuel consumption by GVW and trip type have been established. The study is based on 1973 model vehicles, and on annual fuel consumed vs. miles driven for all purposes.

Trip types are defined as follows:

Local: Urban Stop-and-Go driving - local deliveries, etc.

Short Trip: Daily round trips less than 200 miles (300 km) between cities, with a mixture of urban, suburban, and highway driving.

Cross Country: One-way long distance high speed, primarily highway driving.

8.4 FUEL CONSUMED IN NORMAL USE BY COMPOSITE TRUCK FLEET

Values presented reflect the overall fuel consumption rates of the U.S. truck fleet, weighted by the mileage and consumption rates for each truck type and GVW.

9.0 DIRECT FUEL CONSUMPTION OF BUSES

General Comments:

Buses are used for public mass transportation, and are generally designed into classes to serve specific purposes, such as school bus, city transit, long distance, etc. Power is generally provided by diesel or gasoline engines, electric overhead wires, and, to a limited extent, by liquid propane. Seating capacities and vehicle weights may vary somewhat from the standard values presented.

9.1 INTERCITY SERVICE

Buses providing city-to-city transportation are primarily diesel powered, have 46 seats, and weigh 26,000 lbs (11,800 kg).

9.1.1 Fuel Consumption vs speed and grade are based on tests using several buses and resulting computer model of a vehicle having a 568 cubic inch diesel engine and weighing 36,000 lbs (16329 kg) including passengers.

9.1.2 The fuel consumption value presented is in agreement with several sources and represents the overall rate expected under actual service conditions.

9.2 METROPOLITAN TRANSIT SERVICE

Metro Transit Buses provide transportation service within the same urban area, including line-haul transit between major activity centers, collector-distributor service, and central business districts. In general, they may be defined for the purpose of this report as performing all bus-related transport modes except intercity service.

9.2.1 FUEL CONSUMED AT CONSTANT SPEEDS

Data presented under this section have been extracted from NCHRP Report #111 and represent test results of a 1960 model bus, gasoline powered, having 31 seats and weighing 12,500 lbs (5700 kg). Values for diesel-fueled equivalents have been estimated in the same report.

This vehicle does not correspond to current production buses (see comment 9.2.2) but is the best information available on bus fuel consumption vs. constant speeds.

9.2.2 FUEL CONSUMED IN NORMAL USE

9.2.2.1 The value presented is based on overall bus service statistics of the New York City Transit authority, and represents a 12-year average from 1961 to 1973. The annual consumption rate is relatively constant ($\pm$ 4%) over all these years, and is a good indicator of overall metropolitan transit system fuel consumption. It includes non-revenue miles.

9.2.2.2 School buses are primarily gasoline-powered and are manufactured in various sizes, from small vans to larger vehicles with seating capacities of 60 children and weighing 11,000 lbs (5000 kg). The fuel consumption value presented is based on 1973 statistics and represents fuel consumed in normal use. The average seating capacity associated with the consumption rate has not been identified.

9.2.2.3
9.2.2.4
9.2.2.5 Standard Minibuses are manufactured in two sizes: 13 seats and 33 seats. The 13-seaters are gasoline or diesel powered and weigh 7000 lbs (3200 kg). The 33-seaters are gasoline or diesel powered and weigh 11,300 lbs (5100 kg).

9.2.2.6 Standard Transit Buses are primarily diesel powered, and are manufactured in two lengths 35 ft (10.7 m) and 40 ft (12.2m) with capacities of 45 or 53 seats, respectively, plus 22 standees under "crush" conditions. Weight is approximately 20,000 lbs (9100 kg).

9.2.2.7 Standard Trolley Buses are powered by electricity from overhead wires to a DC traction motor, have 48 seats plus 20± standees and weigh 20,000 lbs (9100 kg).

Electricity consumption values are based on overall service statistics of the Chicago Transit Authority from 1970 to 1972 and data from the same source from 1965 to 1972 show little change in consumption (± 4%) over these years.

9.2.2.9 Values of propane consumption are based on statistics of the Chicago Transit Authority from 1965 to 1972. This propane-powered fleet totaled 1,701 buses whose average rated capacity was 50 seats and 54 standees. (Propane fleet was removed from service in 1972 due to CTA's inability to obtain firm committments from propane suppliers.)

10.0 DIRECT FUEL CONSUMPTION OF TRAINS-GENERAL

General Comments:

Data presented are based on conventional diesel-electric locomotives in current service. Where applicable, energy consumption of electric-powered locomotives has been converted to equivalent diesel fuel consumption.

10.3 HORSEPOWER REQUIREMENTS FOR ASCENDING GRADES

Gross Elevation change is defined in Fig. 12. Some power reserve is usually required in normal operations, and this is reflected in the case where a zero net elevation change requires 21% more horsepower than a theoretical level run.

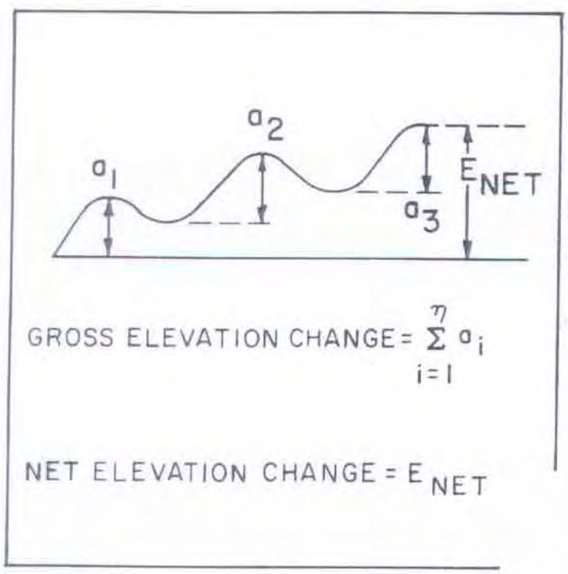


Fig. B1 Definition of gross and net elevation change-trains.

10.4 FUEL CONSUMPTION PER HORSEPOWER-TO-WEIGHT RATIO

Data presented are based on computer simulation of an average train, pulling 5400 trailing gross tons (4899 Metric Tons) and 94 cars over mountainous terrain for 700 miles (1127 km).

11.0 DIRECT FUEL CONSUMPTION OF PASSENGER TRAINS

Data presented have been collected from several sources. Seating capacity is being used as the common denominator for the variety of train configurations in operation.

12.0 DIRECT FUEL CONSUMPTION OF FREIGHT TRAINS

12.1 AVERAGE DISTRIBUTION OF GROSS TRAIN WEIGHT

Values presented are based on 1974 statistics of ten major U.S. railroads.

12.3 FUEL CONSUMED IN NORMAL USE - DIESEL

Values presented are based on 1974 statistics of ten major U.S. railroads.

13.0 DIRECT FUEL CONSUMPTION OF RAIL MASS TRANSIT

General Comments:

Rail mass transit provides transportation for commuters within large metropolitan areas. Average speeds vary from 25 mph (40 km/hr) to 45 mph (72 km/hr). Almost all systems use electric propulsion.

13.1 FUEL CONSUMED IN NORMAL USE

Values presented have been selected from a variety of sources, some of which deviate considerably from the ones selected by xhe authors. Energy consumption figures for the Chicago system are based on 1965-1972 statistics of the Chicago Transit Authority. Energy consumption figures for the New York system are based on 1961-1973 statistics of the New York City Transit Authority. In both systems, the annual energy consumption rates do not vary significantly from year to year ($\pm$ 2.5%).

14.0 PERSONAL RAPID TRANSIT (LIGHT MASS TRANSIT) FUEL CONSUMPTION

General Comments:

Each personal (light) Mass Transit system in operation is a unique, innovative system for transporting people in relatively small, light vehicles for short distances. Each is usually specifically designed for the service performed, and most are electric powered. Information in this section is primarily derived from a report published in 1973.

Numerous PRT systems are in the conceptual, design, or prototype state of development. They are not discussed in this report.

14.1 FUEL CONSUMED IN NORMAL USE

Information on fuel or electric consumption was not available in sufficient detail.

As an aid, the following data of system characteristics are offered:

"N" Railbus: Rubber-tired on concrete track, 2 DC traction motors 50 HP each; Route length 5 miles (8 km); Open-air sight-seeing at the San Diego Wild Animal Park.

Airtrans: Rubber-tired on concrete track, DC traction motor 75 HP; Passenger transport at Dallas-Fort Worth Airport.

Minirail: Rubber-tired on twin steel I-beams, DC Motor. Multi-car arrangement. Open-air. Operational at Montreal (Expo '67), Lausanne, Munich.

"K"-Monorail: Rubber-tired on concrete track, DC traction motor 25 HP pulls 5 cars (60 seats) Route length 0.5-3.0 miles (.8-4.8 km) Sightseeing, Dutch Wonderland, Lancaster, Pennsylvania.

Skybus: Rubber-tired on concrete track, DC traction Motor 100 HP. Tampa and Seattle-Tacoma Airports.

Jetrail: Rubber-tired, suspended from monorail beam. 2 AC motors 5 HP each. Route length 1.4 mile (2.3 km). Braniff Terminal, Dallas-Fort Worth Airport.

People Mover: Passive cars roll over powered stationary rubber tires on concrete and steel track. Electric motors 10 HP each spaced one per car. 4-car arrangement. Route length .75 mile (1.2 km). Open-air sightseeing and attraction at Disneyland.

ACT: Rubber tires on concrete track. 2 DC traction motors 60 HP each. Route length 5 miles (8 km). Proposed for Fairlane development, Dearborn, Michigan.

StaRRcar: Rubber-tired on concrete or steel track. AC induction motor 100 HP. Route Length 8 miles (13 km).

Speedwalk: Moving sidewalk of steel-reinforced rubber belt. Width 3 ft-6 inches (1.07 m). Electric Motor 49 HP. Route length 265 ft-1000 ft (81-305 m). Los Angeles Airport.

15.0 DIRECT FUEL CONSUMPTION OF PASSENGER AIRCRAFT

General Comments:

The most common commercial aircraft in current U.S. service have been selected and classified by type. Primary examples and available data for each type are given in the table below.

Table B6. Examples of Aircraft Type and Characteristics

JUMBO JET

Boeing 747 - 344,300 lbs (156,172 kg), 305-460 passengers

Lockheed L-1011 - 237,500 lbs (107,728 kg), 268 passengers

McDonald-Douglas DC-10 - 299,810 lbs (135,992 kg)
255-270 passengers

LONG RANGE JET

Boeing 707 - 141,400 lbs (64,138 kg), 155 passengers

McDonald-Douglas DC-8 - 150,600 lbs (68,311 kg)
152-206 passengers

MEDIUM RANGE JET

Boeing 727 - 103,720 lbs (47,047 kg) 103-158 passengers

Boeing 737 - 60,430 lbs (27,411 kg) 95-109 passengers

McDonald-Douglas DC-9 - 59,115 lbs (26,814 kg)
80-114 passengers

AIR CARRIER TURBOPROP

Convair 580

Electra L-188

Fairchild-Hiller FH 227

S.T.O.L. (Short take off and landing)

DeHavilland Heron

DeHavilland Twin Otter

GENERAL AVIATION TURBOPROP

Boeing Super King Air 200

Piper Cheyenne

GENERAL AVIATION PISTON

Cessna Cardinal

Cessna 120 Skywagon

Cessna Skymaster

Piper Warrior

15.1 FUEL CONSUMED AT NORMAL OPERATING MODES

Activities included in each mode are as follows:

Mode	Engine Operating Times Included in Mode
Taxi	Transit times between ramp and apron, apron and runway and time required for turning and alignment between taxiway and runway.
Idle	Push back from gate; waiting for signal to begin taxiing; waiting at taxiway intersections; runway queing; gate queing.
Landing	Touchdown to beginning of taxi on taxiway.

Takeoff	After alignment with runway to liftoff.
Approach	3000 ft (914 m) altitude to touchdown.
Climbout	Liftoff to 3000 ft (914 m) altitude.

Time spent in each mode is that used by EPA test methods, and represents average time consumed in normal operations.

15.2 FUEL CONSUMED ASSUMING BEST CRUISING SPEED

Best cruising speed is defined as the fastest sustained speed of the aircraft, on long flights. Short trips, under 500 miles (800 km), are usually flown at lower, less fuel-efficient speeds and altitudes. Airline policies and FAA regulations determine actual speeds and altitudes.

15.3 FUEL CONSUMED IN NORMAL OPERATIONS

Fig. 12 is based on 1972 data and reflects actual use of available in-service aircraft. Aircraft types tend to be more fuel efficient in some operations than others, but airline schedules and availability often require that aircraft are not matched to routes in the most fuel efficient way.

Airline statistics usually give credit for great circle miles, regardless of the actual distance of the flight path. (See section 24.0 for discussion of circuity.)

16.0 DIRECT FUEL CONSUMPTION OF FREIGHT AIRCRAFT

General Comments:

Air cargo is carried in the lower hold of passenger/cargo aircraft, in cargo-only aircraft, and in convertible aircraft that may be used for passenger/cargo or cargo-only service. Typical cargo densities vary from 5 to 14 pcf (80 to 224 kg/m^3), the average being 10.7 pcf (171 kg/m^3).

Cargo-only aircraft consumed 5% of the total fuel used by U.S. air carriers (1971 data).

Data from four differing sources varied significantly. Reported values ranged from .07 to .59 gallons of fuel per ton-mile (.18 to 1.53 litres per metric ton-km) depending on the source of information. Further research is required to establish reliable data.

17.0 DIRECT FUEL CONSUMPTION OF FERRY-BOATS

Data presented under section 17.0 have been obtained from statistics supplied by the operating agencies of ferry systems.

18.0 DIRECT FUEL CONSUMPTION OF INLAND AND COASTAL VESSELS

18.1 Data are derived for intercity passenger service on inland waterways, based on a typical year of the 1965-1970 period.

18.2 Freight service data are based on 1972 U.S. statistics. Breakdown of the total ton-miles shipped was as follows:

Local	1%
Lakewise	12%
Rivers & Canals	29%
Coastwise	58%

19.0 CHARACTERISTICS OF U.S. FLAG MERCHANT SHIPS

Data presented under section 19.0 have been extracted from computerized files of the U.S. Department of Commerce, Maritime Administration, and include all self-propelled U.S. flag vessels active as of December 1976, and exceeding 4000 long tons (4064 metric tons) deadweight.

Estimates of fuel consumption are those of the Maritime Administration, and are based on the following empirical formulae:

Engine Type	Fuel Consumption, Long Tons Per Day
Steam Turbine	(Rated Shaft Horsepower) x .005571
Motor Ship	(Rated Shaft Horsepower) x .003313

19.1 Fuel consumption data are for ships at cruise speed.

19.2 Fuel consumption data are averages for ships in-berth.

20.0 DIRECT ENERGY CONSUMPTION OF PIPELINES

Data presented are based on 1972 statistics of U.S. pipeline service.

21.0 INDIRECT-VEHICLE MANUFACTURING ENERGY

General Comments:

Data presented under this section are intended to provide typical interrelationships between the energy consumed in the manufacture of a vehicle, and its weight, passenger rating, and estimated life. Energy consumed in the maintenance of the vehicles is not included.

21.1.9 Data on energy consumed in the manufacture of locomotives are not available. The following weights of typical diesel-electric locomotives are offered as an aid.

Table B7. Horsepower and Weight of Selected Locomotives

Service	Horsepower	No. of Axles	Weight, lb (kg)
Switcher	600	4	199,000 (90,265)
"	1,000	4	247,000 (112,037)
"	1,500	4	359,000 (162,840)
Passenger	1,800	6	258,000 (117,027)
"	3,000	4	280,000 (127,006)
"	3,600	6	410,000 (185,973)
Freight	1,800	4	250,000 (113,398)
"	1,800	6	358,000 (162,386)
"	2,000	4	257,000 (116,573)
"	2,300	4	260,000 (117,934)
"	2,500	4	274,000 (124,284)
"	2,500	6	390,000 (176,901)
"	3,000	4	277,000 (125,645)
"	3,000	6	416,000 (188,694)
"	3,600	6	412,000 (186,880)

21.1.11 Data on energy consumed in the manufacture of railroad freight cars are not available. A standard railroad freight car weighs 50,000 lbs (22,680 kg) and has a cargo capacity between 100,000 and 200,000 lbs (45,359-90,718 kg). A flatcar (piggyback) weighs 69,100 lbs (31,343 kg) and can carry two (truck) trailers.

21.1.16 Energy consumed in the manufacture of new vessels has not been specifically identified, because of the difficulty of separating shipyard power consumption into new construction and repair functions. Preliminary data obtained by a study using questionnaires indicated that, in 1976, the three largest shipyards in the U.S. consumed a total of 5.444×10^{12} Btu for all purposes. Their work output during this time period was 1035 ship repairs and the construction of 21 new ships totalling 315,335 deadweight long tons.

As an aid, the average total weights of all materials included in a ready-for-service ship (empty vessel weight) have been estimated for the U.S. flag merchant fleet, and are presented on Table B8.

Table B8. Average Ship Weight of U.S. Merchant Fleet, 1976

Ship Type	Deadweight Long Tons	Empty Vessel Weight Long Tons	(Metric Tons)
All types*	26,100	9,730	(9,890)
Container Ship	16,700	12,700	(12,900)**
General Cargo	12,800	7,360	(7,480)
Passenger Vessel	7,960	11,200	(11,380)
Tanker*	39,200	9,850	(10,000)

*Excluding Supertankers (4 ships, 91,849 to 264,073 Dwt. Tons).

**Includes permanent ballast (water or slurry) for stability.

22.0 INDIRECT-VEHICLE MAINTENANCE ENERGY.

General Comments:

Energy consumed in most vehicle maintenance operations has not been adequately identified.

Maintenance operations include routine repairs, adjustments and replacements of worn parts, tolls, taxes, etc. They do not include the energy consumed in the construction and maintenance of repair facilities, (which is presented under section 23.0).

22.1.1 Energy consumed in the overall maintenance of passenger cars has been under study for some time. Published values have been changing significantly as researchers modify their initial estimates based on better data and/or philosophical approach. The value given is the latest, but its reliability is open to conjecture.

Information on comparative maintenance rates on substandard roads is based on an African study (1967).

22.1.2 Data presented are based on a study (published 1971) of approximately 1000 standard size American passenger cars.

22.1.3 Data presented are based on a common size tire used in standard American passenger cars (G78x15 4-Ply Rating, Load Range B, weight 29.0 lbs (13.2 kg), manufacturer's name "Goodyear Custom Power Cushion Polyglass"). A worn tire of the same make and model was studied while undergoing retreading operations.

22.1.3.1 Value is based on an estimated tread life of 25,000 miles (40,200 km) and on an estimated 5 gallons of crude petroleum required to produce one tire(79).

22.1.3.2 Typically, 50% of once-worn tires can be retreaded, and the rest discarded. Value is based on 8.65 lbs "lost" per retreadable tire and 29.0 lbs "lost" per discarded tire, on a 50%-50% ratio.

22.1.3.2 Value is based on the amount of rubber added by retreading (8.47 lbs for wide cap) plus the heat energy required for curing (6.16×10^4 Btu per retread tire) plus 25% indirect energy consumed by the operation. The new tread life is estimated at 15,000 miles (24,100 km). Narrower-width caps vary in weight from 7.0 to 7.5 lbs for the same size tire.

22.3 BUSES

22.3.1 Normal maintenance energy is based on a 1971 study of bus company operations.

22.6 AIRCRAFT

Energy consumption associated with aircraft maintenance has not been identified. Routine maintenance schedules for all civil aircraft in U.S. are governed by Federal Aviation Administration minimum standards, and by airline company policy.

23.0 INDIRECT - SYSTEM CONSTRUCTION & MAINTENANCE ENERGY

23.1 ROADWAY FACILITIES

See Sections 3.0, 4.0, 5.0, 6.0

23.1.2.1 Values presented are based on the published results of a literature search (Ref. 78). Indirect energy of equipment wearout should be added to the values for fuel consumption. An estimate may be obtained at about $5x10^4$ Btu per lb. ($1.16x10^8$ joules/kg) prorated over the life of the equipment (See Appendix A, Section 2.0).

23.1.2.2 Values presented include the energy of materials, operations, and support, and are based on statistics of highway maintenance projects in a 9-county area near San Francisco, California. This area contains 3,965 lane-miles (6,381 ln-km) of flexible pavement and 2,022 lane-miles (3,254 ln-km) of rigid pavement, in generally good condition. Operations include Asphalt or Concrete surfacing and patching, Asphalt Emulsion Fog Seals, various crack and joint repairs.

23.2 RAILROAD FACILITIES (CONVENTIONAL)

Data presented are based on a study of the Bay Area Rapid Transit System specifications in San Francisco, California and includes the materials required for construction, plus an additional 35.7% for fuel consumed in construction.

23.3 RAIL MASS TRANSIT FACILITIES

23.3.1 See Commentary 23.2

23.3.2 Adequate data on stations, yards, etc. are not available. While authors differ greatly on absolute values for the entire system, the following data from reference 64 on the San Francisco Bay Area Rapid Transit may be useful:

Total Energy Requirements over a 50 yr life span	
Construction	1.1×10^{14} BtU (1.20×10^{17} joules)
Direct (Propulsion)	1.0×10^{14} Btu (1.06×10^{17} joules)
Station Operation & Maintenance	0.4×10^{14} Btu (4.22×10^{16} joules)

A variety of disassociated and fragmentary information available on rail systems is presented below, in the interest of preserving the data.

a) Rail weight: 38.3 lbs/ft to 45.0 lbs/ft.

b) Ties: 8 inches x 5.5 inches x 8 ft-0 inch spaced 2816 per mile

c) Width required for double track right-of-way: at station platforms 40 ft; between stations 24 to 35 ft.

d) Average Rapid Transit station spacings (8 cities in Europe): 940 metres (range 500 m to 1400 m).

e) Station HVAC: 2.7×10^3 to 15×10^3 Btu/ft^2 per year.

f) Elevators: 9782 Btu/ft^2 per year (2 hrs per day).

g) Escalators: 2.77×10^8 Btu per year (20 hrs per day).

h) Subway Station Illumination: 3 Watts/ft^2.

i) Maintenance Equipment: 1400-2800 KWH (thermal) per vehicle per year.

23.5 AIR TRANSPORTATION FACILITIES

23.5.2 Value is based on a study of an airport having the following facilities and estimated energies consumed in their construction:

Facility	Area Ft^2 (m^2)	Energy Btu
Runways	1,116,000 (103,680)	3.3×10^{10}
Buildings	35,000 (3,252)	7.2×10^9
Operator Pads	1,100,000 (102,198)	1.1×10^{10}
Excavation	500,000 (382,277)*	1.4×10^{10}
Fencing	5 (8.05)**	6.8×10^8

*Cubic Yards (cubic m)

**Miles (km)

24.0 LOAD FACTORS

General Comments:

Load factors are ratios of the actual transportation service rendered to the potential service available. Circuity is the ratio of actual route length to the great circle distance between two points, and its use equalizes airline mileages (which are reported as great circle distances) with other transportation modes. Data under section 24.0 have been derived from several sources, and they are presented as guidelines only. Specific studies are recommended for specific systems and conditions.

24.1 CARGO-RELATED LOAD FACTORS

24.1.4 Value presented is based on 1975-1976 statistics of the Delaware River and Bay Authority, operating three passenger/car ferry vessels rated 100 cars each over a 16 mile (26 km) route between Cape May and Lewes.

Normal service is 8 crossings per day at 14 knots.

The types of vehicle ferried were as follows:

Bicycles	1%
Passenger Cars	91%
Small Trucks and/or Trailers (20 ft-35 ft)	5%
Buses (35 ft-45 ft)	1%
Large Trucks (45 ft +)	2%

24.2 PASSENGER-RELATED LOAD FACTORS

See Commentary 24.0

24.3 CIRCUITY

Data presented are based on a study by The Boeing Commercial Airplane Company, and a report by the Iowa Department of Transportation.

25.0 ENERGY CONSUMED VS. DOLLAR SPENT.

General Comments:

Data in this section are based on studies comparing dollar (U.S.) costs of goods and services and the energy consumed to provide the same. Since the energy consumption remains relatively constant in comparison to the fluctuation of the value of the dollar, such energy/dollar studies are linked with specific calendar-years. Studies have been made to provide conversion factors which account for the annual fluctuation of the dollar.

25.1 CONSTANT-DOLLAR CONVERSION FACTORS

Data under Section 25.1 are based on 1976 publications. The values presented should be used to convert the dollar costs to the appropriate year under study, and as an aid to extrapolation for future trends.

25.2 ENERGY/DOLLAR FOR ROADWAY CONSTRUCTION (1973-74 $)

Data under section 25.2 are based on a study (1973-74) by the California Department of Transportation, which also found that the (diesel) fuel used by construction equipment accounted for 37% of the total construction energy. Data for structure construction are based on bridge cost estimates by the Office of Structures of the California Department of Transportation.

Rural Construction consumes considerably more energy than urban, primarily due to the additional fuel consumed in the long-distance hauling of equipment and materials.

25.3 ENERGY/DOLLAR FOR SELECTED PROJECTS (1967 $)

Data under section 25.3 have been extracted from a 1976 publication; (also 25.4, 25.5).

25.4 ENERGY/DOLLAR FOR SELECTED MANUFACTURING (1967 $)

Data under section 25.4 have been extracted from a 1976 publication; (also 25.3, 25.5).

25.5 ENERGY/DOLLAR FOR TRANSPORTATION (1967 $)

Data under section 25.5 have been extracted from a 1976 publication; (also 25.3, 25.4).

26.0 ENERGY PRODUCTION OF SELECTED NATURAL SYSTEMS

Data under section 26.0 represent the mean production of various ecosystems. The range of values vary in general by a factor of ± 2 from the mean.

27.0 ENERGY CONSUMED BY DWELLINGS

Data presented under section 27.0 are based on a study by the City of Los Angeles, California.

27.1 Electricity Consumption in KWH is measured at the point of consumption, and is reflected in the utility bills. Energy Consumed at the Powerplant refers to the estimated total energy consumed by the utility system to produce and transmit the given electricity to dwellings, based on 33% efficiency. The values given are in units of energy per surface area of the consumer dwelling.

27.2 Natural Gas Consumption is based on statistical quantities of cubic feet of natural gas consumed, converted to thermal energy at the rate of 1000 Btu/cf.

28.0 LAND USE ENERGY LEVELS

Data presented under section 28.0 are estimates of the annual energy consumption of populated areas.

28.2 Industrial data are based on dollar costs of feedstock, plus all additional dollar costs to the industry for processing, plant operations, etc., to provide the final product.

28.3 Residential data are based on fuel and electricity consumed for utilities, HVAC, and transportation. Utility and HVAC values reflect the quantity of energy at the point of use, and not the primary energy input at the powerplants. Transportation values provide only the direct (fuel) energy consumption by the region.

APPENDIX C

SOURCES FOR HANDBOOK

Energy factors presented in Appendices A and B have been developed by the authors according to information in the following references. Original work by the authors is indicated by an asterisk (*).

Section	Ref. No.
1.0 PROPERTIES OF SELECTED FUELS	
1.1 AMMONIA	15
1.2 BUTANE	24
1.3 COAL	44
1.4 ETHANOL	15
1.5 GAS-NATURAL	24
1.6 GASOLINE (AUTOMOTIVE)	15,24,46
1.7 GASOLINE (AVIATION)	46
1.8 HYDRAZINE	15
1.9 HYDROGEN	15
1.10 HYDROGEN + OXYGEN	15
1.11 JET AIRCRAFT FUEL	46
1.12 KEROSENE	24
1.13 MAGNESIUM HYDRIDE	15
1.14 METHANE	15

Section	Ref. No.
21.0 INDIRECT-VEHICLE MANUFACTURING ENERGY	
21.1 MANUFACTURE ENERGY CHARACTERISTICS OF SELECTED TRANSPORTATION VEHICLES	
21.1.1 Car (standard)	Energy 19, Useful life 18
21.1.2 Car (compact)	Energy 19, Useful life 18
21.1.3 Truck	Energy 17, Useful life 19
21.1.4 Truck	Energy 17, Useful life 19
21.1.5 Truck	Energy 17, Useful life 19
21.1.6 Bus, transit	Energy 16,17,19, Useful life 18
21.1.7 Bus	Energy 16,17,19, Useful life 18
21.1.8 Bus (minibus)	Energy 16,17,19, Useful life 18
21.1.9 Railroad (locomotive)	N.A.
21.1.10 Railroad car (commuter)	Energy 16, Useful life 18
21.1.11 Railroad car (cargo)	N.A.
21.1.12 PRT car	Energy 16, Useful life 18

Section	Ref. No.
21.1.13 Aircraft (commercial jets)	60
21.1.14 Aircraft (gen. av. piston)	19
21.1.15 Ships (ferryboats)	N.A.
21.1.16 Ships (merchant)	37
21.1.17 Pipelines	N.A.
22.0 INDIRECT-VEHICLE MAINTENANCE ENERGY	
21.1 PASSENGER CARS	13,21(79,*Tires)
22.2 TRUCKS	N.A.
22.3 BUSES	22
22.4 TRAINS	22
22.5 PERSONAL RAPID TRANSIT	N.A.
22.6 AIRCRAFT	22
22.7 SHIPS	37
22.8 PIPELINES	N.A.
23.0 INDIRECT-SYSTEM CONSTRUCTION & MAINTENANCE ENERGY	
22.1 ROADWAY FACILITIES	
23.1.1 Roadway construction-see sections	3.0,4.0,5.0,6.0
23.1.2 Roadway maintenance	78,*
23.2 RAILROAD FACILITIES	19,22
23.3 RAIL MASS TRANSIT FACILITIES	17,64,81
23.4 PERSONAL (LIGHT) RAPID TRANSIT FICILITIES	17
23.5 AIR TRANSPORTATION FACILITIES	19,22
23.6 MARINE TRANSPORTATION FACILITIES	N.A.
23.7 PIPELINE TRANSPORTATION FACILITIES	N.A.

Section	Ref. No.
24.0 LOAD FACTORS	
24.1 CARGO-RELATED LOAD FACTORS	
24.1.1 Road transport	N.A.
24.1.2 Rail transport	75
24.1.3 Air transport	32
24.1.4 Marine transport	34
24.1.5 Pipeline transport	N.A.
24.2 PASSENGER-RELATED LOAD FACTORS	
24.2.1 Passenger car	5,28,60,70,71
24.2.2 Bus	5,16,28,60,73
24.2.3 Rail	5,28,71,73
24.2.4 Aircraft	5,28,32,71
24.2.5 Marine	34
24.3 CIRCUITY	28,74
25.0 ENERGY CONSUMED VS DOLLAR SPENT	
25.1 CONSTANT-DOLLAR CONVERSION FACTORS	43
25.2 ENERGY/DOLLAR FOR ROADWAY CONSTRUCTION	42,*
25.3 ENERGY/DOLLAR FOR SELECTED PROJECTS	40, modified as per 41
25.4 ENERGY/DOLLAR FOR SELECTED MANUFACTURING	40, modified as per 41
25.5 ENERGY/DOLLAR FOR TRANSPORTATION	40, modified as per 41

Section	Reference No.
26.0 ENERGY PRODUCTION OF SELECTED NATURAL SYSTEMS	
26.1 NET QUANTITY & ENERGY PRODUCTION	76
26.2 GROSS QUANTITY PRODUCTION	76
26.3 ENERGY CONTENT OF LIVING TISSUE	76
27.0 ENERGY CONSUMED BY DWELLINGS	
27.1 ELECTRICTY CONSUMPTION	77
27.2 NATURAL GAS CONSUMPTION	77
28.0 LAND USE ENERGY LEVELS	83,84,*

APPENDIX D

CONVERSION FACTORS

MULTIPLY	BY	TO OBTAIN
Btu	3.929×10^{-4}	Horsepower - hours
Btu	1054.8	Joules
Btu	2.930×10^{-4}	Kilowatt - hours
Btu/Gal	278.7	Joules/litre
Btu/lb	2325.8	Joules/Kg
Btu/ft^3	37217.5	Joules/m^3
Btu/ft^2	11345.5	Joules/m^2
Btu/lin-ft	3458	Joules/m
Btu/lane-mile	654.9	Joules/lane-km
Btu/Ton-mile	594.59	Joules/metric ton-km
Lb/gal	0.1198	Kilograms/litre
Lb/ft^3	16.023	Kilograms/metre^3
Lb/lin-ft	1.488	Kilograms/lin-metre
MPH	1.609344	Kilometres/hours
MPG	0.42514	Kilometres/litre
MPG	0.42514	Kilometres/cm^3
Ton(2000 lb)	0.907185	Metric tons (1000 kg)
Ton-mile/gal	0.385684	Metric ton-km/litre
Gallon (U.S.)	3.7854	Litres
Foot	0.30480	Metres
Inch	25.40	Millimetres
Lb	0.4536	Kilograms
Long ton(2240 lb)	1016.1	Kilograms
Mile, nautical	1.8520	Kilometres
Mile, statute	1.609344	Kilometres

ONE BARREL CRUDE OIL = 5.80×10^6 Btu

APPENDIX E

GLOSSARY

This glossary is very limited in scope and is intended to explain terms used in "Energy and Transportation Systems." For a more complete coverage, the publication, "Glossary of Energy, Economic, Environmental, Electric Utility Terminology," published by the California Energy Commission, is recommended.

Average Occupancy: The average number of passengers per vehicle in some prescribed time period or operation. In an aggregate operation, average occupancy equals passenger miles traveled divided by vehicle miles traveled (PMT/VMT).

Bbl: Barrels of oil (42 U.S. gallons)

Barrels Per Day Oil Equivalent: A measurement applied to energy sources other than oil for the purpose of making more direct comparisons.

Btu (British thermal unit): The quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit at or near 39.2°F, at standard pressure.

Btu/seat-mile or passenger mile: A measure of energy efficiency, generally implying the fossil fuels (or their equivalent) used in propelling the vehicle. One variation is gallons/square foot (of passenger area), advocated by some for transit operations. Btu/seat-mile is a measure of potential efficiency, resulting from 100% occupancy, while Btu/passenger-mile is a measure of actual efficiency.

Bunker "C" Fuel Oil: A heavy residual fuel oil used by ships, industry, and large scale heating installations. In industry, it is often referred to as No. 6 fuel.

Calorie: Originally, the amount of heat energy required to raise the temperature of 1 gram of water 1°C. Because this quantity varies with the temperature of the water, the calorie has been redefined in terms of other energy units. One calorie is equal to 4.2 joules. (The food calorie is equivalent to one thousand calories defined in this manner.)

Circuity: Ratio of distance actually traveled between two points, to the great circle distance between those points.

Construction Energy: Energy used to build the system, e.g., in Transit Analysis-vehicles, stations, roadbeds, terminals and associate facilities. Includes energy of the materials as well as the energy in placing them.

Cuts or Fractions: Products secured by fractional distillation are referred to as fractions or cuts. Gasoline fractions or gasoline cut, and kerosine fraction or kerosene cut, etc.

Default Value: A design value based on substantial experience or studied conclusions to be used for estimating various parameters in lieu of actual definitive values, e.g., average auto fuel consumption rates.

Elasticity: The sensitivity of the demand or supply of a commodity to the price, e.g., gasoline - the ratio of the percent change in consumption to percent change in price.

Elasticity is also used in other ways, e.g., Bus ridership - The ratio of the percent change in bus usage (ridership) to the percent change in the number of bus miles traveled.

Energy: The capability of doing work. There are several forms of energy, including kinetic, potential, thermal, nuclear, rotational, and electro-magnetic. One form of energy may be changed to another, such as burning coal to produce steam to drive a turbine which produces electricity.

Energetics: A science dealing with the total energy relations and transformations of a system.

Enthalpy: The heat content per unit mass, expressed in BTU per pound.

Entropy: A measure of the disorder (or chaos) in a closed system. The measure of unavailable energy in a closed system.

Feedstock: Fossil fuels used for their chemcial properties, rather than fuel, to produce plastics, synthetic fabrics, etc.

Freight Efficiency: A measure of the amount of freight that can be moved some distance by a given mode of transportation for an expenditure of a certain amount of fuel (energy). It is usually defined as the number of tons of freight moved multiplied by the number of miles obtained per gallon of gasoline used. (See ton-mile)

Great Circle Distance: An arc between two points on the earth's surface formed by the intersection of a plane passing through the center of the earth. For aircraft or ships, it is the shortest distance between two points.

GRT (Group Rapid Transit): Public transportation systems utilizing 8 to 20 passenger automated vehicles on exclusive guideways. Multiple stops, responding to origin and destination desires of passengers. Similar to PRT except uses larger vehicles.

Guideway: A facility for transit vehicles which are not guided by an operator.

HOV (High-Occupancy Vehicle): A vehicle, typically an automobile or van, with most of the seats filled with passengers.

Induced Growth Energy: Energy used in building or operating systems, structures, or devices that are subsequently developed because of the existence of a new transportation facility.

Indirect Energy: A term used to denote all energy imputs to the construction, operation, and maintenance of a system, exclusive of traction (propulsion) energy and parasitic loads within the vehicle.

Input-Output Analysis: A matrix form of analysis, developed for the field of economics, which is a tabular summary of the goods and services used in the process of making other goods or services. The analysis is in terms of dollars and encompasses the entire nation.

Joule: The joule is the work done when the point of application of a force of one newton is displaced a distance of one meter in the direction of the force. (Equal to one watt-second.)

Kilocalorie: The amount of heat required at standard pressure to raise the temperature of one kilogram of water, one degree centigrade.

Kiss and Ride: A form of access to a mass transit station where transit riders use automobiles for the trip from home to the transit station, where the rider is dropped off and the automobile is used by another person.

KWHT: Kilowatt hour thermal - equals 3,413 Btu.

KWHE: Kilowatt hour electric-equals roughly 10,000 Btu, depending on the conversion loss factor assumed (.33 is typical) for converting fossil fuel into electricity.

L.A.S.H.: "Lighter aboard ship", a ship which carries smaller loaded vessels on board (similar in concept to "piggybacking" trailers on train flat cars).

Line Haul: Normally the distance between communities, or population centers.

Load Factor: The average ratio of passengers to seats in some prescribed time period operation, expressed as a decimal or a percentage, e.g., in public transit, the ratio is the average of in-bound (peak) and outbound (off-peak) operations.

Maintenance Energy: Includes energy needed to repair and maintain vehicles and other constructed items of the system.

Megajoule: 10^6 joules (abbreviated MJ)

Newton: The newton is that force which when applied to body having a mass of one kilogram, gives it an acceleration of one meter per second squared.

OPEC: Organization of Petroleum Exporting Countries.

Parasitic Loads: Power requirements in a vehicle by air compressors, colling systems, generators and similar equipment detracting from horsepower delivered to drive wheels.

Park and Ride: A form of access to a mass transit station where transit riders use automobiles for the trip from home to the transit station, where they are parked until the rider returns (P&R).

Passenger-miles: Vehicle-miles multiplied by the (average) number of passengers on board. Abbreviated PMT.

Power: The rate of flow of useful energy.

PRT: Personal rapid transit. Public transportation system utilizing small - 2 to 6 passenger - automated vehicles, operating on exclusive guideways. Multiple stops, responding to origin and destination desires of passengers.

Ramp Metering: The control of vehicles entering a restricted access highway (Freeway) so as to maintain the volume-capacity ratio at a point where free flow (no congestion) exists.

Seat-mile: Vehicle-miles multiplied by the number of seats in the vehicle.

Station Energy: A portion of operating energy. Specifically, the associated parking lots, administration buildings including lighting and heating.

Therm: 100,000 Btu. Also that quantity of a gaseous fuel which contains 100,000 Btu in calorific heat value.

Ton-Mile: In general, one short ton (2,000 lbs.) transported one mile. A misleading term unless one understands the circumstances of its computation: e.g., whether only cargo is involved, and whether empty back-haul is included. Ton-mile/gal is commonly used as a measure of efficiency in moving freight.

Variations Include:

CWT/gal - cargo weight in 100 pound units per gallon of propulsion fuel.

Gross Trailing Tons/Gal - Term used in train freight denoting gross train weight, exclusive of engine units.

Loaded Trailer/Tons/Gal - A term used in TOFC (trailer on flat car) operations, referring to flat car payload of truck trailer and its cargo.

Traction Energy: Includes the energy for vehicle propulsion and any parasitic loads such as lighting, heating, air conditioning or various other energy demands within the vehicle. This term is generally synonymous with Direct Energy, a term favored by some authors. Some disagreement has existed over what parasitic loads are to be included.

Trailing Gross Tons: The gross tonnage being pulled by a train engine. Does not include the weight of the engine.

Travel Speed: Average distance/unit of time area prescribed route.

Unit Train: A system developed for delivering, e.g., coal more efficiently in which a string of cars, with distinctive markings, and loaded to "full visible capacity", is operated without service frills or stops along the way for cars to be cut in and out. In this way, the customer receives his coal quickly and the empty car is scheduled back to the coal fields as fast as it came.

Vehicle-miles: The sum of the distances (in miles) each vehicle travels while conducting its transport function. Abbreviated VMT.

Volume Utilization: A term used in freight space utilization referring to the internal container volume used to store packages. A 60% volume utilization means 40% of the container is unused.

Watt: The watt is the power which requires a supply of energy at the rate of one joule per second.

APPENDIX F

EXAMPLE ANALYSES

Example Problem No. 1

It is proposed to transport by sea 500×10^6 barrels of crude oil annually from Valdez, Alaska to San Diego, California, a distance of 2,300 nautical miles. Shore facilities exist at both ports and are capable of handling 1.0×10^6 barrels per day for each ship, and load/unload 5 ships simultaneously. However, tanker ships are not available, and must be built.

Required: Perform an energy analysis to obtain an estimate of the annual energy (direct and indirect) that will be consumed by this transportation. [To simplify this problem, exclude the energy consumed by shore facilities.]

Helpful Data: A typical U.S. supertanker of recent(1973) construction is the S.S. Brooklyn, length 1,094 ft, breadth 144 ft, draft 70 ft, deadweight 226,100 long tons, cruise speed 17.5 knots, normal bunker capacity 9,955 long tons of "Bunker C" fuel, which gives it a radius of 15,000 miles at a consumption of 270 long tons per day. Empty vessel weight is 15% of deadweight. Assumed density of Alaskan oil is 7.5 lb/gal. At the given rate of production, Alaskan fields would be depleted in 20 years.

Note: Not all data required are available - State your assumptions

Solution to Problem #1

Analysis:

1) Estimation of the number of vessels is required. Assume the vessel size and characteristics will be similar to the S.S. Brooklyn.

a) Revenue Cargo:

Deadweight includes cargo + fuel + stores. Cargo constitutes approximately 99% of deadweight.

Cargo = (0.99)(226,100 l. tons) ≈ 223,800 long tons

Reference: Authors' calculation (not shown)

Cargo in terms of barrels of crude oil:

Cargo = [(223,800 l. tons)(2,240 lb/l. ton)]/[(7.50 lb/gal)(42 gal/Bbl)]

≈ 1,591,500 Bbl/trip

Reference: Appendix A, Sect. 1.16.3

Appendix E, Glossary, "Barrel"

b) Number of annual trips required:

$(500 \times 10^6$ Bbl/yr)/1,591,500 Bbl/trip ≈ 314 trips/year

c) Vessels Required:

Sailing time between ports = (2)(2,300 mi)/17.5 knots	≃ 263 hrs
	≃ 11 days
Reference: Given data	
Time in port = berthing time + load or unload time	
Load/unload = (1,591,500 Bbl)(2 ports)/10^6 Bbl/day	≃ 3.2 days
Berthing = (Authors' estimate)	≃ 0.8 days
Total time per trip = 11+3.2+.8	≃ 15 days

Vessels are available throughout the year on a 24-hour basis, except for routine maintenance and repair.

Routine maintenance requires an estimated 25 days per year.

Available time = 365 - 25 days	≃ 340 days/year
Reference: Appendix A, Sect. 19.3	
Total trips per year = 340 days/15 days per trip	≃ 22.7 trips/year
Total cargo delivered annually by each vessel =	
(22.7 trips)(1,591,500 Bbl/trip)	≃ 36,127,000 Bbl
No. of vessels required = 500x10^6 Bbl/36,127,000 Bbl	≃ 14 ships

2) Direct Energy (fuel) consumed:

Fuel is "Bunker C" oil, 1.54×10^5 Btu/gal, or 4.14×10^7 Btu/long ton.

Reference: Appendix A, Sect. 1.17.6

Energy consumed at sea:

$$\text{Btu} = (22.7 \text{ trips})(11 \text{ days/trip})(270 \text{ l.t./day})(4.14 \times 10^7 \text{ Btu/l.t.})$$

$$\approx 2.79 \times 10^{12} \text{ Btu/yr}$$

Energy consumed in port:

$$\text{Btu} = (22.7 \text{ trips})(4 \text{ days/trip})(1{,}900 \text{ gal/day})(1.54 \times 10^5 \text{ Btu/gal})$$

$$\approx 2.66 \times 10^{10} \text{ Btu/yr}$$

Direct energy per ship per year: $\approx 2.82 \times 10^{12}$ Btu/yr

Total direct energy for whole fleet per year: $\approx \underline{3.95 \times 10^{13}}$ Btu/yr

3) Indirect Energy Consumed:

a) Vessel Construction

Data are scarce. An estimate will be made based on the simplified assumption that the vessels are constructed almost entirely of steel, and obtain an energy value based on Btu per lb. of steel. An estimate will also be made on the amount of energy consumed by the shipyard in the process of building the vessels. Available data on shipyard energy (Appendix B, Sect. 21.1.16) will be divided into ship building and ship repair functions, on an estimated 25%-75% ratio, respectively.

Ship Weight ≈ 15% of Deadweight

≈ (.15)(226,100 l.t.)(2,240 lb/l.t.) ≈ 75,969,600 lb each

Reference: Given; (see also Appendix B, Sect. 21.1.16, Table B8 for smaller vessels)

Material (steel) energy = (14 ships)(75,969,600 lb)(2.64×10^4 Btu/lb)

≈ 2.808×10^{13} Btu

Reference: Appendix A, Sect. 2.13

Energy consumed to build the vessels:

Btu per deadweight long ton built =

(.25)(5.444×10^{12} Btu)/315,355 dwt. long tons ≈ 4,316,000 Btu/l.t.

Reference: Appendix B, Sect. 21.1.16

Shipyard energy = (14 ships)(226,100 l.t.)(4,316,000 Btu/l.t.)

≈ 1.366×10^{13} Btu

Total energy consumed in the manufacture of vessels ≈ 4.174×10^{13} Btu

The indirect energy of vessel manufacture must be pro-rated, based on the estimated useful life of the vessels. Two criteria exist:

1) Typical life expectancy before scrapping = 25 years

Reference: #37 See text Chapter Two

2) Expected number of years to depletion of Alaskan oil fields at the given rate of production = 20 years

Reference: Given; (U.S. Governement Statistics)

Due to the uncertainties involved, it will be assumed that the vessels' useful life will not continue past the 20-year limit.

Prorated vessel manufacture energy = $(4.174\times10^{13}$ Btu)/(20 yrs)

$\approx \underline{2.087\times10^{12}}$ Btu/yr

b) Vessel Maintenance

Data are scarce. An estimate will be made based on available data (Appendix B, Sect. 21.1.16) on shipyard energy, divided into shipbuilding and ship repair (or maintenance) functions, on an estimated 25%-75% ratio, respectively.

Energy consumed to maintain the vessels:

Btu per ship repair = $(.75)(5.444\text{x}10^{12}$ Btu/yr)/1,035 repairs

$\approx 3.945\text{x}10^{9}$ Btu/ship/yr

Annual maintenance energy for fleet:

Btu = (14 ships)($3.945\text{x}10^{9}$ Btu/ship/yr) $\approx 5.52\text{x}10^{10}$ Btu/yr

c) Salvage energy of scrapped vessels:

Data are not available. The energy savings inherent in scrapped vessels would equal the energy saved by re-cycling the existing steel rather than mining and refining ore, etc., minus the energy consumed in the actual scrapping operations and transport.

A value may be placed by conjecture at, say, 20% of the steel in the 14 vessels i.e., $(.20)(2.808\text{x}10^{13}$ Btu)/20 yrs $\approx 2.808\text{x}10^{11}$ Btu

Since this estimate is conjecture, a sensitivity analysis is in order, and will be performed at the conclusion of the calculations.

Total Indirect Energy - Vessel Related

Energy = $2.087\text{x}10^{12}$ Btu/yr + $5.52\text{x}10^{10}$ Btu/yr - $2.808\text{x}10^{11}$ Btu/yr

$\approx \underline{1.861\text{x}10^{12}}$ Btu/yr

d) Facility - Related Indirect Energy

This energy must be considered in a legitimate energy study comparing alternatives. It is omitted in this problem for the sake of simplicity only.

Facility-related energy encompasses all shore establishments which support the vessels, such as docks, shipyards and drydock facilities; harbors and harbor improvements such as channel dredging; support vessels such as tugs, barges, lighters, etc., and the operations of governmental establishments such as the Coast Guard.

e) Peripheral Energy Effects

Available information (in the given problem) does not allow the assessment of peripheral energy effects of this project.

Sensitivity Analysis:

Since the value of salvage energy is based on conjecture, calculations will be performed to determine to what extent the final energy total would be effected by an error in the selection of this value. Assume that for an error to be "significant", it must alter the final total by a factor greater than 10%. The final total direct + indirect (vessels only) is 4.26×10^{13} Btu/yr, therefore the total must be altered by 4.26×10^{12} Btu/yr. The salvage energy has been calculated as being 2.808×10^{11} Btu/yr.

Thus, the value for vessel salvage energy may be 15 times higher or lower than the one selected, without significantly affecting the results of the study.

It is concluded that reasonable errors in the value for vessel salvage energy will not affect the results of this analysis.

SUMMATION:

Annual Equivalent Energy in Btu consumed by the proposed transportation:

Direct Energy:	3.95×10^{13} Btu/yr
Indirect Energy	
Vessel Construction	2.087×10^{12} Btu/yr
Vessel Maintenance	5.52×10^{10} Btu/yr
Vessel Salvage (energy savings)	-2.808×10^{11} Btu/yr
Shore Facility & Support	Not part of this study
Peripheral Effects	Not part of this study
Total Indirect*	1.861×10^{12} Btu/yr
Total Energy* expended annually	4.14×10^{13} Btu/yr
Total Energy in terms of equivalent barrels of crude oil per day:	19,525 Bbl

Reference: Appendix D

*Not including the energy consumed by facilities & support, or peripheral effects.

Conclusion: Based on a 20-year estimated useful life, the energy that will be consumed for propulsion, and the vessel-related indirect energy are calculated to be 19,525 barrels of oil per day. Energy savings related to vessel salvage play an insignificant role in the analysis, and further effort to produce a more reliable value than the one presented - which is based on conjecture - is not necessary. The total energy consumption must include the shore facilities and support of the fleet, as well as the peripheral effects of this project. These two items may consume substantial quantities of energy, and require that an appropriate analysis be made to obtain these quantities.

EXAMPLE PROBLEM NO. 2

The following alternatives are proposed for a roadway transportation project:

Alternative 1. It is proposed to widen an existing major arterial roadway in an urban area, by the addition of two lanes. The section to be widened is within a right-of-way acquired several years previously, and there will be no physical encroachment on the community. The proposed widening will forestall congestion and allow freeflowing traffic conditions, at 45 miles per hour. The total length of the project is 5.60 miles, with vertical alignment as follows: 2.2 miles have a grade of +1%, 1.6 miles are essentially level, and 1.8 miles have a grade of -3%, when viewed traveling upstation. Horizontal alignment is relatively straight, with negligible curvature. Cold starts are not a factor.

The predicted traffic between 1977, when the proposed widening will be opened to traffic, through the year 2000, will have an average daily traffic (ADT) of approximately 25,000 vehicles, counting both directions, of which 8% will be trucks having similar characteristics to "2-axle, 6-or-more tire trucks", and 6% will be trucks having similar characteristics to "tractor semi-trailer trucks". (Pickup trucks and small vans are considered as belonging to the category of passenger cars).

Total cost of the project, to be expended in 1976, will be $3,300,000, of which $66,000 will be spent for structures, $43,000 for landscaping, $15,000 for signals, lighting, & miscellaneous, and the remaining $3,176,000 will be spent on the roadway itself.

Alternative 2. It is proposed that no improvements are made in this area. (A "no-build" alternative.) The existing 4-lane, asphalt concrete roadway will receive only normal maintenance. Future traffic predictions indicate the same ADT and vehicle mix as for alternative 1. However, the heavy traffic expected during peak hours would affect the smooth flow of approximately 5,000 vehicles per day. Attempted speed of traffic will be 45 miles per hour. Alternative 2 will incur no construction costs.

Required:

Perform an Energy Study, comparing the two alternatives from the energy point of view. Note: Not all data required are available - State assumptions.

ENERGY STUDY

This study projects the energy-related effects of two proposed alternatives in a transportation program. Both alternatives involve roadway transportation.

DESCRIPTION:

An existing major arterial roadway in an urban area (give street name, route no., city, maps, etc. as required) does not have the capacity to carry the projected peak-hour traffic in future years. Congestion and slowdowns are expected to begin in 1976 and continue to increase. The (name the transportation agency) was aware of the predicted congestion, and has obtained sufficient right-of-way to allow a widening of the existing four lane road when conditions warrant such action.

A decision must now be made whether or not to proceed with Alternative 1, which is to construct the widening, or with Alternative 2, which is to leave conditions as-is, (also known as a "no-build" alternative). One of the many factors that must be considered in making the decision is the energy-related effect of each alternative.

The average daily traffic projected between 1977 and 2000, is 25,000 vehicles per day, at a speed of 45 miles per hour. Alternative 1, the construction of two additional lanes, will allow smooth-flowing traffic without peak-hour congestion. The construction will cost a total of $3,300,000 and will be accomplished in 1976. Detailed data on design and materials quantities are not available at this preliminary stage. Alternative 2, the "no-build", will incur no construction expenditures, and will thus handle the projected traffic of 25,000 vehicles per day on the existing 5.6 miles of four lane flexible (asphalt Concrete) pavement. These four lanes cannot, however, handle the projected peak-hour traffic smoothly, and it is estimated that an average of 5,000 vehicles will be involved in congested traffic daily, with the remaining 20,000 vehicles encountering no problems. Maintenance of the roadway will continue under both alternatives.

CONCLUSIONS:

An energy analysis has been conducted in order to compare the two alternative projects under consideration.

Alternative 1, the construction of two additional lanes, will require a substantial one-time energy expenditure related to the construction materials, operations, and equipment in 1976. It will also require the normal maintenance of 6 lanes of flexible pavement, with its resulting energy consumption. Against this additional energy consumption, must be balanced the fact that Alternative 1 will allow free-flowing traffic conditions, which will avoid increases in the fuel consumption of vehicles.

Alternative 2, the no construction, or "no-build" alternative, will forego the energy consumption of the construction project, and will require the maintenance of the existing 4 lanes only. Against this energy savings, must be balanced the fact that Alternative 2 will cause traffic congestion which will increase the fuel consumption of a portion of the total vehicles operating on this road.

The table below provides the results of the energy analysis in terms of equivalent annual energy consumption by each alternative, averaged for the time period between 1977 thru 2000. Construction energy, and vehicle indirect energy values have been pro-rated according to estimated "useful lives", thus providing meaningful comparisons.

Energy Consumption by Source	Equivalent Annual Consumption Alternative 1 (Construction)	Alternative 2 (No-Build)
Direct (vehicle fuels)	3.06×10^{11} Btu	3.41×10^{11} Btu
Indirect - Vehicles	2.52×10^{11} Btu	2.66×10^{11} Btu
Indirect - Construction	2.04×10^{9} Btu	0
Indirect - Maintenance	4.03×10^{9} Btu	2.69×10^{9} Btu
Peripheral Effects	Nil	Nil
Total Energy (Annual Average)	5.63×10^{11} Btu	6.10×10^{11} Btu
Total Energy in terms of EQUIVALENT BARRELS OF OIL PER DAY:	266 Bbl	288 Bbl

At the current state-of-the-art, the 8% difference between the energy consumption values of the two alternatives is too small to indicate that one is more energy-intensive than the other. It is concluded that the two alternatives will consume essentially the identical amount of energy, the initial construction expenditures being offset by reduced fuel consumption of vehicles.

Appended are the technical calculations of the energy analysis.

Solution to Problem # 2

Analysis:

1) Breakdown of traffic by vehicle types:

Cars: (25,000 vpd)(.86) =	21,500 vpd
2-Axle, 6 Tire Trucks: (25,000 vpd)(.08) =	2,000 vpd
Tractor Semi-Trailer Trucks: (25,000 vpd)(.06) =	1,500 vpd

Reference: Known values

2) Breakdown of trucks by fuel type:

2-Axle, 6 Tire Trucks, Gasoline: (2,000 vpd)(.95) =	1,900 vpd
2-Axle, 6 Tire Trucks, Diesel: (2,000 vpd)(.05) =	100 vpd

Reference: 12 (See text Chapter 2)

Tractor Semi-Trailer Trucks, Gasoline: (1,500 vpd)(.65) =	975 vpd
Tractor Semi-Trailer Trucks, Diesel: (1,500 vpd)(.35) =	525 vpd

Reference: 13 (See text Chapter 2)

3) Breakdown of average annual traffic by roadway segments having constant grade (one-half of vehicles in each direction).

a) Level Grade:

Cars: (21,500 vpd)(365 days/yr)(1.6 mi) =	12,556,000 veh-mi
2-Axle Trucks, Gasoline: (1,900 vpd)(365)(1.6) =	1,109,600 veh-mi
2-Axle Trucks, Diesel: (100 vpd)(365)(1.6) =	58,400 veh-mi
Semi Trucks, Gasoline: (975 vpd)(365)(1.6) =	569,400 veh-mi
Semi Trucks, Diesel: (525 vpd)(365)(1.6) =	306,600 veh-mi

b) +1% Grade:

Cars: (.5)(21,500 vpd)(365 days/yr)(2.2 mi) =	8,632,250 veh-mi
2-Axle Trucks, Gasoline: (.5)(1,900 vpd)(365)(2.2) =	762,850 veh-mi
2-Axle Trucks, Diesel: (.5)(100 vpd)(365)(2.2) =	40,150 veh-mi
Semi Trucks, Gasoline: (.5)(975 vpd)(365)(2.2) =	391,463 veh-mi
Semi Trucks, Diesel: (.5)(525 vpd)(365)(2.2) =	210,788 veh-mi

c) -1% Grade:

Same as for +1% grade

d) +3% Grade:

Cars: (.5)(21,500 vpd)(365 days/yr)(1.8 mi) =	7,062,750 veh-mi
2-Axle Trucks, Gasoline: (.5)(1,900 vpd)(365)(1.8) =	624,150 veh-mi
2-Axle Trucks, Diesel: (.5)(100 vpd)(365)(1.8) =	32,850 veh-mi
Semi Trucks, Gasoline: (.5)(975 vpd)(365)(1.8) =	320,288 veh-mi
Semi Trucks, Diesel: (.5)(525 vpd)(365)(1.8) =	172,463 veh-mi

e) -3% Grade:

Same as for +3% grade

DIRECT ENERGY CONSUMPTION - Build alternative

1) Direct annual fuel (gasoline) consumption of Cars:

Speed 45 mph, freeflowing conditions: Base Consumption: .049 gpm

Reference: Appendix A, Sect. 7.1, Fig. A5

Correction factor for improved fuel economy, 1977-2000 averaged is

(.955 + .931 + .902 + ... + .583)/24 yrs = .661

Reference: Appendix A, Sect. 7.1.1

Consumption rate, corrected for study years = (.049 gpm)(.661) = .032 gpm

Correction factors for grades are:

Level: No correction required

+1%: 1.15

-1%: 0.78

+3%: 1.49

-3%: 0.44

Reference: Appendix A, Sect. 7.1.2A, 7.1.2B

Fuel Consumed at each grade segment

a) Annual fuel consumed at level grade segment is:

(12,556,000 veh-mi)(.032 gpm) = 401,792 gallons

b) Annual fuel consumed at +1% grade segment is:

(8,632,250 veh-mi)(.032 gpm)(1.15) = 317,667 gallons

c) Annual fuel consumed at -1% grade segment is:

(8,632,250 veh-mi)(.032 gpm)(0.78) = 215,461 gallons

d) Annual fuel consumed at +3% grade segment is:

(7,062,750 veh-mi)(.032 gpm)(1.49) = 336,752 gallons

e) Annual fuel consumed at -3% grade segment is:

(7,062,750 veh-mi)(.032 gpm)(0.44) = 99,444 gallons

Total fuel (gasoline) consumed annually by cars = 1,371,116 gallons

Equivalent energy = (1,371,116 gal)(1.25×10^5 BTU/gal) = 1.714×10^{11} BTU

Reference: Appendix A, Sect. 1.6

2) Direct annual fuel consumption of 2-Axle, 6 Tire Trucks:

Speed 45 mph, freeflowing conditions: Base consumption = 0.092 gpm (gasoline)
.060 gpm (diesel)

Reference: Appendix A, Sect. 8.1.1, Fig A8

Correction factors for grades are:

Grade	Gasoline	Diesel
Level	No correction required	
+1%	1.33	1.47
-1%	0.88	0.88
+3%	2.02	*
-3%	0.54	0.54

Reference: Appendix A, Sect. 8.1.1.1, 8.1.1.2

*Diesel truck cannot maintain speed; Its fuel consumption will be for operations at 30 mph on +3% grade, i.e. .043 gpm with a correction factor of 2.53.

Reference: Appendix A, Sect. 8.1.1, Fig A8, 8.1.1.1, 8.1.1.2

Fuel consumed at each grade segment

a) Annual fuel consumed at level grade segment is:

Gasoline: (1,109,600 veh-mi)(.092 gpm) =	102,083 gallons
Diesel: (58,400 veh-mi)(.060 gpm) =	3,504 gallons

b) Annual fuel consumed at +1% grade segment is:

Gasoline: (762,850 veh-mi)(.092 gpm)(1.33) =	93,342 gallons
Diesel: (40,150 veh-mi)(.060 gpm)(1.47) =	3,541 gallons

c) Annual fuel consumed at -1% grade segment is:

Gasoline: (762,850 veh-mi)(.092 gpm)(.88) =	61,760 gallons
Diesel: (40,150 veh-mi)(.060 gpm)(.88) =	2,120 gallons

d) Annual fuel consumed at +3% grade segment is:

Gasoline: (624,150 veh-mi)(.092 gpm)(2.02) =	115,992 gallons
Diesel: (32,850 veh-mi)(.043 gpm)(2.53) =	3,574 gallons

e) Annual fuel consumed at -3% grade segment is:

Gasoline: (624,150 veh-mi)(.092 gpm)(.54) =	31,008 gallons
Diesel: (32,850 veh-mi)(.043 gpm)(.54) =	763 gallons

Total gasoline consumed annually by 2-axle, 6 Tire Trucks: 404,186 gallons

Total diesel consumed annualy by 2-axle, 6 Tire Trucks: 13,502 gallons

Equivalent energy = [(404,186 gal)(1.25×10^5 Btu/gal)+(13,502 gal)(1.39×10^5 Btu/gal)] = 5.240×10^{10} Btu

Reference: Appendix A, Sect. 1.6, 1.17.2

3) Direct annual fuel consumption of Tractor-Semitrailer Trucks:

Speed 45 mph, freeflowing conditions: Base consumption = 0.179 gpm (gasoline)
0.124 gpm (diesel)

Reference: Appendix A, Sect. 8.2.1, Fig. A9

Correction factors for grades are:

Grade	Gasoline	Diesel
Level	No correction required	
+1%	1.73	1.65 (Extrapolated)
-1%	0.82	0.82
+3%	*	*
-3%	0.45	0.45

Reference: Appendix A, Sect. 8.2.1.1, 8.2.1.2

*Trucks cannot maintain speed; fuel consumption rates will be for operations as follows: Gasoline Trucks: at 40 mph on +3% grade, i.e., .163 gpm with a correction factor of 3.44; Diesel trucks: at 20 mph on 3% grade, i.e., .147 gpm with a correction factor of 1.58.

Reference: Appendix A, Sect. 8.2.1, Fig A9, Sect. 8.2.1.1, 8.2.1.2

Fuel consumed at each grade segment

a) Annual fuel consumed at level grade segment is:

Gasoline: (569,400 veh-mi)(.179 gpm) =	101,923 gallons
Diesel: (306,600 veh-mi)(.124 gpm) =	38,018 gallons

b) Annual fuel consumed at +1% grade segment is:

Gasoline: (391,463 veh-mi)(.179 gpm)(1.73) =	121,224 gallons
Diesel: (210,788 veh-mi)(.124 gpm)(1.65) =	43,127 gallons

c) Annual fuel consumed at -1% grade segment is:

Gasoline: (391,463 veh-mi)(.179 gpm)(.82) =	57,459 gallons
Diesel: (210,788 veh-mi)(.124 gpm)(.82) =	21,433 gallons

d) Annual fuel consumed at +3% grade segment is:

Gasoline: (320,288 veh-mi)(.163 gpm)(3.44) =	179,592 gallons
Diesel: (172,463 veh-mi)(.147 gpm)(1.58) =	40,056 gallons

e) Annual fuel consumed at -3% grade segment is:

Gasoline: (320,288 veh-mi)(.179 gpm)(.45) =	25,799 gallons
Diesel: (172,463 veh-mi)(.124 gpm)(.45) =	9,623 gallons
Total gasoline consumed annually by Semi Trucks:	485,997 gallons
Total diesel consumed annually by Semi Trucks:	152,258 gallons

Equivalent Energy: $[(485{,}997 \text{ gal})(1.25 \times 10^5 \text{ Btu/gal}) + (152{,}258 \text{ gal})(1.39 \times 10^5 \text{ Btu/gal})] = 8.191 \times 10^{10}$ Btu

Total direct energy consumed annually by all vehicles over the 5.6 mile-long widened project is = $1.714 \times 10^{11} + 5.240 \times 10^{10} + 8.191 \times 10^{10}$ Btu = $\underline{\underline{3.057 \times 10^{11} \text{ Btu}}}$

DIRECT ENERGY CONSUMPTION - No-build alternative

Correction of fuel consumption rate due to congested traffic:

Fraction of traffic that is freeflowing =	20,000 ADT/25,000 ADT = .80
Fraction of traffic that is congested =	5,000 ADT/25,000 ADT = .20

1) Direct energy consumption of cars:

Correction factor for dense traffic: Insufficient information requires an assumption to be made, to allow use of Appendix A, Sect. 7.1.5A

Assume "heavy traffic, 2 stops per mile", and that the effects due to an attempted speed of 45 mph are similar to an attempted speed of 25 mph. Then, the equivalent correction factor would be 1.47.

Reference: Appendix A, Sect. 7.1.5A

The overall correction factor for all cars would then be:

Factor = [(.80)(1.00) + (.20)(1.47)]/(.80 + .20) = 1.09

Thus, the energy consumption of cars under the no-build alternative would be 9% higher than for the build alternative, due to excess fuel consumed by congestion.

Equivalent energy consumed annually by cars = $(1.09)(1.714 \times 10^{11}$ Btu) = 1.868×10^{11} Btu

2) Direct energy consumption of 2-axle, 6 tire trucks:

Correction factor for dense traffic: Similar assumptions as for cars.

Assume "heavy traffic, 2 stops per mile". The equivalent correction factor would be 1.66.

Reference: Appendix A, Sect. 8.1.1.5A

The overall correction factor for all 2-axle trucks would then be:

Factor = [(.80)(1.00) + (.20)(1.66)]/(.80 + .20) = 1.13

Thus, the energy consumption of 2-axle, 6 tire trucks under the no-build alternative would be 13% higher than for the build alternative, due to excess fuel consumed by congestion.

Equivalent energy consumed annually by 2-axle, 6 tire trucks =
$(1.13)(5.240x10^{10}$ Btu) = $5.921x10^{10}$ Btu

3) Direct energy consumption of tractor-semitrailer trucks:

Correction for dense traffic: Similar assumption as for cars

Assume "heavy traffic, 2 stops per mile". The equivalent factor would then be approximately 1.80 by extrapolation from tables.

Reference: Appendix A, Sect. 8.2.1.5A

The overall correction factor for all semi trucks would then be:

Factor = [(.80)(1.00) + (.20)(1.80)]/(.80+.20) = 1.16

Thus, the energy consumption of semi trucks under the no-build alternative would be 16% higher than for the build alternative, due to excess fuel consumed by congestion.

Equivalent energy consumed annually by tractor-semitrailer trucks:
= $(1.16)(8.191x10^{10}$ Btu) = $9.502x10^{10}$ Btu

Total direct energy consumed annually by all vehicles over the 5.6 mile-long existing arterial is: $1.868 \times 10^{11} + 5.921 \times 10^{10} + 9.502 \times 10^{10}$ Btu = $\underline{\underline{3.410 \times 10^{11} \text{ Btu}}}$

INDIRECT ENERGY CONSUMPTION - Build alternative

1) Vehicle-related energy consumption:

Vehicles travelling over this project consume indirect energy as a result of wearout and maintenance related to their operation. A proportionate quantity of the total energy required to manufacture and maintain vehicles must be assigned to the project.

a) Manufacture energy:

Cars: Assume the average weight of cars operating during the study period is between 3500 and 2500 lbs. The energy required to manufacture such vehicles averages 39250 Btu/lb. With an estimated useful life of 100,000 miles, the manufacture energy consumed, expressed in terms of mileage is = (3000 lbs/veh)(39250 Btu/lb)/100,000 mi = 1178 Btu per vehicle-mile.

Reference: Appendix A, Sect. 21.1.1, 21.1.2

Total manufacture energy consumed annually by cars is:

(21,500 vpd)(365 days/yr)(5.6 miles)(1,178 Btu/veh-mi) = 5.177×10^{10} Btu

2-axle, 6-Tire Trucks: For an average weight of 10,000 lbs, the energy required to manufacture such vehicles is 58,000 Btu/lb with an estimated useful life of 200,000 miles, the manufacture energy consumed, expressed in terms of mileage is = (10,000 lbs)(58,000 Btu/lb)/200,000 mi = 2,900 Btu per vehicle-mile.

Reference: Appendix A, Sect. 21.1.4

Total manufacture energy consumed annually by 2-axle, 6-tire trucks is (2,000 vpd)(365 days/yr)(5.6 mi)(2,900 Btu/veh-mi) = 1.186×10^{10} Btu

Tractor-Semi Trailer Trucks: For an average weight of 20,000 lbs, the energy required to manufacture such vehicles is 61,400 Btu/lb. With an estimated useful life of 300,000 miles, the manufacture energy consumed, expressed in terms of mileage is = (20,000 lb)(61,400 Btu lb)/300,000 mi = 4,093 Btu per vehicle-mile

Reference: Appendix A, Sect. 21.1.5

Total manufacture energy consumed annually by tractor-semi trailer trucks is = (1,500 vpd)(365 days/yr)(5.6 mi)(4,093 Btu/veh-mi) = 1.255×10^{10} Btu

The total annual energy associated with vehicle wearout over the project is:

$5.177 \times 10^{10} + 1.186 \times 10^{10} + 1.255 \times 10^{10} = 7.618 \times 10^{10}$ Btu

b) Salvage energy:

The potential energy saving associated with vehicle salvage is assumed to be insignificant.

c) Maintenance energy:

<u>Cars</u>: The value of 1,400 Btu/veh-mi presented in Appendix A, Sect. 22.1.1 appears low. Based on the commentary in Appendix B, Sect. 22.1.1, this value is rejected in favor of estimates using the energy related to tire wear in Appendix A, Sect. 22.1.3.

Energy consumed by tire wear = (4 tires/veh)(580 Btu/mile) = 2,320 Btu/mi

Reference: Appendix A, Sect. 22.1.3.2.

Assume that remaining maintenance would be equivalent to one third the energy required to manufacture the vehicle, i.e., 393 Btu/mi

Thus the required maintenance energy is = 2320 + 393 = 2713 Btu/mi

Total maintenance energy consumed annually by cars is:

(21,500 vpd)(365 days/yr)(5.6 miles)(2,713 Btu/mi) = 1.192×10^{11} Btu

Since the figure of 393 Btu/mi is conjecture, a sensitivity analysis is in order, and will be performed at the conclusion of the calculations.

2-axle, 6-Tire Trucks: Information on maintenance energy is not available; therefore a reasonable estimate would be that it would be similar to cars, and differ by the same ratio as their manufacturing energies:

Thus, the maintenance energy would be: (2,713 Btu/mi)(2900/1178) = 6,679 Btu/mi

Total maintenance energy consumed annually by 2-axle, 6 tire trucks is:

(2,000 vpd)(365 days/yr)(5.6 mi)(6,679 Btu/mi) = 2.730×10^{10} Btu

Tractor-Semi Trailer Trucks: Information on maintenance energy is not available; therefore the same assumption is made as for the 2-axle trucks. The maintenance energy would then be: (2,713 Btu/mi)(4,093/1,178) = 9,426 Btu/mi

Total maintenance energy consumed annually by Tractor-Semi Trailer Trucks is:

(1,500 vpd)(365 days/yr)(5.6 mi)(9,426 Btu/veh-mi) = 2.890×10^{10} Btu

The total annual energy associated with vehicle maintenance over the project is = $1.192 \times 10^{11} + 2.730 \times 10^{10} + 2.890 \times 10^{10}$ Btu = 1.754×10^{11} Btu

The total annual indirect energy associated with vehicle operation over the 5.6 mile-long widened project is = $7.618 \times 10^{10} + 1.754 \times 10^{11} = 2.516 \times 10^{11}$ Btu

2) Facility-related Energy Consumption

Energy consumed by this facility is related to the materials and operations required for construction, including transport, and the energy consumed by operation and maintenance of the project.

a) Construction:

Specific data as to materials quantities are not available; however, cost estimates are available and will be used to estimate the energy consumption, thru use of Appendix A, Sect. 25. Costs, in 1976 dollars, must be converted to 1973-74 constant dollars to permit use of Section 25.2.

Conversion of costs to 1973-74 constant dollars:

Conversion factor for 1976 is not available; it is extrapolated from tables to be 137.67 (for base year 1972).

Conversion: 1976-1973/4 = (.5)(105.92 + 116.20)/137.67 = .807

Reference: Appendix A, Sect. 25.1

Therefore, equivalent 1973/4 costs of proposed project are:

Structures:	(.807)($66,000)	$53,300
Landscaping:	(.807)($43,000)	$34,700
Miscellaneous:	(.807)($15,000)	$12,100
Roadway:	(.807)($3,176,000)	$2,563,000

Information on useful lives of construction, required in order to pro-rate the initial energy expenditure over the life of the project, are not available. The following assumed useful lives will be used:

Structures:	30 yrs
Landscaping:	10 yrs
Miscellaneous:	10 yrs
Roadway:	25 yrs

Equivalent annual energy consumed by construction would be:

Structures: ($53,200)($1.63 \times 10^4$ Btu/$)/30 yrs = 2.896×10^7 Btu

Reference: Appendix A, Sect. 25.2.3

Landscaping: ($34,700)($1.03 \times 10^4$ Btu/$)/10 yrs = 3.574×10^7 Btu

Reference: Appendix A, Sect. 25.2.4

Miscellaneous: (\$21,100)(9.70×10^3 Btu/\$)/10 yrs = 1.174×10^7 Btu

Reference: Appendix A, Sect. 25.2.5

Roadway: (\$2,562,100)(1.92×10^4 Btu/\$)/25 yrs = 1.968×10^9 Btu

Reference: Appendix A, Sect. 25.2.2.4

Total equivalent annual energy consumed by construction is:

$2.896 \times 10^7 + 3.574 \times 10^7 + 1.174 \times 10^7 + 1.968 \times 10^9 =$ 2.044×10^9 Btu

Energy consumed annually for maintenance is not known in sufficient detail, and no distinctions exist between maintenance of new or old sections. The estimate will be made using the best available data, assuming that most of the maintenance energy is expended on the roadway, and making no distinction between new and old pavements. After construction, the "build" alternative would require maintenance of both the old plus the widened sections, a total of 6 lanes, or 33.6 lane-miles, of AC (flexible) pavement.

Annual Maintenance Energy = (33.6 ln-mi)(1.20×10^8 Btu/ln-mi/yr) = 4.032×10^9 Btu

3) Peripheral energy consumption effects will be negligible, since the project

a) will not increase traffic volume by significant levels

b) will not pre-empt use of other transportation modes

c) will not encroach upon land and structures currently used, or likely to be used for other purposes.

Total indirect energy consumed annually by build alternative is:

$2.516 \times 10^{11} + 2.044 \times 10^{9} + 4.032 \times 10^{9} = \underline{\underline{2.577 \times 10^{11}}}$ Btu

INDIRECT ENERGY CONSUMPTION - No-Build Alternative

1) Vehicle-related Energy Consumption

Since the traffic volume is the same as for the build alternative, indirect energy would be substantially the same, or slightly higher due to the portion of vehicles which are involved in congested traffic.

No information is available on indirect energy related to traffic congestion. It will be assumed that one-half of the vehicle indirect energy is related to mileage only, and the remainder may be influenced by the same factors that affect fuel consumption. Then, half of the total indirect energy would be equal to the same as for the build alternative, i.e. $(.5)(2.516 \times 10^{11}$ Btu$) = 1.258 \times 10^{11}$ Btu, and the remaining half would be higher by the ratio of their direct energy (fuel) consumption, i.e. $(.5)(2.516 \times 10^{11}$ Btu$)(3.398 \times 10^{11}/3.045 \times 10^{11}) = 1.404 \times 10^{11}$ Btu.

The total annual energy associated with vehicle operations over the existing 5.6 mile long section is $= 1.258 \times 10^{11} + 1.404 \times 10^{11} = 2.662 \times 10^{11}$ Btu

2) Facility-related Energy Consumption

Energy consumed by this facility is related to maintenance only, as there is no new construction, and no data are available to allow estimation of useful life and date of possible reconstruction of the existing road. In addition, the original construction energy has already been expended, and, being unrecoverable, has no bearing in this analysis.

The existing section consists of 4 lanes, or 22.4 lane-miles of AC (flexible) pavement.

Annual Maintenance Energy = (22.4 ln-mi)(1.20×10^{8} Btu/ln-mi/yr) = 2.688×10^{9} Btu

Total indirect energy consumed annually by the no-build alternative is = $2.662 \times 10^{11} + 2.688 \times 10^{9} =$ <u>2.689×10^{11} Btu</u>

Sensitivity Analysis: Since vehicle maintenance energy (less tires) was based on conjecture, calculations will be performed to determine to what extent the final energy total would be effected by an error in the selection of this value. This will be done for the "build" alternative only.

Assume that for an error to be "significant", it must alter the final total by a factor greater than 10%, or 5.622×10^{10} Btu annually.

The total vehicle maintenance energy has been computed as 1.754×10^{11} Btu.

Of this figure, the fraction affected by the value under investigation is $(393/2713)(1.754 \times 10^{11}$ Btu$) = 2.541 \times 10^{10}$ Btu annually.

Thus, the value for vehicle maintenance energy may be 2.2 times higher or lower than the one selected, without significantly affecting the results of the study.

It is concluded that reasonable errors in the value for vehicle maintenance energy will not affect the results of this study.

SUMMATION:

Annual equivalent energy in Btu consumed by alternatives.

	Build	No-Build
Direct Energy		
Cars	$1.714x10^{11}$	$1.868x10^{11}$
2-Axle-6 Tire Trucks	$5.240x10^{10}$	$5.921x10^{10}$
Tractor-Semitrailer Trucks	$8.191x10^{10}$	$9.502x10^{10}$
Total Direct	$3.057x10^{11}$	$3.410x10^{11}$
Indirect Energy		
Vehicle-related	$2.516x10^{11}$	$2.662x10^{11}$
Facility Construction	$2.044x10^{9}$	0
Facility Maintenance	$4.032x10^{9}$	$2.688x10^{9}$
Peripheral Effects	NIL	NIL
Total Indirect	$2.577x10^{11}$	$2.689x10^{11}$
Total Energy expended annually:	$5.634x10^{11}$	$6.101x10^{11}$
Total energy in terms of equivalent barrels of crude oil per day:	266 Bbl	288 Bbl

Reference: Appendix D

Conclusion: The "build" alternative will consume approximately 8% less total energy than the "no-build" alternative. However, due to uncertainties about the data at the current state-of-the-art, this small difference between the alternatives indicates that both alternatives are essentially equal with respect to energy consumption.

Example Problem No. 3

A large metropolitan area, consisting of an urban core and low density suburbs, has a freeway system which, in the past, provided excellent transportation service. Congestion is now beginning to develop during commute hours from suburbs to core, and it is expected that levels of service will be significantly affected in the future.

The planning agency is considering several alternative actions to alleviate or improve the impending conditions. One of the alternatives is the creation of an electric-powered rail mass transit system between the core and suburbs, on available right-of-way. It is hoped this system will attract commuters using private cars, whose occupancy factor is a low 1.1 persons per vehicle, thus creating a more energy-efficient transportation.

Required: Discuss briefly the items that must be considered in an energy analysis for the rail mass transit alternative.

Solution to Problem No. 3

It should be emphasized at the outset that this problem considers only one of several competing alternatives, and a separate analysis should be made for each, prior to comparisons.

Discussion of steps required for the energy analysis:

1. Direct Energy

Rail Mass Transit vehicles consume electrical energy for propulsion. Given the proposed time, distance, and route schedules, and the energy consumption characteristics of the vehicles, the direct energy will be computed. Since the "fuel" is electricity, the value must be multiplied by a factor of 3 to account for the quantity of primary energy input at the electric powerplant.

In case information on energy consumption is not available, estimates will be made using Appendix A, Section 13.0 which presents data from selected rail mass transit systems.

Transportation is portal-to-portal, thus direct energy must include the relatively short trips from places of residence to the stations, and from other stations to the place of work, and back again. Connector trips made by car will be assumed to consume fuel under "cold start" conditions, which is less efficient (Appendix A, Section 7.0). Trip lengths would depend on whether "park-n-ride" or "kiss-n-ride" situations prevail. Connector trips made by other mode, such as local bus service will also be considered (Appendix A, Sect. 9.2.2). An estimate will be made of the percentage of bus system riders which would use it as a connector, and the appropriate portion of bus direct energy will be charged to this alternative.

Estimates must also be made of the number and type of vehicles removed from the freeway because the riders would switch to the mass transit system. The direct energy of these vehicles (energy saved) will be credited to this alternative.

The sum of the above computations will represent the total direct energy consumed by this alternative. Since traffic, ridership, and other parameters change with time, it is convenient to present data based on an "average year" representing the time period under study.

2. Indirect Energy

a. Vehicle Related

The energy consumed in the materials and manufacturing of the mass transit vehicles will be computed. A search through current literature may be necessary to provide data. In case better information is not available, estimates based on Appendix A, Section 21.0 will be used. Manufacturing energy will be pro-rated over the expected useful life of the vehicles.

The energy consumed for the materials and manufacture of "connector" cars, busses, etc. will be computed, and pro-rated over their useful lives. A portion of the resulting values will be charged to the alternative, in direct proportion to their use as connectors. Similarly, a portion of the manufacture energy of those vehicles removed from the road will be credited to the alternative.

Vehicle maintenance energy will be computed, for the mass transit and connector vehicles. Available data are scarce, and a literature search may be necessary to provide meaningful values. Appendix A Section 22.0 provides insufficient information. As a reasonable estimate, a maintenance value of 2/3 times the manufacture energy for mass transit vehicles will be used. This would be pro-rated over the useful life of the vehicles.

b. System Related

The energy consumed by materials and construction of the rail system will be computed. This would encompass all facilities, including trackage, stations, maintenance yards, access roads and/or parking lots (if any), and all other installations connected with the system. Depending on the detail of information available, energy estimates will be made based on materials quantities and construction, using Appendix A, Sections 3.0, 4.0, 5.0, and 23.2. If only cost figures are available, estimates will be made based on Appendix A, Section 25.0. The system construction energy will be pro-rated over its expected useful life.

System operation energy (less direct, propulsion energy) will be estimated. This would include station operations, lighting, HVAC, escalators, as well as signals, traffic control monitoring, administration buildings, etc. Available data are scarce, and a literature search may be necessary to provide meaningful values. Appendix B, Section 23.3.2 provides limited information.

System maintenance energy will be estimated, and a literature search will be necessary, as data are not available. Existing systems may be studied to determine the quantity and size of their maintenance facilities such as yards, rail and vehicle repair equipment, routine maintenance schedules. An estimate of the annual energy of the system will be made. Included would be an appropriate portion of the energy consumed in maintaining the connector systems.

An estimate will also be made of the potential energy savings (or loss) available in the future salvage of the system. Information on this aspect of the analysis is not available. It is believed that the magnitude of salvage energy is not significant.

c. Peripheral Energy Change

A study will be made of the regional electrical energy supply. If the additional load due to the mass transit facility will necessitate construction of additional powerplant(s), the energy to construct and maintain such plant(s) will be charged to this alternative.

A study will be made of the effect of population growth and shift of land use (if any) attributable to the new transportation system. Cultivated land produces energy in the form of biological products, which would be lost if the land is converted to housing or other non-agricultral development. Appendix A, Section 26.0 or other data sources will be used to compute the bioenergy lost.

Shifting of land use caused by this alternative will have an effect on the energy consumption characteristics of the region. Increase or decrease in population, and changes in population density will affect the rate of consumption. Appendix A, Section 28.0 or other data sources will be used to compute the energy change. If significant quantities of additional energy will be required to meet predicted needs, the alternative must be charged with providing this energy.

Another factor to be considered is induced growth in freeway trips. Relief of congestion on the road, brought about by shifts from automobile to mass transit, will attract other automobile trips not previously made. The mass transit alternative may reduce the need for additional vehicles per family, thus saving the manufacture and maintenance energy of each vehicle not purchased. On the other hand, automobiles previously committed to commuting would be available for other uses, which may generate new, additional travel. Once this information is developed, energy impacts will be computed using ~~Appendix A data.~~

SUMMARY

The computed values would be summed and presented in the format of direct, indirect, and total energy. Units would be in terms of Btu (or joules) per year for an average year of operation. A value of equivalent barrels of crude oil per day would also be presented for the benefit of laymen.

This alternative would be compared with similar analyses of other alternatives which would provide the equivalent transportation service.

APPENDIX G

TRANSPORTATION ENERGY COMPUTER PROGRAMS

SELECTED TRANSPORTATION MODELS

1) Multi-Modal (freight)

a) The TRANSEN Model

TRANSEN is a computer model which was developed to quantify mode- and commodity-specific energy intensiveness under different assumptions about future energy consumption by the different modes in intracity freight. The model relates transportation performance parameters to energy utilization, which permits analysis of the way in which changes in operating conditions and technology affect transportation performance and, consequently, energy consumption. See Leilich, Robert H.; Modal Energy Consumption and Intensity, a paper delivered at Union College, August 6, 1976, covering work by Peat, Marwick, Mitchell and Company under contract to transportation Systems Center, Cambridge University.

2) Truck

a) VMT Model (Vehicle Mission Simulation model developed by Cummins Engine Company)

This model is being used to analyze individual truck routes, predicting fuel economy for a given set of road conditions and truck operating characteristics (engine size, gearing, tires). It permits fuel economy analysis without actual test runs on any on-highway vehicle. See Schutz, Peter W.; Kokkenga, Donald A.; and Stattenfield, David B.; "Vehicle Mission Simulation", SAE Paper 700567.

3) Auto-Truck

a) FREQ4CP Model

An advanced technology transportation model that can be used to assess the short- and longer-term impacts of freeway ramp control and preferential freeway lanes on fuel consumption. FREQ4CP is written in ANS FORTRAN language See Kruger, Abraham J. and May, Adolf D.; The Analysis and Evaluation of Selected Impacts of Traffic Management Strategies on Freeways, University of California, Berkeley Special Report UCB-ITS-76-4, October 1976.

b) TRANSYT 6B Model

A surface street model which can be used to assess the energy impacts of various traffic management strategies. See Clausen, Thomas J. and May, Adolf D.: The Analysis and

Evaluation of Selected Impacts of Traffic Management Strategies on Surface Streets, University of California, Berkeley, Special Report UCB-ITS-SR-76-10, October 1976, (119 pp).

c) UTCS-1 Model

A validated microscopic simulation traffic model wherein each vehicle is identified and processed as a discrete entity. Fuel consumption is presented for each network link, and also aggregated over the network. See Worrall, R.D. and Lieberman, E. B.; Network Flow Simulation for Urban Traffic Control System, Phase II, Volumes 1-5, Technical Reports PB 230-760 through 764, March 1973.

d) ENDEL Model

This program calculates optimal traffic signal timing for minimizing delay and for minimizing excess fuel consumption due to traffic signals. Restricted to 2 phase, 4 legged approaches with or without "all red" period. Write Engineering and Industrial Experiment Station, College of Engineering, University of Florida, Gainsville, Florida (32611). Also see Traffic Engineering magazine, November 1975, article by Courage and Papapar.

e) ENERGY3 Model

This computer program calculates propulsion energy over a particular roadway along with indirect energies associated with the construction, maintenance, and replacement of the vehicles, roadways, and appurtenant features. In the model, indirect energies are mostly derived from dollar costs by the use of energy coefficients. Propulsion energy is predicated on NCHRPR #111 methods, with corrections for newer auto technologies. This program is written in Basic TENET language. (California Department of Transportation, TRANSLAB, 5900 Folsom Boulevard, Sacramento, CA 95819)

4) Rail

a) TPS Model

A very sophisticated model permitting the introduction of many parameters, and written in FORTRAN language and employed by the Transportation Systems Center (TSC) of Cambridge University. See Hopkins, John B.; Railroads and the Environment, Estimate of Fuel Consumption in Rail Transportation, PB 244150, May 1975.

b) Aerospace Corporation's APL (language) simulation of Rail Travel

A somewhat simpler model, augmented for corridor studies by their TSS model, designed to compute modal split. This model is usable by anyone having an APL terminal. APL language can be easily converted into Cobol, FORTRAN, or PL-1, if an APL compiler is lacking. This program was originally designed for the analyses of the Northeast Corridor passenger rail service. See Sokolsky, S.; Energy Savings Resulting From Modal Shifts to Corridorrail, the Aerospace Corporation, El Segundo, CA.