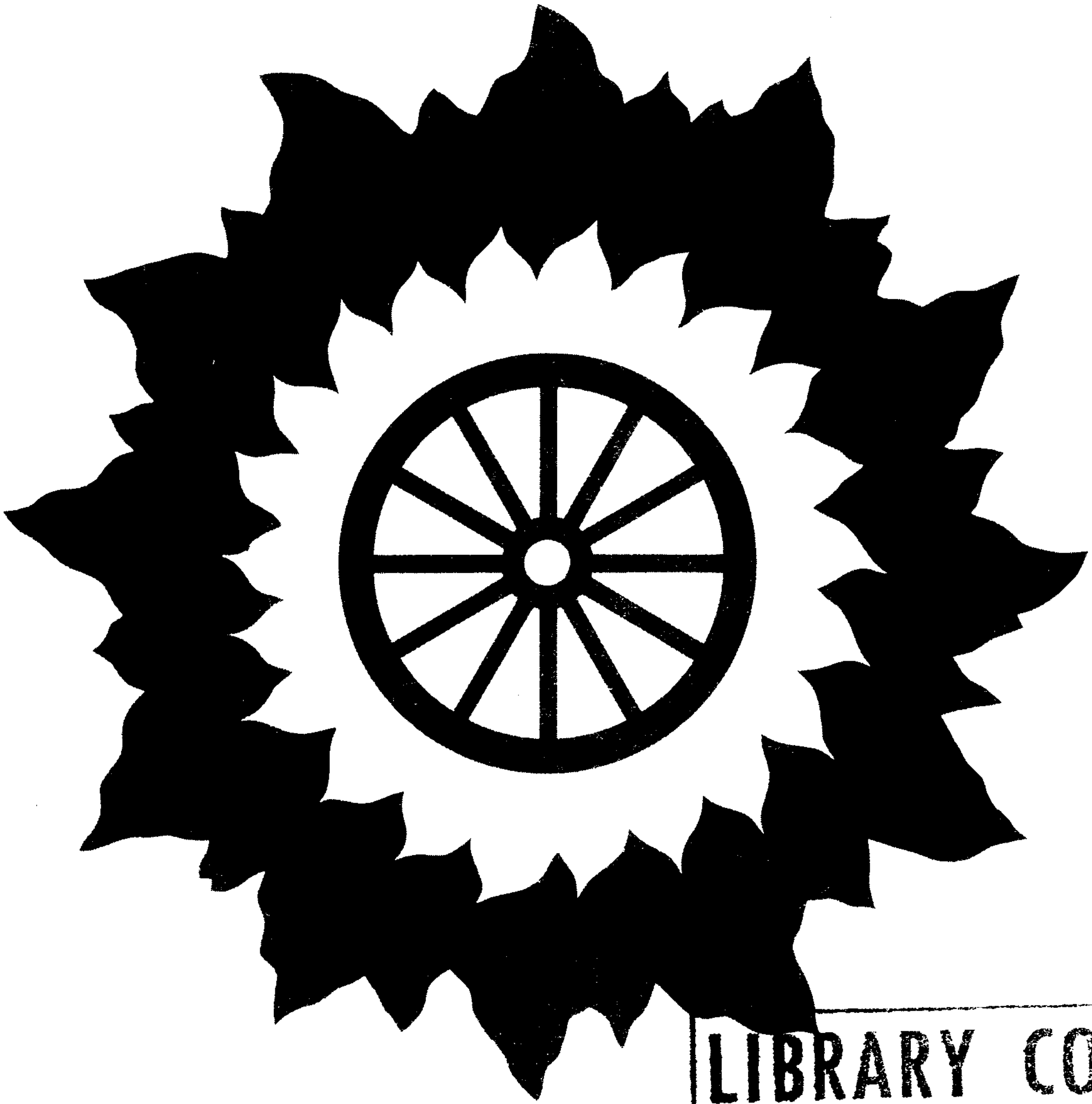
Energy Requirements for Transportation Systems

June 1980



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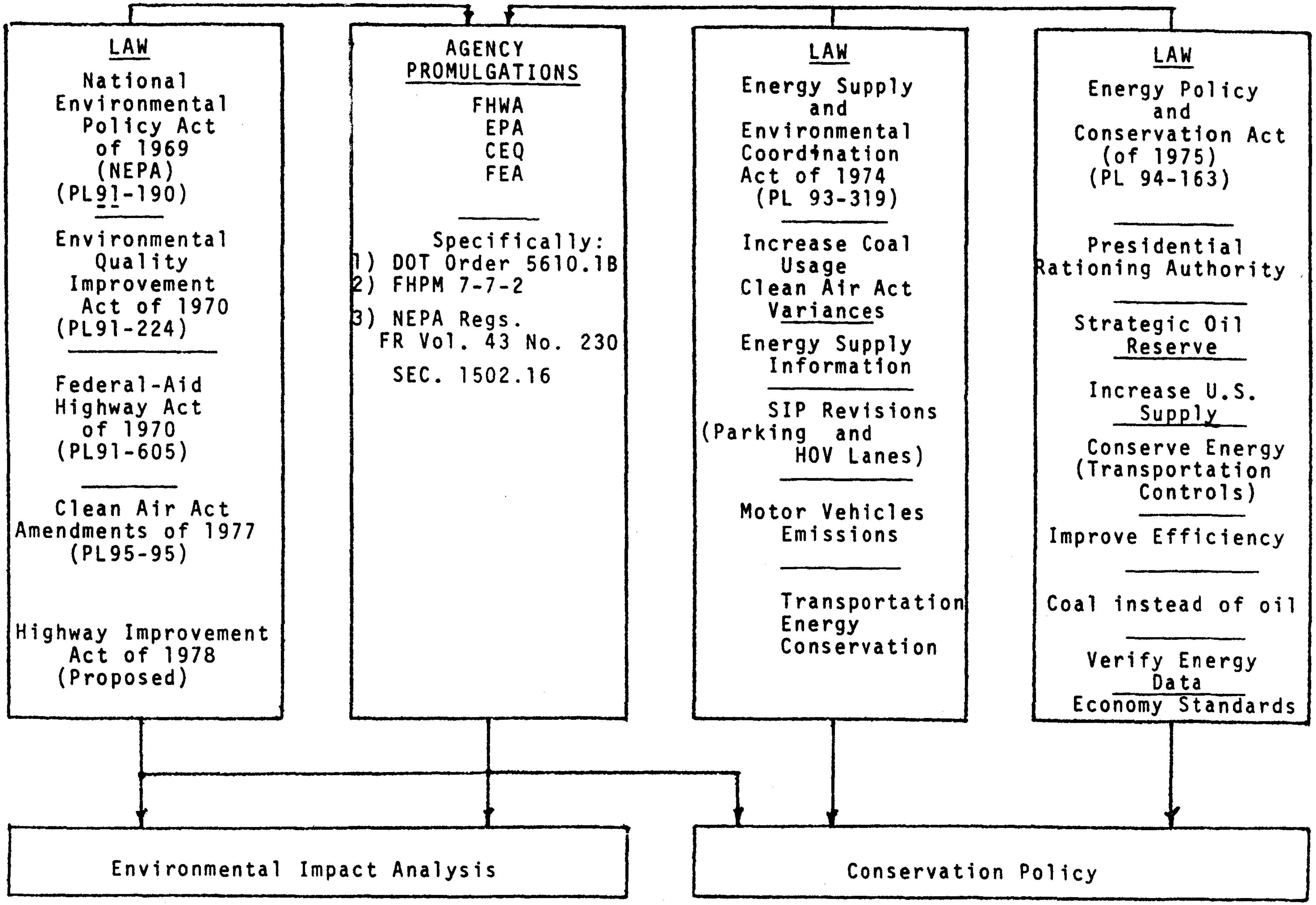
FEDERAL LEGISLATION AND REGULATIONS
AFFECTING TRANSPORTATION/ENERGY RELATIONSHIPS



FEDERAL
PROMULGATIONS ESTABLISHING THE REQUIREMENT FOR AN ENERGY ANALYSIS IN AN EIS

1) DOT Order 5610.1B contains the following (about EIS's) in Attachment 2:

> "10. Energy Supply and Natural Resources Development. Where applicable, the statement should reflect consideration of whether the project or program will have any effect on either the production or consumption of energy and other natural resources, and discuss such effects if they are significant."

2) FHPM 7-7-2 contains the following:

> "(2) Direct (primary) impacts upon the narrow band adjacent to the highway may be included when significant to the whole of the region or the community. The discussions under this section should address the probable significant impacts of the action (as opposed to individual alternative locations or designs). These might include the probable impact upon elements, factors, and features listed below."
>
> > "(a) Natural, Ecological, or Scenic Resources Impacts. This section will summarize the significant effects on natural, ecological, and scenic resources anticipated to be associated with the implementation of the proposed action, including a summary of consultations with the appropriate public and governmental agencies. One example of a natural resource impact would be the effect an action would have on the consumption of energy resources."

3) CEQ regulations to implement Section 102(2) of NEPA were promulgated in FR Vol. 43, No. 230, on November 29, 1978 and become effective July 30, 1979. Article 1502.16, of these regulations calls for the discussion of energy impacts in an EIS as follows:

> "(e) Energy requirements and conservation potential of various alternatives and mitigation measures."

Discussion in the promulgation concerning that paragraph is as follows:

> " Subsection(e) of this section requires an environmental impact statement to discuss energy requirements and conservation potential of various alternatives and mitigation measures. One commenter asked whether the subsection would require agencies to analyze total energ costs, including possible hidden or indirect costs and total energy benefits of proposed actions. The Council intends that the subsection be interpreted in this way."

SOME ENERGY SOURCES AND FORMS

	ORGANIC	INORGANIC	
Non-renewable (Capital Energy)	Fossil Fuels Oil Gas Coal Oil Shale Etc.	Atomic & Molecular Bonds Chemical Bonds Geothermal	Stored by Nature
Renewable (income energy)	New Fuels Wood Decomposition Gas Fermentation Bio-Waste Etc.		
Available Day to Day (Income Energy)	Muscle Power	Wind Tide Thermal Gradient Solar Heat Solar Light Falling Water, etc.	Temporarily Storable by man

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 [illegible] respect to modal, spatial, and temporal alternatives both for planning [illegible] design using the energy factors established. The final objective was to develop a rational method for reporting [illegible] 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.

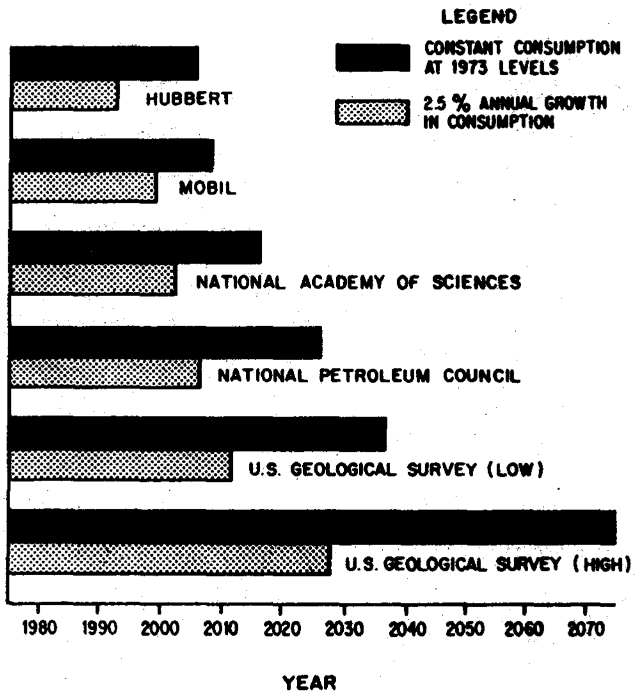


Fig. 1 Estimates of exhaustion date for domestic oil and natural gas liquids, assuming 35 percent imports.
Source: Ref. (2)

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.

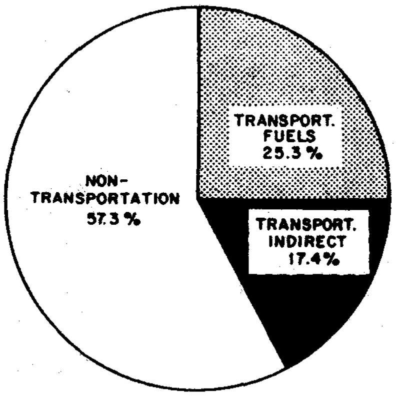


Fig. 2. Distribution of total U.S. energy consumption (1967).
Source: Loebl et al.(6).

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 gasoline by 1985, as opposed to the prevailing rate of 14 to 15 miles per gallon in 1975, when the law was signed.

Long-term conservation techniques involve research in the field of transportation 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 in the field of alternative modes of transportation 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).

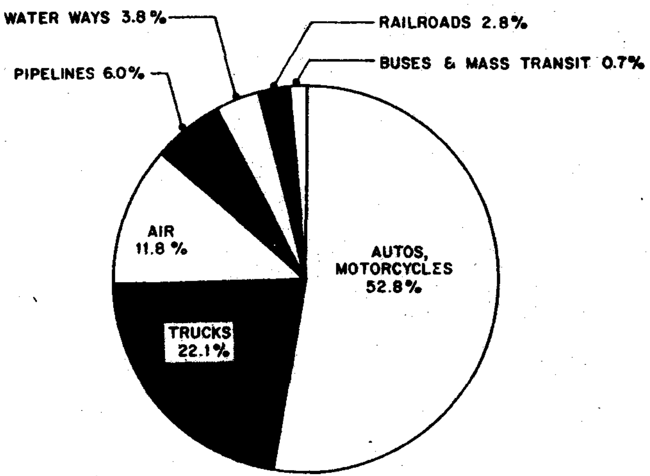


Fig. 3. Proportion of direct energy consumed, by transportation mode (1972).
Source: Pollard et al (5).

The real problem, however, is one inescapable fact: All indications are that 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 lead 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 systems-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 informed 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.

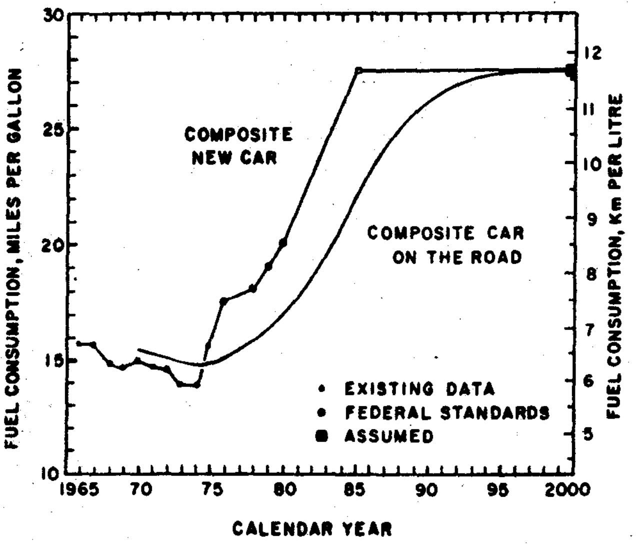


Fig. 4. Fuel consumption rates of composite passenger cars (weighted EPA: 45% rural cycle, 55% urban cycle).

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.

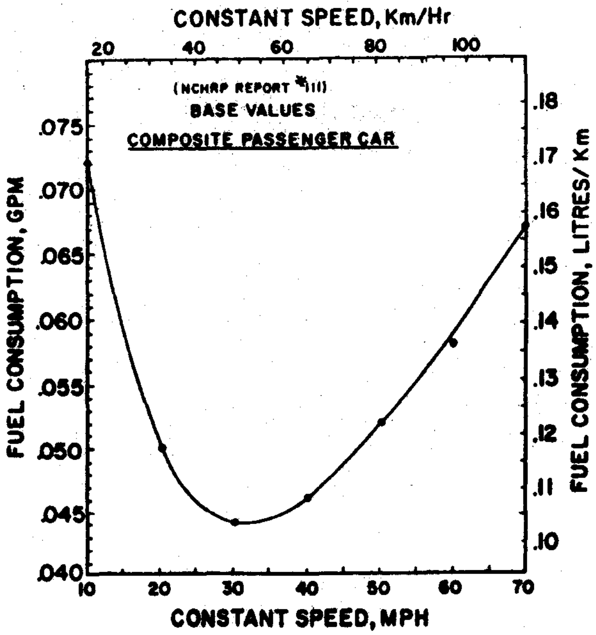


Fig. 5. Fuel consumption of composite passenger car on the road, at constant speeds. (base year = 1974)

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.

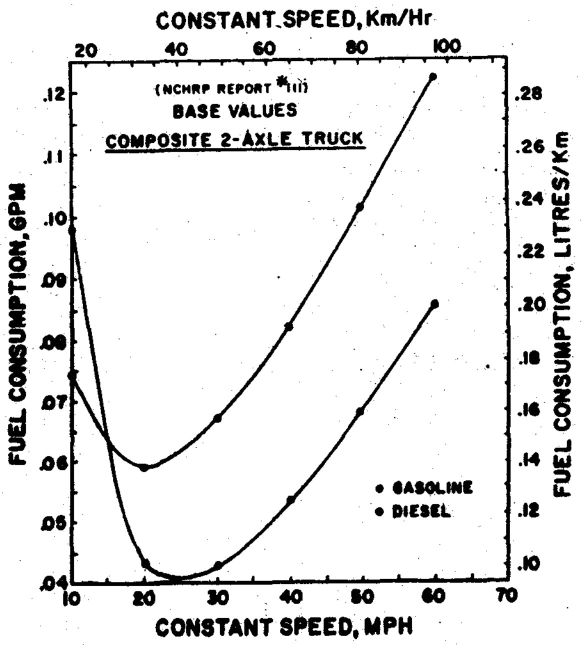


Fig. 6. Fuel consumption of composite 2-axle, 6-tire truck.

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.

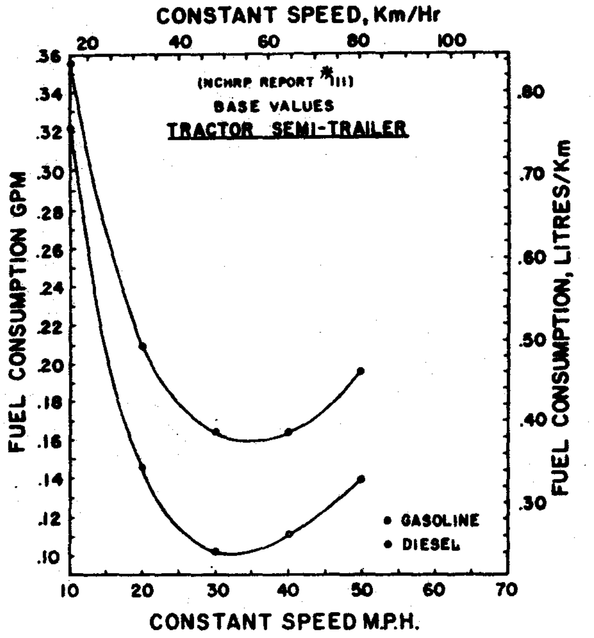


Fig. 7. Fuel consumption of composite tractor-semitrailer truck from 40,000 to 50,000 lb GVW.

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.

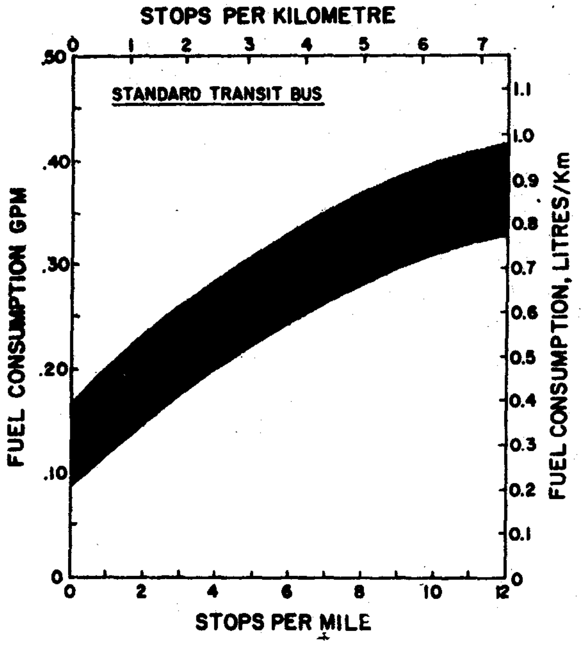


Fig. 8. Diesel fuel consumed vs bus stop frequency.

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-semitrailer 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 distance 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 of 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 the 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.

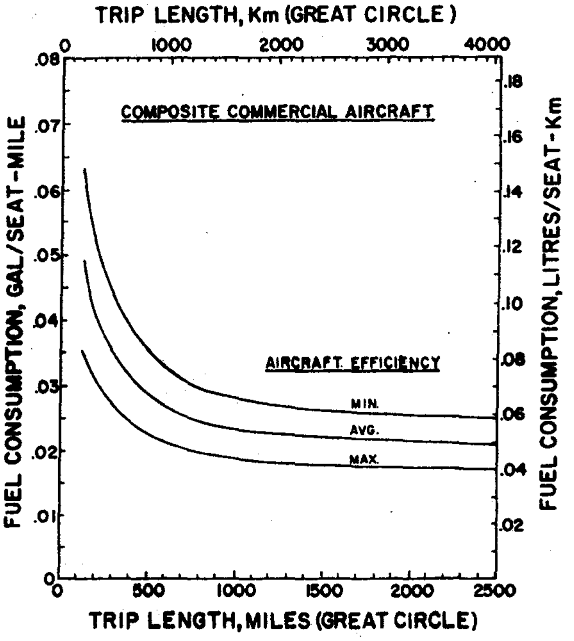


Fig. 9. Influence of trip length on jet fuel consumption of composite commercial passenger airplane.

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 efficienty 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.

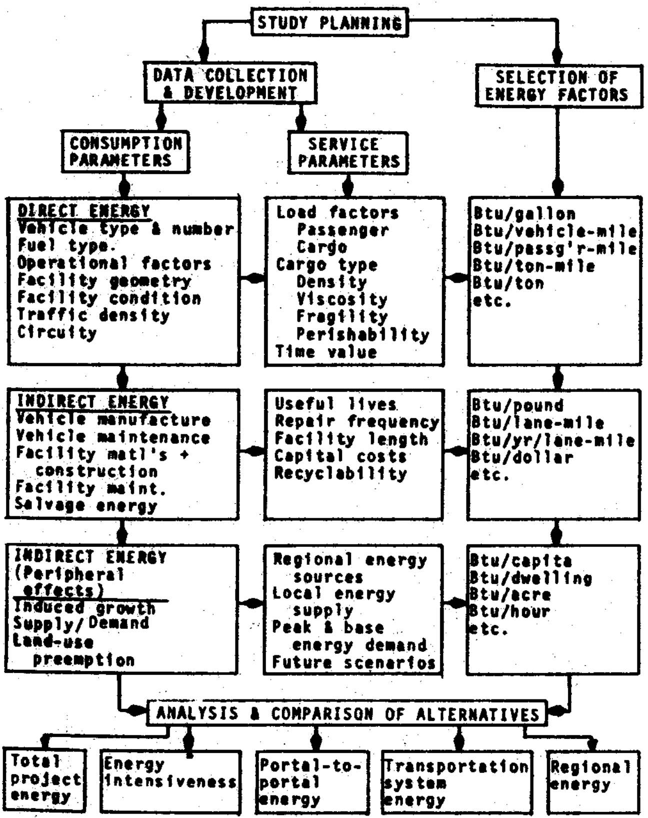


Fig. 10. Flow diagram: energy study methodology.

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 wastes 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 factors 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.

	Equivalent Annual Consumption	
Energy Consumption, by Source	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 3 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.

ENERGY CONSERVATION

More and more people are recognizing that certain resources (metals, petrochemicals, mineral fuels, etc.), important to our life style, are in increasingly short supply. The demand for these resources, while increasing at a relatively uniform rate in the United States (4.5% for energy) and other developed countries, is accelerating very rapidly in the developing nations of Africa, Asia, and South America.

One of the most important of these resources supporting our life style is petroleum. An end to the "age of oil" is foreseen around the close of the century. Other sources of energy either are not fully developed, or are limited by a finite supply (uranium), to the extent that energy will be an extremely critical resource during the transition period from oil to other sources. For this reason, if no other, conservation should be a paramount concern. This is recognized in the Energy Supply and Environmental Coordination Act of 1974, and the Energy Policy and Conservation Act of 1975.

Both of these Acts recognize the magnitude of energy consumption by the transportation sector, the special need for portable energy, and the opportunities for energy conservation in that sector.

To be successful in today's world, a resource conservation program should do three things: 1) make the resource last as long as possible; 2) minimize environmental impact, 3) establish coordination with goals of other programs, and 4) educate the Public to obtain their support.

Making the resource last as long as possible is best illustrated by looking at a "typical" depletion curve. The quantity (Q) is finite and the length of time over which it is available depends upon the rate of usage.

Avenues of approach to extend a resource are: 1) substitution of natural or synthetic products, 2) recycling, and 3) decreasing the use of the resource through reorientation of life style or improving the efficiency of usage of the resource. The first two avenues are aimed at artificially increasing Q, while the third changes the rate of usage. The ideal avenue, of course, would be to arrive at an "Environmental Balance" where the interactions of population control and life style would balance the rate of availability of the resource.

Minimizing environmental impact is especially important where energy is concerned. Historically, the uncontrolled burning of high sulfur fuels and the mining of coal, in particular, have created totally unacceptable impacts. The program for the substitution of coal for oil will have to move carefully through these areas. Changes in life style constitute a social environmental impact. The magnitude of this impact heavily affects public willingness to accept the conservation strategy. The Los Angeles area "Diamond Lane" controversy on the Santa Monica Freeway is a case in point.

Coordination with the goals of other programs would seem to be an obvious aim. Looking at three existing automobile programs - safety, air pollution, and energy conservation - shows that coordination appears to be very difficult to attain. Taken at face value, the first two programs are counter productive to the third. Safety was approached by adding weight while it must be taken off for energy conservation and the early automotive air pollution control approaches increased fuel consumption.

The most often overlooked aspect of any governmental program is the education of the public as to the reason for the program, its extent, and the importance of their cooperation.

Opportunities for energy conservation in a transportation system are wide ranging. The alternatives are both technological and administrative. They are both short-term and long-term. They exist in direct energy usage, indirect energy usage, and peripheral energy usage. They exist with a particular mode and between different modes. They exist for all the functions - planning, design, construction, operation, and maintenance.

An energy conservation program consists of several strategies. The strategies, in turn, consist of a mix of the alternatives listed above, some of which may be in the nature of disincentives.

APPROACH SUMMARY

Strategies are often seen in terms of general approaches. A report (85) from the Mitre Corporation lists the following five categories:

1) Shift traffic to more efficient modes.
2) Increase load factors.
3) Reduce travel demand.
4) Increase energy conversion efficiency.
5) Improve usage patterns.

The U. S. Department of Transportation (86) had the same things in mind, but was a little more definitive in listing ten objectives:

1) Improve high occupancy vehicle (HOV) flow.
2) Improve total traffic flow.
3) Increase car and van occupancy.
4) Increase transit patronage.
5) Encourage pedestrian and bicycle modes.
6) Improve the efficiency of taxi service and goods movement.
7) Restrict traffic.
8) Adjust transportation pricing.
9) Reduce the need to travel.
10) Restrict energy use.

The Transportation Systems Center of the U. S. DOT took a look (87) at the following categories, depending on the mode analyzed:

1) Vehicle efficiency.
2) Load factor.
3) Operational improvements.
4) Service reduction.
5) Speed limits.
6) Increased hold usage on passenger aircraft.
7) Rail electrification.
8) Mode shifts.
9) Vehicle life extension.

A conservation matrix developed by the National Petroleum Council (88) listed some general and some specific measures:

1) Car-pooling.
2) Travel characteristics.
3) Speed limits.
4) Vehicle design.
5) Vehicle maintenance.
6) Change to small cars.
7) Relax emission standards.
8) Mode shifts.
9) Weight (trucks).
10) Operating procedures (trucks).
11) Expanded bus utilization.
12) Roadway improvements.
13) Flight reductions (aircraft)

14) Increased peak hour ridership (mass transit).
15) Spreading peak hour ridership (mass transit).
16) Improved load factor (buses).
17) Additional urban buses.
18) Mini-bus (vans) commuting system.

The Department of Energy of the State of New Jersey states (89) that conservation is not curtailment, but rather the elimination of waste. The focus of efforts to eliminate waste is primarily on the promotion of technologies to increase efficiency of use and secondarily on the advocacy of changes in life style. Conservation measures that the Department will support are directed at the energy-efficient use of vehicles and roadways and include:

1) Increased auto occupancy.
    a) Active marketing of ridesharing.
    b) HOV traffic and toll preference.
2) Improve low-speed traffic flow.
3) Encourage more energy-efficient cars.
4) Enforce the 55 MPH speed limit.
5) Promote energy efficient street lighting.
6) Improve bus access and movement.
7) Improve parking management.
    a) HOV preference.
    b) Park and ride expansion.
    c) Short-term parking preference.
    d) Coordination of parking restrictions with mass transit improvement.

Conservation concerns of the Congress for transportation energy, expressed in the "Energy Supply and Environmental Coordination Act of 1974", focused on the expansion and improvement of public transportation systems and encouragement of increased ridership.

The 1975 "Energy Policy and Conservation Act" looked at transportation energy conservation from the viewpoint of improving automotive fuel economy (efficiency) at the point of manufacture. With regard to State Energy Conservation Plans, specific actions of: 1) promoting carpools, vanpools, and public transportation; and 2) permission of right-turn-on-red laws were made mandatory. The inclusion of "Transportation Controls" in the Plans was made elective.

CONCLUSIONS

Analysis of the various conservation measures, ignoring those which impose restrictions on travel or fuel purchase, shows that the greatest savings occur in the areas of increased vehicle efficiency and increased load factors. A report by U. S. DOT (90) shows that the "highway mode" has the major potential for energy conservation in these areas over the next 20 years.

Very little mention was made of conservation efforts aimed at indirect usage of energy. While major savings will be made through changes in overall fleet fuel economy and lesser changes through increased load factors, it is still important to effect economies in such areas as lighting, HVAC, construction, maintenance, etc.

A recent publication from the Transportation Research Board (91) emphasized ways of optimizing the use of materials and energy during the construction phase of transportation projects.

Increased emphasis on the coordination of other programs (e.q., safety and air quality) with energy conservation efforts is badly needed. Another area worthy of attention is that of public education. Not only do many proposed conservation measures require changes in life style to insure their success, but also much of the public is ignorant of, or not concerned with, the impendin fossil fuel crisis. A public education program should be an integral part of all energy conservation programs.

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