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16. ABSTRACT

The objective of this study was to upgrade the publication titled, "Energy and Transportation Systems." The most recent data for establishing factors for calculating direct and indirect energy usage on a highway improvement project were incorporated into a new report. Energy analysis and updated factors are discussed separately for recycling asphalt concrete pavements and for light rail systems.

A new criterion for impact was developed and life cycle costing is discussed. The computer program for performing an energy analysis on a highway project has been expanded and improved.

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ENERGY AND TRANSPORTATON SYSTEMS

JULY 1983

Caltrans

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF ENGINEERING SERVICES
OFFICE OF TRANSPORTATION LABORATORY

ENERGY AND TRANSPORTATION SYSTEMS

July 1983

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Neither the State of California nor the United States Government endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.

CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English Unit	Multiply By	To Get Metric Equivalent
Length	inches (in) or (")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft) or (')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in ^{2}) square feet (ft ^{2}) acres	6.4516×10^{-4} .09290 .4047	square metres (m ^{2}) square metres m ^{2}) hectares (ha)
Volume	gallons (gal) cubic feet (ft ^{3}) cubic yards (yd ^{3})	3.785 .02832 .7646	litre (l) cubic metres (m ^{3}) cubic metres (m ^{3})
Volume/Time	cubic feet per		
(Flow)	second (ft ^{3}/s)	28.317	litres per second (L/s)
	gallons per minute (gal/min)	.06309	litres per second (L/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph) feet per second (fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s ^{2})	.3048	metres per second squared (m/s ^{2})
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s ^{2})
Density	(lb/ft ^{3})	16.02	kilograms per cubic metre (kg/m ^{3})
Force	pounds (lb) kips (1000 lb)	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British thermal unit (Btu)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (in-lb) foot-pounds (ft-lb)	.1130 1.356	newton metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (°)	$\frac{°F - 32}{1.8} = °C$	degrees celsius (° C)
Concentration	parts per million (ppm)	1	milligrams per kilogram (mg/kg)

CONVERSION FACTORS

Multiply	By	To Obtain
Btu	3.929×10^{-4}	horsepower - hours
Btu	1054.8	joules
Btu	2.930×10^{-4}	kilowatt - hours
Btu/gal	278.7	joules/liter
Btu/lb	2325.8	joules/kg
Btu/ft^3	37217.5	joules/m^3
Btu/ft^2	11345.5	joules/m^2
Btu/lin-ft	3458	joules/m
Btu/lane-mile	654.9	joules/lane-km
Btu/ton-mile	594.59	joules/metric ton-km
Lb/gal	0.1198	kilograms/liter
Lb/ft^3	16.023	kilograms/meter^3
Lb/lin-ft	1.488	kilograms/lin-meter
MPH	1.609344	kilometers/hours
MPG	0.42514	kilometers/liter
MPG	0.000425	kilometers/cm^3
Ton(2000 lb)	0.907185	metric tons(1000 kg)
Ton-mile/gal	0.385684	metric ton-km/liter
Gallon(U.S.)	3.7854	liters
Foot	0.30480	meters
Inch	25.40	millimeters
Lb	0.4536	kilograms
Long ton(2240 lb)	1016.1	kilograms
Mile, nautical	1.8520	kilometers
Mile, statute	1.609344	kilometers

One Barrel Crude Oil = 5.80×10^6 Btu

ABBREVIATIONS

A.C. - Air Conditioning
AC - Asphalt Concrete
AC/DC - Conversion of electrical energy from alternating current to direct current
AS - Aggregate Subbase
ADB - Advanced Design Bus
ADT - Average Daily Traffic
ART - Articulated Bus

BART - Bay Area Rapid Transit
BOE - Barrel of Oil Equivalent
Btu - British thermal unit

CAFE - Corporate Average Fuel Economy
CEQA - California Environmental Quality Act of 1970
CTB - Cement Treated Base

DOE - Department of Energy
DOT - Department of Transportation

EIR - Environmental Impact Report
EIS - Environmental Impact Statement
EPA - Environmental Protection Agency
ETS - Energy and Transportation Systems

FAA - Federal Aviation Administration
FHWA - Federal Highway Administration
ft - foot or feet
ft/sec^2 - feet per second squared

gal - gallon
GRT - Group Rapid Transit

HDV - Heavy Duty Vehicle
hr - hour

I/O - Input-Output

kg - kilogram
km - kilometer
kmh - kilometer per hour
kwh - kilowatt-hour

lb - pound
lb/ft^3 - pounds per cubic foot
lb/yd - pounds per yard
LCC - Life Cycle Costing
LDV - Light Duty Vehicle
lf - linear-foot
LRT - Light Rail Transit
LRV - Light Rail Vehicle

MDV - Medium Duty Vehicle
mpg - miles per gallon
mph - miles per hour
m/s^2 - meters per second squared
MW - Megawatt

NEPA - National Environmental Policy Act of 1969
NL - New Look

O/H - Overhead

PCC - Portland Cement Concrete
PSI - Pavement Serviceability Index

Rte-ft - Route Feet
R/W - Right-of-Way

TM - Track Mile
Trk-ft - Track feet
TSM - Transportation System Management

UC - Undercrossing
UP - Underpass
UMTA - Urban Mass Transportation Administration

VMT - Vehicle Miles Traveled

yr - year

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David Saia
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Chapter 1

INTRODUCTION

The Transportation Laboratory published "Energy and Transportation Systems" (ETS) in December 1978(1). It has been used since as a primary reference for transportation energy studies. Performing energy studies when improvements to the transportation system are proposed is a part of the process to develop an Environmental Impact Statement (EIS) and, in California, an Environmental Impact Report (EIR).

This report is not intended to void anything in ETS but to augment and update that publication. Some of the important topics in ETS are condensed in this publication. It is suggested that the reader refer to ETS if additional background information to this publication is desired. For ease of reference, most of the factors shown in ETS have been included in this report in their updated or original form.

The purpose of this study was to update, revise and improve:

1. Fuel consumption factors
2. Procedures for analyzing a project
3. Procedures for reporting the results
4. Software capabilities

Appendix A is a Glossary, Appendix B is a Summary of Laws, Regulations and Policies.

Fuel Consumption Factors

Study objectives were accomplished by researching the literature for the best information available. In many cases, the authors took the only available information or made an analysis of the information from various sources and selected or developed the best factor where differences existed. Due to the many variables which exist, the factors published in this report should be considered as informed estimates rather than precise numbers. A caveat statement is appropriate.

Energy use continues to be categorized in terms of direct and indirect energy. Direct energy is the fuel that goes to propel the vehicle under varying conditions of traffic and facility. Indirect energy is all the remaining energy needed to construct, operate, and maintain the roadway and manufacture and maintain the vehicles using the roadway.

Indirect energy is divided into two broad categories of central energy use and peripheral energy change. Central energy use encompasses the energy required to manufacture and maintain the vehicles and construct, operate and maintain the facility.

Peripheral energy change addresses the potential effect that a transportation system may have on energy use and availability in the area it serves. For example, a highway can take agricultural land and, consequently, shift population and traffic patterns which, in turn, affect energy use.

Procedures for Analyzing a Project

The procedures for analyzing a highway project are presented in Appendix C and remain the same as presented in ETS. Information is provided for analyzing a recycling project (Appendix D) and a light rail transit system (Appendix E). A life cycle costing method of evaluating project energy use is also presented, (Appendix H). No detailed information is provided for analyzing other systems such as aircraft, water and pipelines. Examples are also provided for energy analysis of Transportation System Management (TSM) and Contingency Planning strategies in Appendix I. Appendix F and G contain various factors for analyzing projects.

Procedures for Reporting the Results

The procedures for reporting the study are in Chapter 11. In most cases, an energy analysis provides input into the EIS and EIR and serves as an additional element in the decision-making process. A number of assessment criteria have been refined so that decision makers and others can make a better judgment of differences in energy usage between a "no-build" and various "build" alternatives for a highway project.

Computer Capabilities

The computer program for analyzing the project has been expanded to include more variables. New factors have replaced many that were in ETS. The program has been written so that new factors can be substituted as they become available. The program only applies to highway projects. A user's manual will be available in Appendix J.

Report Format

This report initially provides background information on where energy comes from, how it is used and the laws which relate to transportation energy. This is followed by a section on conservation of energy in transportation.

Sensitivity analysis and its use to determine the importance of various factors is discussed. Then the development of the factors, performing an energy analysis and reporting the study are treated.

Appendices contain the various factors, backup material, and examples of energy studies.

Chapter 2

PROJECT SUMMARY

- Direct energy usage accounts for more than half of the total energy used when analyzed in terms of the life of a project.

- The sensitivity analysis indicates that a change in speed, ADT, or percent trucks (±10%) has a significant effect on the total project energy. Similar changes in pavement type, roadway grade and construction costs would have little effect on the output.

  This is not be be confused with an item such as maintenance energy which has little effect on a life-cycle project energy analysis, but could have a significant cumulative effect on energy when used in terms of a statewide maintenance program.

- New energy usage factors were developed for cars, medium and heavy trucks, buses, light rail, construction dollars versus energy, vehicle maintenance, materials and fuel energy, miscellaneous construction and maintenance processes and for pavement recycling.

- Information on fuel consumption and distribution of types of vehicles, especially cars, continues to be published and the fuel consumption factors need to be updated on a regular basis.

- An improved criterion for impact takes into account project payback and total energy consumption during the project study period. Another criterion using the energy efficiency of the transportation system (Btu/VMT) is presented.

- The software capability for analyzing a project has been improved.

Chapter 3

IMPLEMENTATION

The results of this research have been implemented by Caltrans. Revised and refined direct and indirect energy factors have been incorporated into an expanded energy computer program to provide better analytical methods. Further implementation will occur when this report is distributed to District and Headquarters personnel.

Benefits

Benefits of this research are as follows:

Better methods for analyzing energy impact.

Expanded energy computer program capabilities.

The capability to more accurately analyze the energy impact of a transportation project or program by using most recent factors.

Greater insight into the importance of the various energy parameters which are considered in the analysis of a transportation project or program.

Suggested Future Research

1. There should be a continuing effort to keep energy factors up to date.

2. Studies should be performed and models developed to evaluate fuel usage for operational improvement projects such as ramp metering, HOV lanes, signal timing, one-way streets and lane reversals.

3. Fuel consumption under congested conditions should be studied more closely.

4. Guidelines should be developed to assist the coordination of energy research in using standardized vehicle classifications. This will help insure that all research is applicable and transferable to the transportation energy data base.

Chapter 4

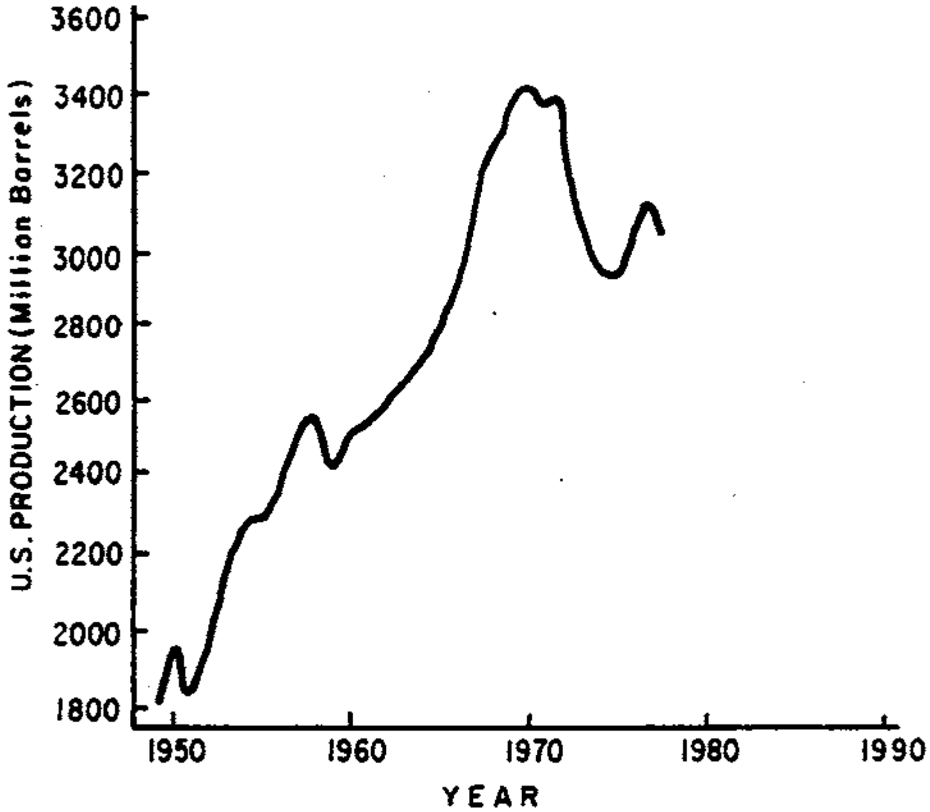
BACKGROUND

Historical

In 1973, the United States experienced its first energy crisis. Before that time, very few people considered petroleum as a finite resource or the rate at which this resource was being consumed. Energy, and gasoline in particular, were inexpensive and people assumed that new oil fields would continue to be discovered and conservation was not practiced. After the petroleum shortfall in 1973, energy received a lot of publicity and many research studies were funded to examine energy use in all sectors of the economy. However, it appeared that shortly after the 1973 crisis, the concern in this country about energy decreased.

Another energy shortfall developed in 1979. That crisis was quickly resolved, but it contributed to dramatic increases in the prices of petroleum products which, in turn, has affected almost every facet of the economy.

Although people are now aware that energy is expensive, most do not perceive the long-term problem associated with a diminishing supply of a finite resource. Figure 1 illustrates a declining petroleum production rate even though the number of wells drilled has almost doubled since 1960(2)



Source: Bureau of Mines, U.S. Department of Interior

FIGURE 1, DOMESTIC OIL PRODUCTION

The vast majority of energy expended for a transportation project is petroleum based. Since petroleum is a rapidly diminishing resource and the supply is subject to disruption, each transportation project must be carefully analyzed to determine its energy impact. Concurrently, transportation energy conservation strategies should be pursued and alternative sources of transportation energy investigated as a means of reducing our dependence on petroleum energy.

Figure 2 shows the types and uses of various energy resources in the United States. Figures 3 and 4 show California energy by origin and use by sector. Figure 5 shows the energy used for transportation in California.

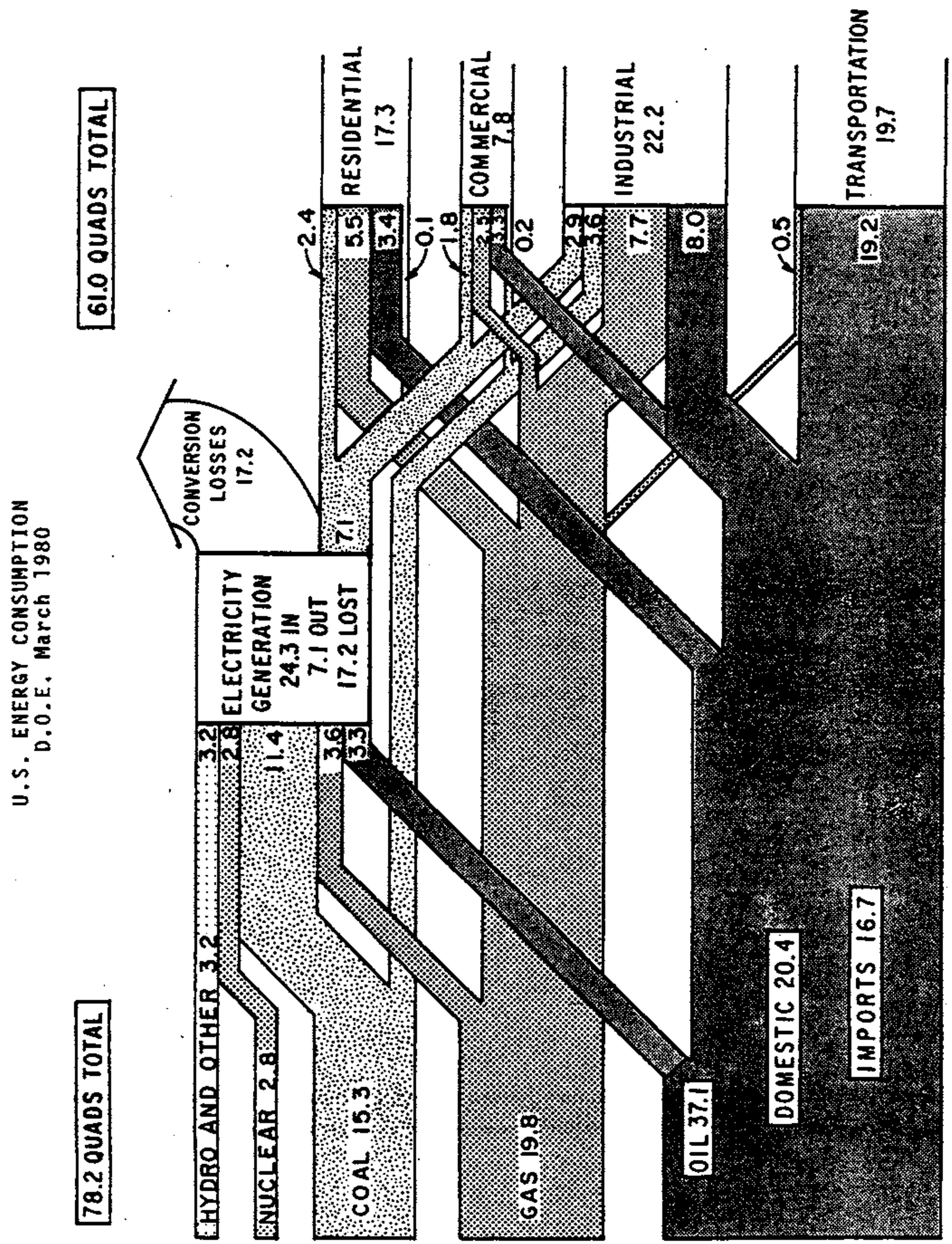
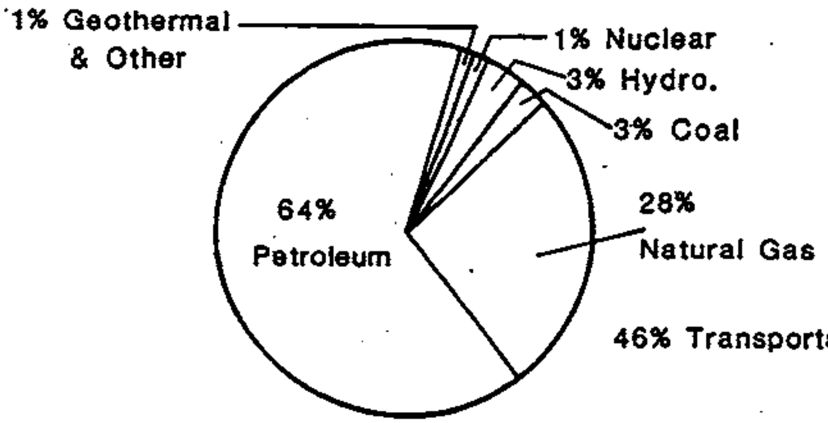

U.S. ENERGY CONSUMPTION
D.O.E. March 1980
78.2 QUADS TOTAL
61.0 QUADS TOTAL
HYDRO AND OTHER 3.2
NUCLEAR 2.8
COAL 15.3
GAS 19.8
OIL 37.1
DOMESTIC 20.4
IMPORTS 16.7
ELECTRICITY GENERATION
24.3 IN
7.1 OUT
17.2 LOST
CONVERSION LOSSES 17.2
RESIDENTIAL 17.3
COMMERCIAL 7.8
INDUSTRIAL 22.2
TRANSPORTATION 19.7
3.2
2.8
11.4
3.6
3.3
7.1
2.4
5.5
3.4
0.1
1.8
0.2
2.9
7.7
8.0
0.5
19.2

FIGURE 2

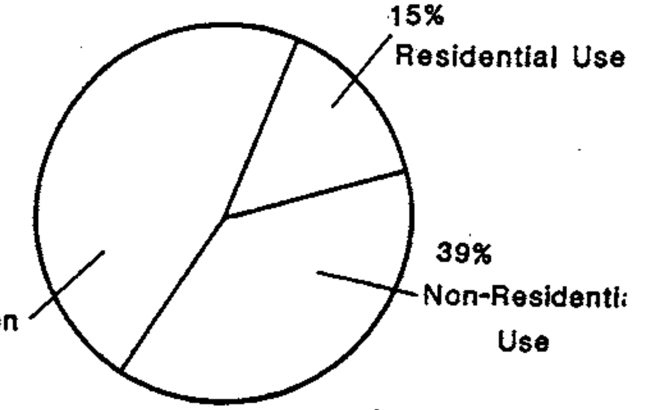
CALIFORNIA ENERGY FLOWS 1979

Re: California Energy Commission



ENERGY BY ORIGIN

FIGURE 3



ENERGY BY SECTOR

FIGURE 4

DISTRIBUTION OF DIRECT TRANSPORTATION ENERGY BY MODE IN CALIFORNIA - 1980

Re: California Energy Commission

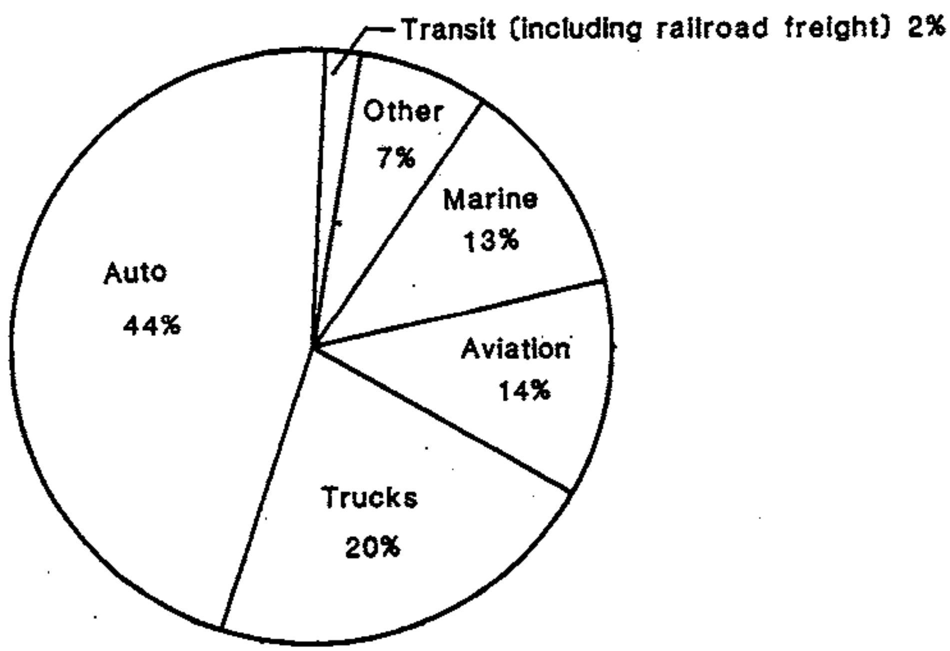


FIGURE 5

Laws Relating to Energy

Various federal and state laws, regulations and policies require energy studies for input into environmental documents and/or are directed to conservation of energy. Figure 6 shows the more important federal laws.

A complete listing and a brief summary of the more important federal and state laws, regulations and policies is contained in Appendix B.

FEDERAL LEGISLATION AND REGULATIONS

AFFECTING TRANSPORTATION/ENERGY RELATIONSHIPS

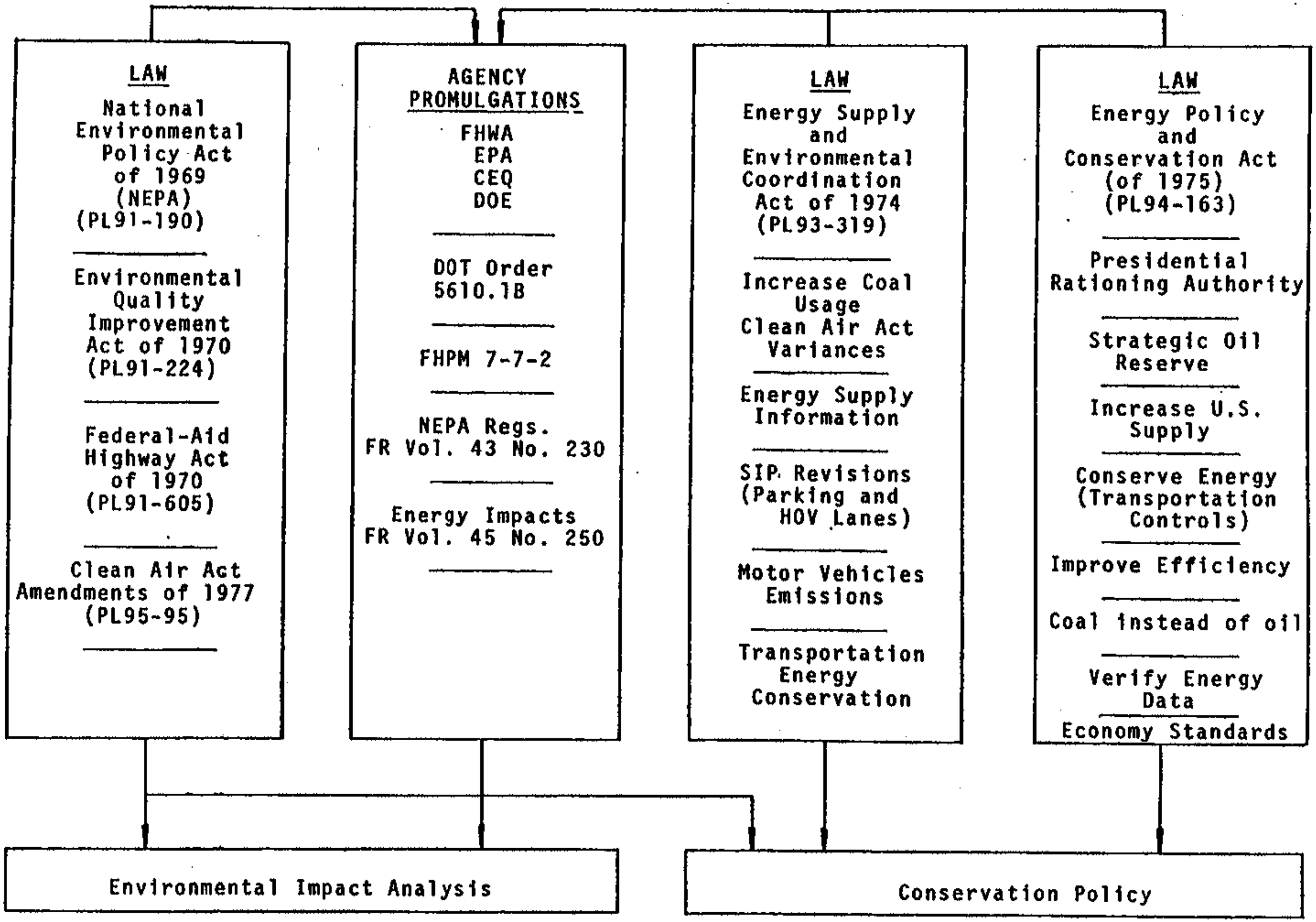


Figure 6

Chapter 5

CONSERVATION OF ENERGY

Petroleum is a finite resource that in the near future will require more energy to extract from the earth than it will provide. Various estimates have been made which indicate that petroleum supplies will no longer be adequate to supply transportation needs sometime early in the 21st century.

The important fact is that the long-term petroleum supply is decreasing and alternative fuels must be developed. This requires time and conservation is the best immediate strategy for prolonging the available supply and providing time.

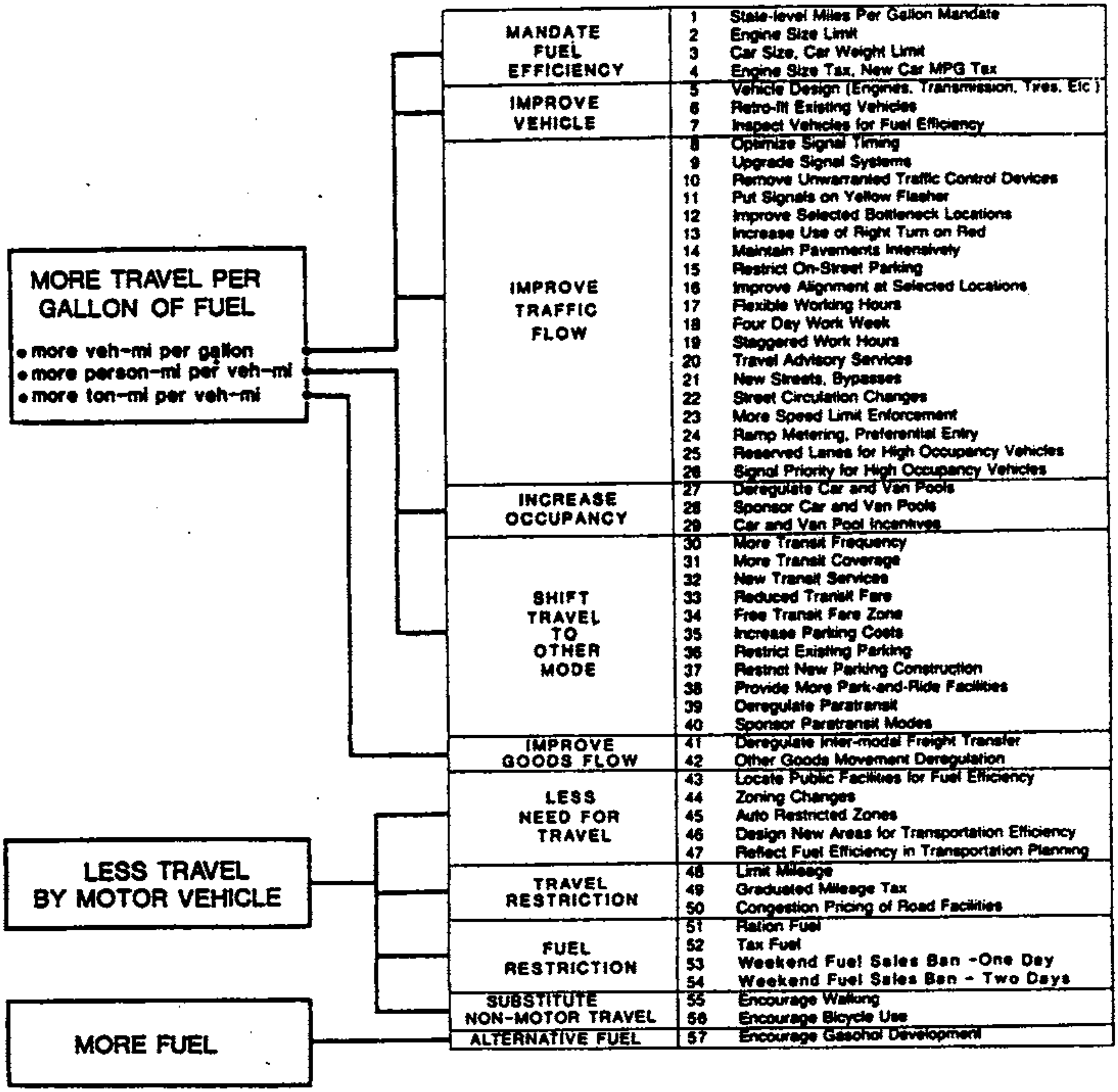
The various laws, regulations and policies were covered in the previous section of this report that directly or indirectly involves conservation. The most important law is "The Energy Policy and Conservation Act of 1975"(3) which set average vehicle fleet mileage for future years. It has done more to conserve petroleum energy than any strategy presently being used.

Table I provides estimates of fuel savings from "Highway Energy Conservation Strategies". Figure 7 shows "Generation of Alternative Actions" which is similar to Table I but has additional strategies to conserve fuel. Figure 8 shows additional areas of consideration to conserve fuel.

TABLE I

SUMMARY OF HIGHWAY ENERGY CONSERVATION STRATEGIES

Program Area	Elements Included	*Estimated Saving Total Direct Transp.Energy
1. Vehicle Technology Improvements	° Downsizing model lines ° Design Improvements - Reduce weight - Reduce drag - Improve transmissions & drive trains	10-20%
2. Ridesharing	° Ridesharing matching program ° Ridesharing marketing ° Employer programs ° HOV incentives	2-5%
3. Traffic Flow Improvements	° Traffic signal improvements ° One-way streets ° Reversible lanes ° Intersection widening ° Ramp metering ° Freeway surveillance & control	1-4%
4. Other Transportation System Management Strategies	° Fringe parking ° Alternative Work Schedule ° Priority lanes for HOV's ° Pedestrian & Bicycle improvements ° Pricing, parking & highway facilities	1-4%
5. Goods Movement Efficiency Improvements	° Improved routing & scheduling of urban goods delivery ° Truck size & weight changes ° Truck deregulation ° TOFC	1-4%
6. Transit Improvements	° Modal shifts to transit through: - Park and ride - Improved service - Marketing - Preferential highway lanes - Fare reduction ° Improved Routing & Scheduling ° Improved maintenance ° Vehicle rehabilitation	1-3%
7. Construction and Maintenance	° Improved highway maintenance ° RRR ° Substitute sulfur-based materials for asphalt ° Pavement recycling	1-3%
8. 55 mile per hour speed limit	° Better enforcement and compliance to achieve fuel saving and reduced facilities	0-2%
9. Improved Driving Habits & Vehicle Maintenance	° Radial tires ° Higher tire inflation ° Improved maintenance ° Travel planning trip linking	1-5%
10. Rationing	° Private autos ° Taxis/trucks	15-50%
11. Pricing, Decontrol	° Gas Tax ° Parking fees/policies ° Road pricing ° Vehicle registration	5-25%



GENERATION OF ALTERNATIVE ACTIONS

FIGURE 7

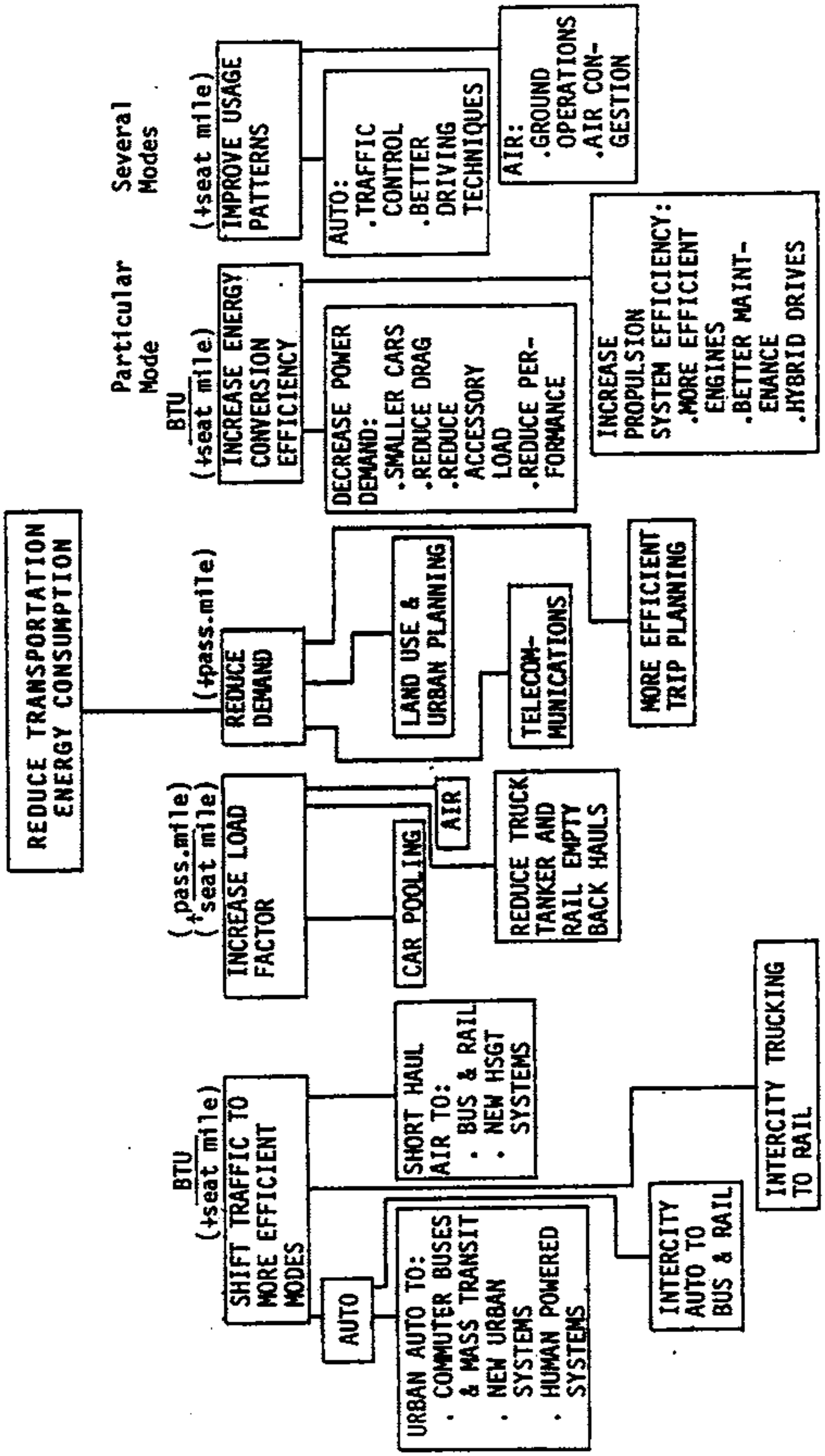

REDUCE TRANSPORTATION ENERGY CONSUMPTION
BTU
(÷seat mile)
SHIFT TRAFFIC TO MORE EFFICIENT MODES
AUTO
URBAN AUTO TO: · COMMUTER BUSES & MASS TRANSIT · NEW URBAN SYSTEMS · HUMAN POWERED SYSTEMS
SHORT HAUL AIR TO: · BUS & RAIL · NEW HSGT SYSTEMS
INTERCITY AUTO TO BUS & RAIL
INTERCITY TRUCKING TO RAIL
(pass.mile / ÷seat mile)
INCREASE LOAD FACTOR
CAR POOLING
AIR
REDUCE TRUCK TANKER AND RAIL EMPTY BACK HAULS
(÷pass.mile)
REDUCE DEMAND
LAND USE & URBAN PLANNING
TELECOMMUNICATIONS
MORE EFFICIENT TRIP PLANNING
Particular Mode
BTU
(÷seat mile)
INCREASE ENERGY CONVERSION EFFICIENCY
DECREASE POWER DEMAND: .SMALLER CARS .REDUCE DRAG .REDUCE ACCESSORY LOAD .REDUCE PERFORMANCE
INCREASE PROPULSION SYSTEM EFFICIENCY: .MORE EFFICIENT ENGINES .BETTER MAINTENANCE .HYBRID DRIVES
Several Modes
(÷seat mile)
IMPROVE USAGE PATTERNS
AUTO: .TRAFFIC CONTROL .BETTER DRIVING TECHNIQUES
AIR: .GROUND OPERATIONS .AIR CONGESTION

FIGURE 8

Conservation of energy in facility planning, construction, operation and maintenance also needs to be considered and practiced. Facility includes the buildings (office, rest stops, maintenance) and the highway (landscape, lights, signs, etc.).

In many cases, buildings were constructed before energy became expensive and designers did not optimize the energy efficiency features. However, conservation can be achieved by things such as using fluorescent lights, turning the thermostat down for heat and up for air conditioning, improving insulation, sealing cracks and using thermal windows.

Conservation can also be applied to recycling pavements, hardware items (guardrail, signs, tires, lighting standards, right-of-way fence, etc.), using indigenous plants for landscaping, and planning the maintenance of the roadway itself. Other measures are using high pressure sodium vapor lamps for lighting, promoting carpools, vanpools, buses and bicycle projects.

Chapter 6

TRANSPORTATION SYSTEM MANAGEMENT (TSM)

TSM involves management strategies which have the goals of improving the utilization of existing transportation systems in order to relieve congestion, reduce travel time, reduce costs, improve air quality and conserve energy. These strategies are generally considered to be short range and require minimum capital expenditures. Many strategies have been employed for years by traffic engineers to attain elements of the goals mentioned above.

Signalized Intersections

Improvements to traffic signal systems can have a positive impact on energy consumption in addition to improving traffic operations. Most improvements of this type are made to reduce vehicle delay and congestion. These types of projects can also save fuel. Numerous studies are referred to in "Opportunities for Energy Conservation in Transportation Planning and Systems Management"(4) which all show that these types of projects save fuel.

Even greater fuel savings can be achieved by the use of electronically activated traffic control systems. These systems can relieve traffic congestion, increase the average speed on heavily traveled roadways and decrease the number of traffic light stops. This means that there are fewer speed change cycles and stops. "Traffic Control Systems Save Energy"(5) identified some of these systems and the energy saving attributed to them. The system in

Eau Claire, Wisconsin covered 11 intersections and produced a 20% reduction in energy consumed. One in Greensboro North Carolina shows an estimated savings of 1400 gallons of gasoline per day. When all the other positive impacts are considered, these are obviously very efficient systems.

Ramp Metering

The energy impact of ramp metering is less quantifiable. "Guidelines for Selection of Ramp Control Systems"(6) shows that, depending on the specific site conditions, there can be very modest decreases or increases in energy consumption due to ramp metering. A recent study (unpublished) by Caltrans District 4 (San Francisco) showed fuel savings of around 10% for ramp metering projects.

Although ramp metering can reduce congestion, it also tends to increase the speed on the freeway thereby potentially increasing fuel consumption. Also, ramp metering may cause some drivers to travel upstream to enter the facility at an unmetered zone, thereby increasing both VMT and fuel consumption.

Caltrans District 7 (Los Angeles) made a study titled, "The Assessment of the Impact of Ramp Metering on Air Quality and Energy Consumption"(7). Their conclusion was that there could be a negative or positive energy impact due to ramp metering depending on what assumptions are made and the type of project.

HOV Lanes on Freeways

There are six (6) types of priority treatment for buses and carpools involving freeways:

1. Separated Facilities
2. Concurrent Flow
3. Reserved Lanes
4. Contra-flow Reserved lanes
5. Priority Access, Bypass ramps, Metered ramps
6. Priority Access Exclusive use ramps

Typically, the priority treatment is in effect only during peak commute periods and frequently projects use more than one type of treatment. Various projects of this nature have been calculated to save from 1,000 to 11,400 gallons of gasoline per day(8).

The energy impact of the diamond lanes on I-10 in Los Angeles indicated energy savings between 1,475 and 11,400 gallons of gasoline per day(9). The problem with an energy analysis for this type of facility is similar to that for a transit facility. The assumptions made concerning access energy can have a major impact on the results of a study. The conclusions indicate HOV lanes on freeways are probably energy efficient.

Chapter 7

SENSITIVITY ANALYSIS

A sensitivity analysis was made early in the study to determine which parameters are of primary importance when making an energy analysis for a transportation project. The purpose of the sensitivity analyses was to determine the effect of a change in an input parameter on the total project energy.

A classical sensitivity analysis is made by holding all parameters constant but one in an analysis methodology and then varying that parameter in increments to determine the effect on the output. A modest change in a sensitive parameter causes a noticeable alteration in the output while a major modification in an insensitive parameter causes a nonsignificant change in the output.

A sensitivity analysis was performed on "ENERGY3", a software package that uses the same factors and methodology as in the old Energy and Transportation Systems (ETS). This analysis was undertaken to ascertain the answers to two questions. 1) Which factors used in the program should be further investigated and refined by the researchers. It served to prioritize the work that needed to be done. 2) Which factors are the most crucial to those applying the computer program to project studies.

There were three different types of situations examined in the sensitivity analysis. The first type represents a change in the user identified input parameters that are normally specified at the beginning of each run. These include the time span of the analysis, the average daily traffic (ADT), the percent of medium and heavy trucks, the percent grade and the construction costs. The second was an actual change in the preprogrammed values for such parameters as pavement maintenance and indirect vehicle energy. The third type of situation modeled was the effect of increasing the capability of the program to handle curvature, road surface condition, and speed change cycles.

The results of the sensitivity analysis were as follows:

- Curvature, speed changes, and roadway surface condition were found to have a significant effect on the program output using the old ETS factors. Considerable time was spent examining these parameters. It was decided to include them in the new computer programs.

- Indirect vehicle energy (manufacturing and maintenance) accounted for 42% of the total energy for the base case in the sensitivity analysis. It was decided to thoroughly evaluate these factors.

- Roadway construction and maintenance energy were found to have a relatively minor effect on the total energy consumption for most projects.

- The program output was very sensitive to changes in ADT and percentage trucks. These parameters are often very difficult for environmental investigators to accurately predict. Many projections are thought to be valid to ±50%. It was decided to develop the new computer program so that these traffic parameters can be easily varied, with the effect on the output being immediately available. This will allow the investigator to make multiple runs for high and low traffic estimates, if desired.

Chapter 8

DEVELOPMENT OF FACTORS BY TRANSPORTATION MODE

Transportation Modes

This chapter addresses the energy factors for the following transportation modes:

1. Roadway
2. Rail
3. Personal and Group Rapid Transit
4. Air
5. Marine
6. Pipeline

The energy characteristics of each transportation mode are discussed.

1. Roadway Transportation Mode - Most roadway vehicles use gasoline or diesel; these were the only fuel types considered in this study although others such as natual gas, hydrogen or gasohol may be used more widely in the future.

Fuel consumption characteristics vary for each vehicle but data from organizations such as the Environmental Protection Agency (EPA), Department of Energy (DOE) and the Department of Transportation (DOT) permitted estimates to be calculated for "composite" vehicles by type.

Variables that affect fuel consumption are vehicle and facility related. Vehicle related items include such things as engine size, fuel type, weight, speed and cold starts. Lesser factors are driver behavior, engine tune, tire type and pressure and aerodynamics. Most of these minor factors are usually not included directly in an energy analysis.

Facility related variables affecting energy consumption are such things as grade, traffic congestion (slowdowns or stop and go) and substandard pavements. Lesser factors are roadway curvature, altitude and weather conditions. Substandard pavements, altitude and weather are usually not included in a fuel consumption analysis.

Most of the variables mentioned in Appendix C show fuel consumption adjustment factors which were developed by the authors or taken directly from other publications. The Commentary to Appendix C provides additional background information and the sources for the factors.

Passenger cars are usually defined as 2 axle, 4 wheels, weighing less than 8,000 lbs and designed to carry passengers. However, for purposes of performing an energy analysis, pickups and vans are classed as cars even though they can carry cargo.

Fuel consumption factors for cars change each year because older cars are driven less and new fuel efficient cars replace the older cars. EPA requires that the Corporate Average Fuel Economy (CAFE) for the new passenger vehicle fleet must reach 27.5 mpg by 1985(3). Most estimates seem to indicate that this average will be accomplished although the actual on-road mpg is expected to be three or four miles less than the official EPA figure.

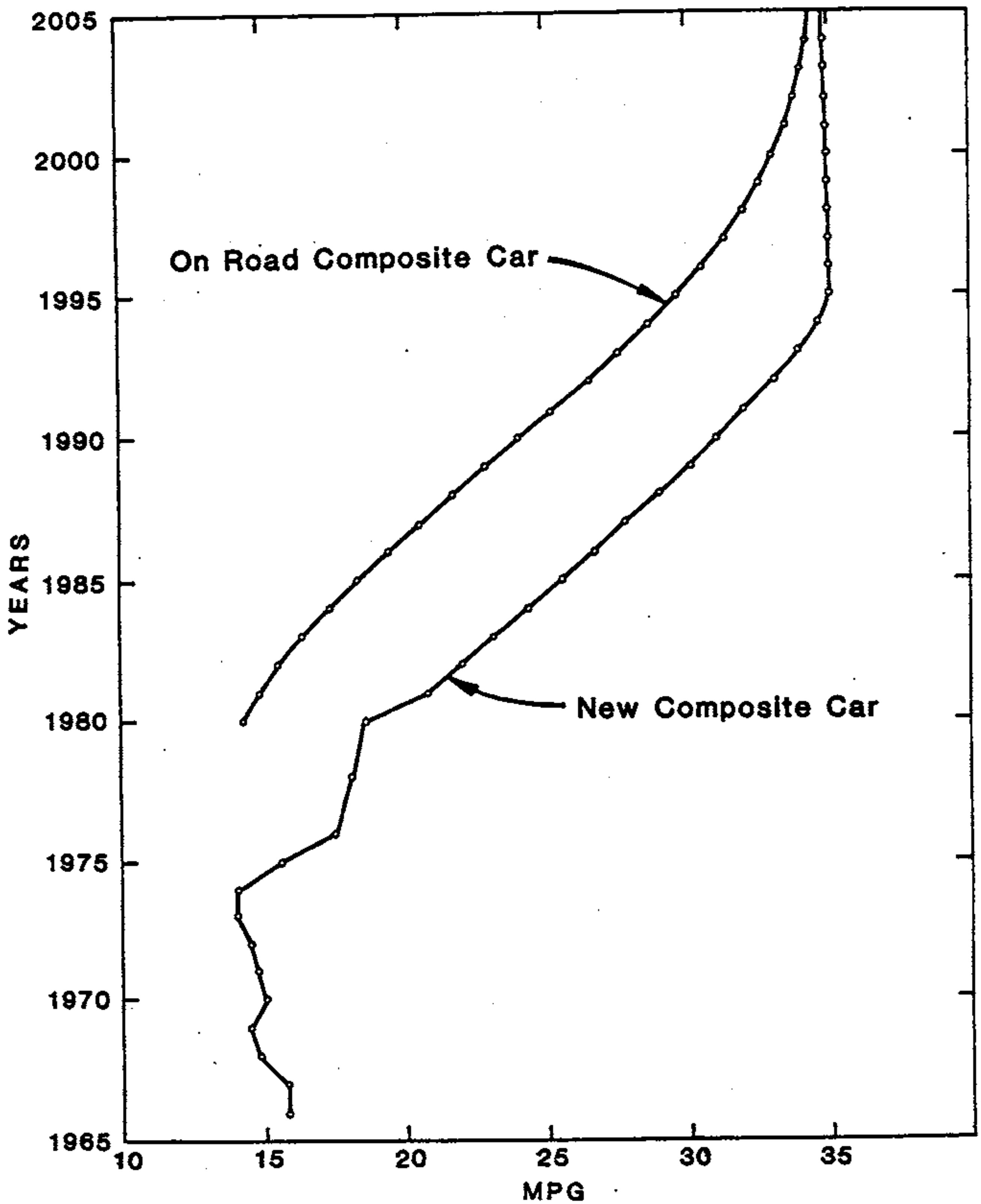
Figure 9 illustrates the fuel consumption required of new cars and an estimate of the "composite" (old and new) fleet for various years.

Trucks are divided into light and heavy categories. Light trucks have 2 axles, 6 tires, weigh between 8,000 and 19,500 lb (gross vehicle weight) and are designed to carry cargo. Heavy trucks have more than 2 axles, 6 tires and weigh over 19,500 lb.

Buses are treated as another category and have their own fuel consumption factors based on the type of service for which they are used.

In addition to the direct energy required to propel the vehicles, data are available to calculate indirect energy required to construct, operate and maintain the facility and to manufacture and maintain the vehicles. Vehicle manufacturing information is based on studies of the energy required to produce each material, form the component parts and assemble the vehicle. In a like manner, the energy required to construct transportation facilities can be estimated and factors developed to predict construction energy for future projects. Maintenance energy factors for the vehicles and facilities were developed by studies performed in a manner similar to the manufacturing and construction energy.

Inadequate pavement surface conditions have been shown to have a major effect on the rates of tire wear, depreciation and maintenance and repair of the vehicles. Correction factors have been developed for each of the major vehicle types under a wide range of pavement surface conditions. Pavement conditions were found to have a negligible effect on direct fuel consumption.



FUEL CONSUMPTION RATES OF COMPOSITE PASSENGER CARS

FIGURE 9

2. Rail Transportation Mode - Fixed rail vehicles are trains and rail mass transit units. They carry passengers or cargo, seldom both. Their power plants are diesel fueled engines which run generators to supply electric drive motors. Some trains run directly from overhead or a third rail which supply the electricity.

Light rail transit is an urban transportation system that uses electrically powered rail cars operating individually or in short trains on a fixed dual rail guideway system. The system may be grade separated or it can share space with automotive traffic. San Diego's "Tijuana Trolley" is an excellent example of this type of system. Appendix E presents an example light rail energy study.

Modern heavy rail transit for carrying passengers refers to systems such as the Bay Area Rapid Transit (BART) or the Capitol Metro in Washington, D.C. Such systems are energy efficient when operated with high load factors. However, most operations take place at relatively low load factors since they are primarily commuter oriented systems.

Old heavy rail transit refers to systems such as the ones in New York City, Chicago, Boston, Cleveland and Philadelphia. The energy efficiency of these systems varies widely.

Energy consumption of trains is influenced by three major factors: speed, gross weight and terrain. Other factors for commuter trains are the number of slowdowns and stops, track conditions and the rate of acceleration. A number of computer programs are available to determine the energy efficiency of trains under different operating conditions(10).

Since trains serve specific routes, the power plants are designed to meet the requirements of the route. Passenger trains are usually composed of a standard number of units and weigh essentially the same whether empty or full. Therefore, given the 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. Where required, additional locomotives are assigned to perform the task of climbing steep grades. Locomotives are rated according to their maximum horsepower and weight is usually expressed in tons.

The railroad industry has conducted studies to aid in conservation of fuel. Through these and other studies, information as to fuel consumption rates of locomotives has become available.

The energy required to construct and maintain heavy rail mass transit systems is dependent on things such as the basic type of construction, the amount of system at grade versus the amount that is elevated, subway tunneling or cut and cover. Data are sparse, but some estimates are presented for BART and the system in Toronto, Canada.

<u>3. Personal Rapid Transit (PRT)</u> - An automated guideway transit system that uses small vehicles of two to six-passenger capacity operating under computer control between off-line stations. It provides demand responsive service except perhaps during peak periods with headway of three seconds or less.

Group Rapid Transit (GRT) - An automated guideway that has either on-line or off-line stations and vehicles that carry 6 to 100 passengers and may combine to operate as a single train. At one time, it was thought that such systems could play a major role in solving urban transportation problems. However, the systems which are now in operation serve very specific purposes, such as airports or a means of access between major activity centers.

Nearly all systems are powered by electricity using AC or DC 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 GRT and PRT are scarce and are expected to vary substantially from one system to another.

<u>4. Air Transportation Mode</u> - 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 and naptha-type fuel, and piston-powered aircraft use aviation gasoline.

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

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

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

c. Climb-out, where slightly less than maximum power is used from lift-off until an altitude of 3,000 ft is reached.

d. 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.

e. Approach and land, from 3,000-ft altitude to touchdown, where the power is slightly increased or reduced from that used in the cruise phase, 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 phases, given the aircraft type, cruise speed and distance traveled. 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. 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 for air transportation.

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.

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 require special analysis.

5. <u>Marine Transportation Mode</u> - 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. 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 determind 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). 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 are not readily available. Statistical studies have determined values for energy consumed versus actual service rendered for the entire system (Appendix F).

Deep-sea vessels transport passengers or cargo, seldom both. Two types of power plants 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(11). 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

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.

The indirect energy consumed in ship building and maintenance is difficult to measure. Studies have been conducted to determine the energy consumed by shipyards and the 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. Currently a typical figure for newly constructed deep-sea vessels is 25 years, as opposed to 20 years for vessels built circa 1960(11). Information on useful lives of inland vessels or ferryboats is not available.

All vessels require shore facilities (terminals, loading equipment, warehouses, drydocks) 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 of material(12).

6. Pipeline Transportation Mode - 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 can then be pumped. 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 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 versus service rendered of U.S. pipelines but details are not readily available. Energy consumption of pipelines is influenced by the velocity and viscosity of the fluid, pipe diameter, 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, install and maintain these systems has not been extensively studied.

Chapter 9

ENERGY ANALYSIS

Energy Units

Transportation may be defined as the moving of goods and/or people. To perform this act, certain impeding forces (gravity, friction, etc.) must be overcome. This requires the expenditure of energy. Energy is defined as the ability to do 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 can be classified in many forms such as chemical, kinetic, nuclear, potential and thermal. One of the most important forms related to transportation is the chemical energy inherent in fuels. This is determined by equating it with the fuel's heating or thermal energy value. Classical experiments have determined the correlation between thermal energy and mechanical energy (ft-lb) and in fact, the units for all forms of energy are convertible to each other.

Commonly used units of transportation-related energy are the British thermal unit (Btu) in the English System and joule (J) in the International System of Units (SI). Still in considerable use is the kwh (kilowatt-hour) which usually describes electrical energy.

This report uses Btu as the primary energy descriptor.

Fuels

Transportation consumes a variety of substances as fuels. Approximately 96% of these fuels are derived from petroleum. The direct thermal energy inherent in these fuels can be measured in the laboratory. Published values for crude oil vary by ±15% due to the differing chemistry of natural deposits. Refined petroleum products, however, generally have fairly consistent values.

Approximately 15% of the crude oil consumed in the U.S. is used for petroleum refining. The vast majority of this is expended for the advanced processing necessary to produce transportation fuels. Through an extensive analysis of the refining industry, the authors have been able to determine the approximate value for the refining energy associated with some of the more commonly used transportation fuels. These values are presented in Appendix G. All energy values in this report have been upgraded to include this refining energy whenever possible. Using this method, the energy quantities calculated from this report will translate directly into the amount of crude oil which must be consumed to generate the transportation fuels, rather than the significantly smaller quantity of energy inherent in those fuels.

Non-petroleum-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 direct energy to produce, but also requires considerable energy for storage. Hydrogen as a pressurized gas is heavy and requires large containers (which require energy to manufacture). As a supercold liquid it must constantly leak in order to maintain temperature or it can be 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 for these types of fuel reported in Appendix G represent the direct thermal energy only.

Another example of an alternative fuel is gasohol (10% ethanol and 90% gasoline) which was popular in some parts of the country during the gasoline shortfall. However, data indicate that gasohol was competitive with gasoline prices only because of tax subsidies. Net energy analyses of ethanol have been conflicting and inconclusive. The energy savings are questionable because the energy needed to grow, harvest and process the biomass to produce ethanol may be greater than the energy of the gasoline it is replacing.

Methanol (methyl alcohol) is another alternate fuel which can potentially be produced in great quantities from coal or other organic material, although currently most methanol is produced from natural gas. It does have a high octane rating, which should give it good performance characteristics in engines specifically designed for its use.

Areas with serious air quality problems are looking at methanol fuels which burn cooler and more efficiently as a means of reducing emission levels. A major impediment to widespread use of methanol as a fuel in the United States can be attributed to the dilemma of what comes first, methanol vehicles or methanol fuel supply. In all probability, it will take higher gasoline prices for methanol to become competitive.

Special consideration is given to electricity which is a form of energy produced from other energy sources. Electricity requires energy input to a power plant in the form of petroleum, natural gas, coal, hydraulic pressure, nuclear material or geothermal taps (wind, wave and solar power are still largely experimental). The majority of electric power plants use petroleum and natural gas fuels, and their efficiency when transmission losses are included was 28.8% in 1980 (Reference, Appendix, GR8). Thus, it is 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 or four times greater). Transportation energy analyses must consider the total energy consumed to provide a given service and thus, should use the larger figure.

Alternative fuels may have a significant impact on the energy analysis for a future transportation project. However, the procedures in this publication do not provide for an energy analysis using alternative fuels because little or no information is available for other than experimental usage.

Considerations in an Analysis

In general, the purpose of an energy analysis is to provide meaningful comparisons between alternatives, including the "no build" alternative. This requires careful consideration of the factors involved in analyzing the energy impacts of each alternative. Figure 10 provides an overview of the considerations in an energy analysis.

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 analysis must consider the total transportation system (and energy use) required to transport, say, a commuter, from his home address to 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

CONSIDERATIONS IN AN ENERGY ANALYSIS

Objectives
-or-
what we must produce

INTRODUCTION AND ORGANIZATION
Transportation & Energy - Legal Requirements - Envir. Impact

New Words & Ideas
Concept of Energy

ENERGY - LANUGAGE AND CONCEPTS
BTU, KWH, Energy-Related Terminology, Energy Concepts

Planning
-or-
How do we begin

PLANNING AN ENERGY STUDY
Definition and comparisons of Alternatives
For a System or For a Project

Constructing the study
-or-
How and what input data we need

DIRECT ENERGY	
Vehicle Oriented	Service Oriented
Vehicle type	Load factors
Fuel Type	
Speed	Cargo Wt.
Road Geometry	
Traffic Density	Cargo Dens.
Road Condition	
Cold Starts	
Idling	
Trip length	

INDIRECT ENERGY		
Materials & Construction	Operation & Maintenance	Peripheral Effects
Vehicle Manuf.	Useful Lives:	Project-Induced Energy
Facility Constr.	Vehicles	Energy Production for Large-Consumption Projects:
Roads	Facilities	Sources
Rail Lines	Routine Maint.	Siting
Stations	Repair/Repl.	Land-use preempted
Docks	Auxil.Equip.	Bioenergy
Airports		Sources
Pipelines		Sites

Analysis
-or-
How we find what we want

ANALYSIS
Processing Data -- Filling in With Reasonable Estimates -- Obtaining Values

Results
-or-
What we think will happen and what to do about it

ENERGY REPORT
Checklist
Format
Presentation
Summary, Conclusion & Opinion

FIGURE 10

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 versus 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 six 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 not shipped in this fashion. Natural gas and pipelines go together, but appliances are transported by rail and truck. Cargo density and fragility also become important factors in determining which mode of transportation is practical. A commonly used unit of goods transport is the "ton-mile" which depicts the movement of one ton of freight the distance of one mile. However, 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, or is somehow accounted for, 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, also falls in this category. Although these materials are not "consumed" when used in construction, their inherent thermal energy is rendered unavailable for future use due to the impracticality of extracting these materials once they are placed. For the purpose of this report, these construction materials are charged with an energy value equivalent to the amount of energy that would have been expended if they had been used as a fuel. For asphalt, this is the inherent energy of the asphalt minus the processing energy necessary to refine it into clean burning fuels (see Appendix G). Once placed, the materials are given a zero salvage value. Therefore, if they are used in the future in a recycling operation, the remaining inherent energy is considered as a bonus for the recycling project, rather than a debit for the initial construction.

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 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) versus 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 of the input energy is lost mostly in the form of heat at the stack and in mechanical losses. Such a system is said to have an efficiency of 0.33.

The Process Analysis Approach

Fuel consumption factors for things such as manufacturing an automobile or constructing a highway bridge can be developed by estimating the total energy required for the process (process approach). This includes the energy directly required to operate the various pieces of equipment used in manufacturing or constructing the product. It also includes the energy required to mine or obtain the raw material, to transport and to refine the material. Some authors even include the energy consumed by workers commuting to the work place. The drawbacks of the process analysis approach are that it requires considerable data collection and calculation and it is difficult to define an endpoint to the study of the various input elements. Its advantages are that it readily identifies the most intensive operations and it more easily allows the analyst to see the effects of changing assumptions or updating a data base.

The Input Output (I/O) Approach

Another approach to developing energy factors such as those used for highway or bridge construction is to estimate the total quantity of fuel which must be input into an industry to obtain a given dollar value output. The cost of the product is then multiplied by this industry-wide Btu to dollar ratio to obtain the fuel cost. All costs must be reduced to a base year before this method can be applied.

The drawbacks of the I/O approach are that it is based on inadequate statistical data and the cost of fuels vary from region to region and inflation does not apply uniformly to all products. Also, it does not allow differentiation of products of different energy intensity within a given industry.

However, only cost estimates are usually available in the early planning stages of a project. Because of this reason and the simplicity of this approach, the I/O method is often used for analyzing project construction energy.

Chapter 10

PROCEDURES FOR CONDUCTING A PROJECT ENERGY STUDY

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 of a proposed action on the consumption of energy. Usually, an action is presented in the form of several proposed alternatives (no build and build) 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, and (5) locate and designate sources for the data.

1. <u>Determining the Need</u> - 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 will 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 or 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, material 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 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.

After the general objectives are defined and data sources are evaluated, it may be desirable 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, parameters include the direct fuel consumption characteristics of specific vehicles used plus the various indirect energy considerations pertaining to each mode.

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 calculated from the vehicle-miles traveled by each vehicle class. Each of these 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. This is accounted for in an analysis by the use of a "load factor" which is a ratio of actual to potential service. Studies have been conducted to determine typical load factors for various modes of transport using statistical data. However, studies should be conducted 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, and 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 of 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, transportation energy 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 improvement studies, in which methods of improving the energy efficiency of system operation are involved (for example, freeway ramp metering, or changing the cruising speed and schedule of ferryboats).

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

Although each general category may call for a different level of analysis and input data, certain elements are basic to any analysis once the specific definitions of alternatives have been developed. 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 section and shown in block diagram form in Figure 11. Although the general tone of the discussion is directed at land surface transportation, these principles of analysis apply equally to air, marine and pipeline transportation.

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. A hypothetical list (for roadways only) illustrates possible data categories for a fairly comprehensive project level analysis (Figure 2).

Table II shows service parameters which supplement Figure 11 in certain situations.

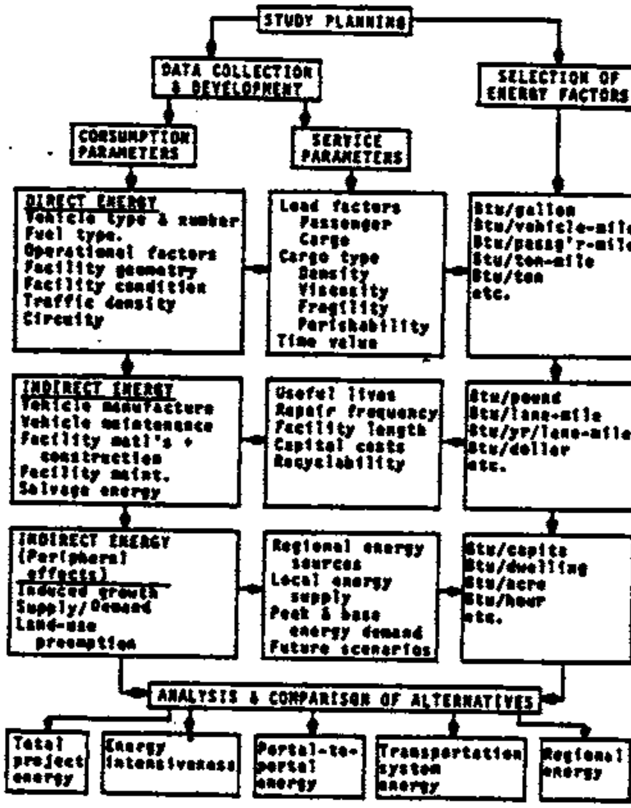
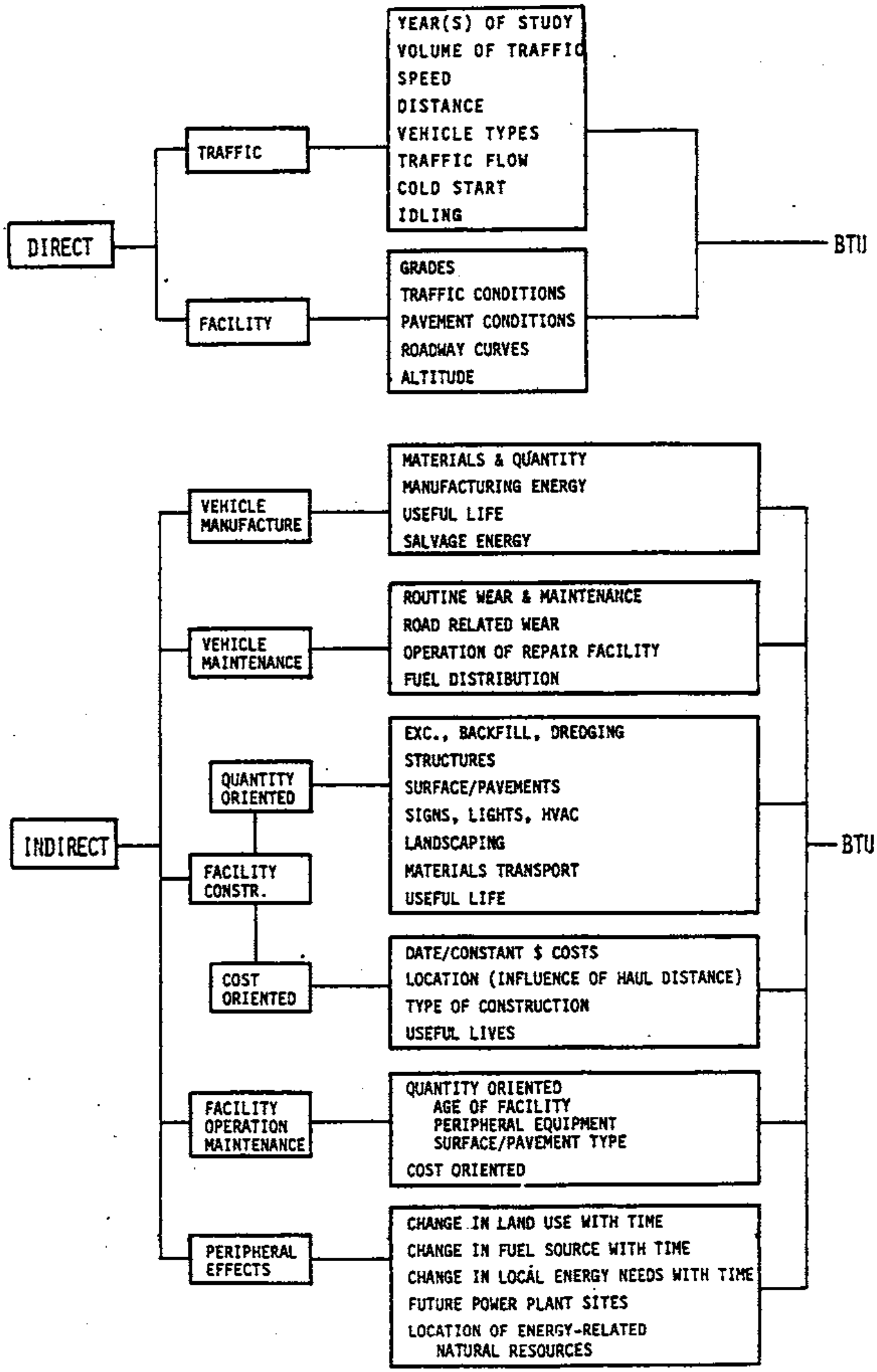

STUDY PLANNING
DATA COLLECTION & DEVELOPMENT
SELECTION OF ENERGY FACTORS
CONSUMPTION PARAMETERS
SERVICE PARAMETERS
DIRECT ENERGY
Vehicle type & number
Fuel type.
Operational factors
Facility geometry
Facility condition
Traffic density
Circuity
Load factors
Passenger
Cargo
Cargo type
Density
Viscosity
Fragility
Perishability
Time value
Btu/gallon
Btu/vehicle-mile
Btu/passg'r-mile
Btu/ton-mile
Btu/ton
etc.
INDIRECT ENERGY
Vehicle manufacture
Vehicle maintenance
Facility matl's + construction
Facility maint.
Salvage energy
Useful lives
Repair frequency
Facility length
Capital costs
Recyclability
Btu/pound
Btu/lane-mile
Btu/yr/lane-mile
Btu/dollar
etc.
INDIRECT ENERGY (Peripheral effects)
Induced growth
Supply/Demand
Land-use preemption
Regional energy sources
Local energy supply
Peak & base energy demand
Future scenarios
Btu/capita
Btu/dwelling
Btu/acre
Btu/hour
etc.
ANALYSIS & COMPARISON OF ALTERNATIVES
Total project energy
Energy intensiveness
Portal-to-portal energy
Transportation system energy
Regional energy

FIGURE 11



YEAR(S) OF STUDY
VOLUME OF TRAFFIC
SPEED
DISTANCE
VEHICLE TYPES
TRAFFIC FLOW
COLD START
IDLING
TRAFFIC
DIRECT
BTU
FACILITY
GRADES
TRAFFIC CONDITIONS
PAVEMENT CONDITIONS
ROADWAY CURVES
ALTITUDE
VEHICLE MANUFACTURE
MATERIALS & QUANTITY
MANUFACTURING ENERGY
USEFUL LIFE
SALVAGE ENERGY
VEHICLE MAINTENANCE
ROUTINE WEAR & MAINTENANCE
ROAD RELATED WEAR
OPERATION OF REPAIR FACILITY
FUEL DISTRIBUTION
QUANTITY ORIENTED
EXC., BACKFILL, DREDGING
STRUCTURES
SURFACE/PAVEMENTS
SIGNS, LIGHTS, HVAC
LANDSCAPING
MATERIALS TRANSPORT
USEFUL LIFE
INDIRECT
FACILITY CONSTR.
BTU
COST ORIENTED
DATE/CONSTANT $ COSTS
LOCATION (INFLUENCE OF HAUL DISTANCE)
TYPE OF CONSTRUCTION
USEFUL LIVES
FACILITY OPERATION MAINTENANCE
QUANTITY ORIENTED
AGE OF FACILITY
PERIPHERAL EQUIPMENT
SURFACE/PAVEMENT TYPE
COST ORIENTED
PERIPHERAL EFFECTS
CHANGE IN LAND USE WITH TIME
CHANGE IN FUEL SOURCE WITH TIME
CHANGE IN LOCAL ENERGY NEEDS WITH TIME
FUTURE POWER PLANT SITES
LOCATION OF ENERGY-RELATED NATURAL RESOURCES

FIGURE 12

TABLE II

Service Parameters

Passengers:
- Rated passenger-miles
- Load factors
- Effect on other modes

Cargo:
- Type of cargo
- Rated ton-miles
- Load factor
- Effect on other modes
- Fragility
- Time value

Often, required data will not be available in sufficient detail. Such gaps in the data must be covered by reasonable estimates prior to proceeding further. A sensitivity analysis (such as the one previously discussed) may be an aid to determining the significance of possible inaccuracies in such an estimate. The new computer analysis capability has been developed specifically to aid in the development of such a sensitivity analysis. This allows the user to quickly see how changes in specific input parameters will affect the final output.

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 generated 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 be compatible with the data requirements of energy models. Because traffic data requirements for energy analyses are similar to those for air quality, acquired data for one type of analysis will generally be applicable to the other.

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 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 life, 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 life, 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

System and project level studies often require different types of energy factors. System studies are usually broad in scope and use factors developed from generalized information. Due to their nonspecific nature, these factors are more suitable for gross estimates rather than precise calculations. Most of the factors for air, marine, and pipeline transport fall into this category. Project level studies are usually more precisely defined and this allows the use of much more specific energy factors. The detailed nature of project level energy calculations allows individual differences between competing alternatives to be determined with a high degree of accuracy.

Direct energy analysis for system studies is often dependent solely on the vehicle type and total miles traveled. For highway modes, it is also dependent on the year the study takes place because highway vehicles are expected to become more fuel efficient in the future.

Highway project studies can involve the use of many energy factors. Usually a base fuel consumption rate will be established for each vehicle type under a given speed and grade. To this are applied various modifying factors for curvature, slowdown/speedups, stops, cold starts, etc. A future year correction factor must also be applied for studies conducted in subsequent years.

A new direct fuel consumption methodology has been developed which can be used for both project and system level highway studies. It can be used to determine the fuel consumption for congested urban conditions without using a detailed speed-distance tachograph normally necessary for a project level study. All that is necessary is a determination of the vehicle's average speed. The calculation procedure and energy factors are described more thoroughly in Appendix C.

Indirect energy is calculated by determining the energy equivalent of all the material products and operations necessary to keep the transportation system operable. This task is performed in the following manner:

1. The total energy consumed by vehicle manufacture is prorated 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. This would include estimates of tire wear and oil consumption.

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 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 in the "Highway Construction Price Index" table found in Appendix C. 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 proration over a given time period and the resulting value of peripheral energy may be reported separately as a gross total.

6. All values of direct and indirect energy consumption are added (with the possible exception of peripheral energy) to provide a total consumption figure which may then be compared with a similar analysis for a different alternative. Because the numerical value in Btu is often astronomical in magnitude, it is recommended that the final totals be converted to 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).

Service parameters are often presented along with energy consumption because system or project alternatives are being proposed to provide a given service. This service should be stated in terms of vehicle miles, passenger-miles or ton-miles for specified type(s) of cargo. These service parameters 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 the various appendices. The time-value of service must also be considered. For example, if the desired result of a set of alternatives is 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 <u>operational improvements</u> 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 primarily involve existing equipment and technology. The emphasis is 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 life.

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 life.

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

Life Cycle Costing (LCC)

LCC has been used as an economic evaluation method which takes into account all relevant costs of a construction project for its given life cycle. These are items such as the design, construction, maintenance and operation of the system over a given period of time where reasonable predictions can be made. It is a valuable tool that is suited for evaluating alternatives.

With the cost of energy escalating and the petroleum reserves declining, it has become important to evaluate transportation construction projects in terms of their energy intensities. LCC is a method for comparing the "no build" versus the "build" alternative in terms of energy for a transportation project for a given time period. Although the discounting of the future worth of capital is common in economic evaluations using the LCC, this report did not include any discounting or compounding of energy and simply used the total amount of energy expended for a project.

Two methods for ranking alternatives using LCC are by quantifying cost benefit and payback period. The cost can be referred to as the energy expended to build the project and the benefit is the difference between the build and no build energy (energy saved). Payback in years is the energy used to build the project divided by the annual benefit. In many cases, the benefit is a minus value indicating the total energy consumption for the build situation was greater than that for no-build.

The preceding discussion should include salvage energy. These would be items such as pavements, guardrails and light standards. Energy savings from recycling salvageable materials are benefits to the project. However, a salvage analysis is often not made because of the lack of data.

Both the cost benefit and payback were used to develop the guidelines for estimating the potential impact between a build and no build alternative for a highway project.

An alternate method of ranking alternatives is by their energy efficiency. The energy efficiency may be determined by dividing the total energy consumption by the quantity of service provided. For example, a given project may increase capacity along a transportation corridor, thereby allowing more traffic to flow and using more energy. However, the total energy per vehicle mile traveled may decrease due to the system having become more efficient. If the assumption is made that the additional travel generated by the new facility is actually travel that had previously taken place on the surrounding regional system and this travel is more efficient than that of the surrounding system, then the new facility may actually be reducing the overall energy consumption on a regional or national basis.

Appendix D shows an example energy analysis between a recycling and conventional highway project using asphalt concrete pavement. An example energy analysis between an asphalt concrete and portland cement concrete pavement is included in Appendix H. Appendix C gives an example of a classical roadway energy problem. These examples are intended to illustrate the approach and methods for performing an analysis. The many variables which occur during any analysis of this type could make a considerable difference in the outcome and the numerical values used in the example are not to be applied in a general manner.

Measures of Effectiveness (M.O.E.s)

Currently there are no legislatively mandated standards to determine the level of significance of an energy impact. Generally, using less energy is better than using more, but this is only true if both alternates provide the same level of service.

Three different measures of effectiveness have been devised for this study. They are: Total Project Energy, Energy Payback Period and Energy Efficiency.

1. The total project energy is the sum of the direct and indirect energy consumption for each alternative over the entire study period. 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 level of 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.

The preceding discussion on LCC was used to develop a criteria for assessing impact. An arbitrary criteria for impact was developed based on the total project energy. If the number of barrels of oil saved or lost during the life of the project was ±7,000, the project is considered as having no significant impact. Under this criteria, an analysis of 73 Caltrans projects indicate 19% positive impact, 25% no significant impact and 56% negative impact.

As a comparison, the total project energy criteria in ETS suggested that if two alternatives differed by ±10 percent or less, this difference should not be considered significant. An analysis of the 73 projects using this criteria is also shown on Table III. The data indicate 12% positive impact, 60% no significant impact and 27% negative impact.

TABLE III

Criterion for Impact

	New Criterion		Old Criterion	
Impact	Barrels of Oil Saved or Lost During the Life of Project	No. and Percent of Projects	ETS	No. and Percent of Projects
Positive Impact	>+7,000	14 (19%)	>+10%	9 (12%)
No Significant Impact	±7,000	18 (25%)	±10%	44 (60%)
Negative	>-7,000	41 (56%)	>-10%	20 (27%)

2. The energy payback period is the amount of time it takes to recover the quantity of energy expended for the construction of a project. It is determined by dividing the construction energy by the annual energy savings due to the project. If the project uses more energy than the no build alternative, there is no annual energy savings and the payback period is infinity. This MOE provides a method of determining the time it takes to get a return on the (construction) investment.

A payback period of under 5 years is excellent and is considered as a superior investment. A payback period of greater than 20 years will generally be beyond the forseeable future of the project, and therefore not a good investment. A payback period of between 5 and 20 years is considered as not significant.

3. The energy efficiency is the total project energy divided by the total VMT it took to generate that energy consumption. It is generally reported in units of Btu/VMT.

This is the only MOE that directly accounts for the level of service. Competing projects may involve different levels of development of a transportation corridor which may draw different volumes of traffic from the surrounding system. Obviously, the largest project will draw the greatest volume of traffic and consume the largest gross quantity of energy. However, such a project may reduce congestion and allow the most efficient traffic flow on a Btu/mile or Btu/trip basis.

A transportation project's energy efficiency can be compared to the national average efficiency for a fleet with the same vehicle mix. A project with a greater efficiency than the national average (i.e., less Btu/VMT than the national average) will have a positive impact on national energy consumption while one with a lesser efficiency than the national average will have a negative impact. The project with the best energy efficiency is the most desirable.

The criteria suggested in this report should be considered a temporary guideline until better information is available.

Computer Output

For highway transportation energy, the new Highway Energy Analysis Program (HEAP) will print out the following information for each alternative:

1. A summary of the direct and indirect energy for the project.

2. The average energy efficiency of this project in units of Btu/VMT. This will be compared to a national average for the project vehicle mix and time period.

3. The energy payback period, if applicable.

Comparison of Alternatives

1. Project boundaries. In order to compare projects on an equivalent basis, it is imperative that the geometric boundaries of the analysis be consistent for all alternatives. If one alternate necessitates the analysis of traffic on a competing side street, then all alternates should include this street. Generally, the limits of the analysis boundaries will be determined by the alternate that induces the largest perturbations in the traffic patterns. Any side street that experiences a traffic change of ±5% should be included in all analyses if possible.

2. 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 these vehicles should be added to that of the main mode(s). Also, certain alternatives may be more circuitous than others. Both line-haul and access/egress travel should be considered in the trip distance of each mode. The final comparison should compare the energy consumed to provide portal-to-portal service.

3. 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 or a more efficient mode, and the possiblility 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.

4. 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 10 years hence. At that time, deficit 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 pay back 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.

Transportation Systems Management (TSM)

TSM is a term commonly applied to almost any management strategy designed to maximize the efficient use of transportation systems. These strategies are usually intended to reduce congestion and increase fuel economy. These goals can be obtained through a variety of schemes including, but not limited to: ramp metering, ridesharing, high occupancy vehicles, computerized signal systems, flexing of work hours, and parking management.

TSM often involves tradeoffs between competing modes of transportation within a region. As such, they are local issues and are best analyzed on a regional basis.

TSM is a broad subject and its complete ramifications are beyond the scope of this text. The basic energy analysis, however, is accomplished in a manner similar to that of any other transportation project. The specific method for any given analysis will vary considerably with the specific strategy being used. Appendix I presents an example study for a ramp metering project.

Chapter 11

REPORTING AN ENERGY STUDY

The technical document resulting from an energy study conducted, analyzed and reported as described here can be considered 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 must 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 Environmental Impact Statement (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 both 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. Depending on the study objectives, this summary can be presented in a form suitable for incorporation in an EIS.

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 range rather than 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.

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 EIS.

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 that describes 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 provide ample background information (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 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:

(1) 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.

(2) Effects of the alternatives on local and regional energy supplies and on requirements for additional capacity.

(3) 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).

(4) Effects of the alternatives on peak- and base-period regional energy demands.

(5) Compliance of alternatives with existing energy regulations or standards.

(6) The effects of the alternatives on national energy resources.

For both the build and the no-build 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 the preemption of 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. A recommendation on the preferrred alternate would not be included in this summary. This section would usually be written to summarize information presented in Sections 8 through 11. This information is an input to the various phases of a project and serves to identify opportunities for energy conservation and prevention of wasteful or inefficient consumption.

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 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 provides a "memory freshener" for study review in the future. Briefly, this section of the report includes 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 and calls 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 concerning the new 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.

TABLE IV

ENERGY REPORT CHECKLIST

EIS Content (Ref. F.R. 12-29-80)	Yes	No
1. Alternatives which promote energy conservation have been included in the study		
2. Analysis differentiates between petroleum and nonpetroleum energy sources		
3. Energy consumption in facility operation and maintenance		
4. Regional energy impacts of the proposed action and the regional transportation plan		
5. Present analysis in terms of BTU		
6. Total energy consumed by vehicles predicted to use facility		
HIGHWAYS		
7. Vehicle miles traveled		
8. Average vehicle occupancies		
9. Changes in energy consumption through changes in traffic flow		
10. Generated or induced trip		
11. Energy use for street lighting and tunnel operation (if significant)		
AIRPORTS		
12. Energy use in terminal facility		
13. Energy use by aircraft		
14. Passenger load factor		
15. Energy use in transportation to and from airport		
TRANSIT AND RAIL		
16. Energy use by transit vehicles or trains		
17. Energy use at terminals		
18. Passenger load factors		
19. Changes in modal split		
20. Energy use in access to transit		

SIGNIFICANT INDIRECT IMPACTS	Yes	No
21. Changes in land use patterns contributing to longer or more energy consuming commuting trips stimulated or supported by the proposal		
22. Trips diverted from other more or less energy efficient modes		
23. Increased auto use generated by terminal construction or expansion of parking facilities		
CONSERVATION		
24. Selection of energy efficient alternatives		
25. HOV lanes		
26. Interface with transit services in urban highway proposals		
27. Measures to improve traffic flow		
28. Bicycle and pedestrian facilities		
CONSTRUCTION ENERGY		
29. Energy impacts of construction including energy used by construction equipment		
30. Significant impact on or use of natural resources such as coal, minerals, etc.		
31. Trade offs between operating and maintenance energy savings and construction energy consumption		
OTHER FACTORS		
32. Consistency of the proposed action with any state, regional or local energy conservation plan		
33. Reflection of energy elements of transportation planning		
34. Indication of whether the proposed action is part of an energy contingency plan or will be relied upon during an emergency		

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3. Energy Policy and Conservation Act; PL94-163; 1975.

4. Arnold, E.; Opportunities For Energy Conservation In Transportation Planning and System Management; Virginia Highway and Transportation Research Council, VHTRC 79-R24, November 1978.

5. Traffic Control Systems Save Energy; Better Roads Publication, June 1979.

6. Blumentritt, C., Pinell, D., Ross, D. W., McCausland, W. R. and Glazer, J.; Guidelines of Selection of Ramp Control Systems; NCHRP Report 232.

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10. Harrington, Craig, P.E., "Light Rail Transit Simulation Model," California Department of Transportation Laboratory, September 1982.

11. U.S. Maritime Administration, U.S. Department of Commerce, 450 Golden Gate Avenue, San Francisco, California 94102.

12. Transportation Research Board, National Research Council, "Inland Waterways Transportation," Transportation Research Record 545, 1975.

APPENDIX A

GLOSSARY

APPENDIX A

GLOSSARY

This glossary is very limited in scope and is intended to explain terms used in "Energy and Transportation Systems." For a more complete coverage, the publication, "Glossary of Energy, Economic, Environmental, Electric Utility Terminology," published by the California Energy Commission, is recommended.

Average Daily Traffic (ADT): Average number of vehicles that pass a specified point during a 24-hour period in both directions.

Average Occupancy: The average number of passengers per vehicle in some prescribed time period or operation. In an aggregate operation, average occupancy equals passenger miles traveled divided by vehicle miles traveled (PMT/VMT).

Bbl: Barrels of oil (42 U.S. gallons).

Barrels Per Day Oil Equivalent: A measurement applied to energy sources other than oil for the purpose of making more direct comparisons.

Btu (British thermal unit): The quantity of heat required to raise the temperature of one pound of water one degree Fahrenheit at or near 39.2°F, at standard pressure.

Btu/seat-mile or passenger mile: A measure of energy efficiency, generally implying the fossil fuels (or their equivalent) used in propelling the vehicle. One variation is gallons/square foot (of passenger area), advocated by some for transit operations. Btu/seat-mile is a measure of potential efficiency, resulting from 100% occupancy, while Btu/passenger-mile is a measure of actual efficiency.

Bunker "C" Fuel Oil: A heavy residual fuel oil used by ships, industry, and large scale heating installations. In industry, it is often referred to as No. 6 fuel.

Calorie: Originally, the amount of heat energy required to raise the temperature of 1 gram of water 1°C. Because this quantity varies with the temperature of the water, the calorie has been redefined in terms of other energy units. One calorie is equal to 4.2 joules. (The food calorie is equivalent to one thousand calories defined in this manner.)

Calorific Energy: It is the heat energy released when the product is completely burned. The energy required to refine, mine, or otherwise prepared such fuels for use is not included in calculating the amount of heat available in fuels. The characteristic of primary concern for materials used as fuels.

Construction Energy: Energy used to build the system, e.g., in Transit Analysis-vehicles, stations, roadbeds, terminals and associate facilities. Includes energy of the materials as well as the energy in placing them.

Cuts or Fractions: Products secured by fractional distillation are referred to as fractions or cuts. Gasoline fractions or gasoline cut, and kerosine fraction or kerosine cut, etc.

Default Value: A design value based on substantial experience or studied conclusions to be used for estimating various parameters in lieu of actual definitive values, e.g., average auto fuel consumption rates.

Drive: The equipment used for converting available power into mechanical power suitable for operation of a machine.

Drive, Diesel-Electric, Oil-Electric: A self-contained system of power generation and application in which the power generated by a diesel engine is transmitted electrically by means of a generator and a motor, or multiples of these, for purposes of propulsion.

Drive, Gasoline-Electric: A self-contained system of power generation and application in which the power generated by a gasoline engine is transmitted electrically by means of a generator and a motor, or multiples of these, for purposes of propulsion.

Drive, Gas-Turbine-Electric: A self-contained system of power generation and application in which the power generated by a gas-turbine engine is transmitted electrically by means of a generator and a motor, or multiples of these, for purposes of propulsion.

Drive, Steam-Turbine-Electric: A self-contained system of power generation and application in which the power generated by a steam turbine is transmitted electrically by means of a generator and a motor, or multiples of these, for purposes of propulsion.

Freight Efficiency: A measure of the amount of freight that can be moved some distance by a given mode of transportation for an expenditure of a certain amount of fuel (energy). It is usually defined as the number of tons of freight moved multiplied by the number of miles obtained per gallon of gasoline used. (See ton-mile.)

Great Circle Distance: An arc between two points on the earth's surface formed by the intersection of a plane passing through the center of the earth. For aircraft or ships, it is the shortest distance between two points.

GRT (Group Rapid Transit): Public transportation systems utilizing 8 to 20 passenger automated vehicles on exclusive guideways. Multiple stops, responding to origin and destination desires of passengers. Similar to PRT except uses larger vehicles.

Guideway: A facility for transit vehicles which are not guided by an operator.

Horsepower: Measure of power approximately equal to 746 watts. The force that will raise 746 kilograms a distance of one meter in one second.

HOV (High-Occupancy Vehicles): A vehicle, typically an automobile or van, with most of the seats filled with passengers.

HOV Lanes: Highway lanes reserved for HOV's.

Induced Growth Energy: Energy used in building or operating systems, structures, or devices that are subsequently developed because of the existence of a new transportation facility.

Indirect Energy: A term used to denote all energy inputs to the construction, operation, and maintenance of a system, exclusive of traction (propulsion) energy and parasitic loads within the vehicle.

Input-Output Analysis: A matrix form of analysis, developed for the field of economics, which is a tabular summary of the goods and services used in the process of making other goods or services. The analysis is in terms of dollars and encompasses the entire nation.

Joule: The joule is the work done when the point of application of a force of one newton is displaced a distance of one meter in the direction of the force. (Equal to one watt-second.)

Kilocalorie: The amount of heat required at standard pressure to raise the temperature of one kilogram of water, one degree centigrade.

Kiss and Ride: A form of access to a mass transit station where transit riders use automobiles for the trip from home to the transit station, where the rider is dropped off and the automobile is used by another person.

KWHT: Kilowatt hour thermal - equals 3,413 Btu.

KWHE: Kilowatt hour electric-equals roughly 10,000 Btu, depending on the conversion loss factor assumed (.33 is typical) for converting fossil fuel into electricity.

L.A.S.H.: "Lighter aboard ship", a ship which carries smaller loaded vessels on board (similar in concept of "piggybacking" trailers on train flat cars).

Line Haul: Normally the distance between communities or population centers.

Load Factor: The average ratio of passengers to seats in some prescribed time period operation, expressed as a decimal or a percentage, e.g., in public transit, the ratio is the average of in-bound (peak) and outbound (off-peak) operations.

Maglev: Magnetic levitation; raising a vehicle by magnetic force (repulsion or attraction).

Maintenance Energy: Includes energy needed to repair and maintain vehicles and other constructed items of the system.

Magajoule: 10^6 joules (abbreviated MJ).

Newton: The newton is that force which when applied to body having a mass of one kilogram, gives it an acceleration of one meter per second squared.

OPEC: Organization of Petroleum Exporting Countries.

Operating Energy Intensity: Vehicle propulsion energy measured in Btu's per passenger or seat mile.

Parasitic Loads: Power requirements in a vehicle by air compressors, colling systems, generators and similar equipment detracting from horsepower delivered to drive wheels.

Park and Ride: A form of access to a mass transit station where transit riders use automobiles for the trip from home to the transit station, where they are parked until the rider returns (P&R).

Passenter-miles: Vehicle-miles multiplied by the (average) number of passengers on board. Abbreviated PMT.

Petroleum Energy: The total number of Btu's that are generated from petroleum based fuels.

Power: The rate of flow of useful energy.

PRT (Personal rapid transit): Public transportation system utilizing small - 2 to 6 passenger - automated vehicles, operating on exclusive guideways. Multiple stops, responding to origin and destination desires of passengers.

Processing Energy: The amount of fuel and/or electrical energy required to provide a unit of the material in a usable form - is the principal energy consideration for processed and manufactured materials.

Ramp Metering: The control of vehicles entering a restricted access highway (freeway) so as to maintain the volume-capacity ratio at a point where free flow (no congestion) exists.

Seat-mile: Vehicle-miles multiplied by the number of seats in the vehicle.

Station Energy: A portion of operating energy. Specifically, the associated parking lots, administration buildings including lighting and heating.

Therm: 100,000 Btu. Also that quantity of a gaseous fuel which contains 100,000 Btu in calorific heat value.

Ton-Mile: In general, one short ton (2,000 lbs.) transported one mile. A misleading term unless one understands the circumstances of its computation; e.g., whether only cargo is involved, and whether empty back-haul is included. Ton-mile/gal is commonly used as a measure of efficiency in moving freight.

Variations Include:

CWT/Gal - cargo weight in 100 pound units per gallon of propulsion fuel.

Gross Trailing Tons/Gal - Term used in train freight denoting gross train weight, exclusive of engine units.

Loaded Trailer/Tons/Gal - A term used in TOFC (trailer on flat car) operations, referring to flat car payload of truck trailer and its cargo.

Traction Energy: Includes the energy for vehicle propulsion and any parasitic loads such as lighting, heating, air conditioning or various other energy demands within the vehicle. This term is generally synonymous with Direct Energy, a term favored by some authors. Some disagreement has existed over what parasitic loads are to be included.

Trailing Gross Tons: The gross tonnage being pulled by a train engine. Does not include the weight of the engine.

Travel Speed: Average distance/unit of time area prescribed route.

Unit Train: A system developed for delivering, e.g., coal more efficiently in which a string of cars, with distinctive markings, and loaded to "full visible capacity", is operated without service frills or stops along the way for cars to be cut in and out. In this way, the customer receives his coal quickly and the empty car is scheduled back to the coal fields as fast as it came.

Vehicle-miles: The sum of the distances (in miles) each vehicle travels while conducting its transport function. Abbreviated VMT.

Volume Utilization: A term used in freight space utilization referring to the internal container volume used to store packages. A 60% volume utilization means 40% of the container is unused.

Watt: The watt is the power which requires a supply of energy at the rate of one joule per second.

APPENDIX B

LEGISLATION AND REGULATIONS RELATED TO TRANSPORTATION ENERGY

APPENDIX B

Legislation and Regulations Related to Transportation Energy

Federal Laws and Regulations

1. National Environmental Policy Act (NEPA) of 1969 (P.L. 91-190)

This act does not specifically refer to energy but requires discussion of any irreversible and irretrievable commitments of resources which would be involved in the action.

2. Environmental Quality Improvement Act of 1970 (P.L. 91-224)

This act assures that each federal department and agency conducting or supporting public works activities which have an effect on the environment shall implement any policies established under existing law.

3. Federal Aid Highway Act of 1970 (P.L. 91-605)

This act requires a report which indicates the considerations given to the social, environmental, economic and other effects of a plan, highway location or design and various alternatives which were raised during a hearing or were otherwise considered.

4. Clean Air Act Amendment of 1977 (P.O. 95-95)

This act requires assessment of the energy impact of various transportation control measures and strategies.

5. DOT Order 5610 IC

This order states that alternatives studied for a project should include those which promote energy conservation. Impact analysis should identify petroleum and nonpetroleum energy sources. Requires energy analysis for transit, rail, highways and airport actions and a thorough analysis of various other impacts.

6. Federal Highway Procedure Manual (FHPM) 7-7-2

This procedure requires environmental impact statements to document major direct and indirect energy impact of project alternatives and their potential for conservation, mitigation measures to enhance energy conservation and discuss the project relationship with state and regional energy planning.

7. Energy Impact Regulation, Federal Register Volume 45, No. 250

This regulation details items that need to be addressed in the environmental impact statement.

8. NEPA Regulations, Federal Register Volume 43, No. 230, Section 1502.16

This regulation states that in any environmental impact statement, the environmental consequences section should include a discussion of energy and natural or depletable resources.

9. Energy Supply and Environmental Coordination Act of 1974 (P.L. 93-319)

This act provides a means to assist in meeting the essential needs of the United States for fuels with existing national commitments to protect and improve the environment and to provide requirements for reports.

10. Energy Policy and Conservation Act of 1975 (P.L. 94-163)

This act sets vehicle fleet mileage averages for various years and requires that the U.S. Department of Transportation set standards for passenger vehicles for future model years after 1980. It emphasizes energy conservation and requires states to submit energy conservation plans to federal agencies.

11. The President's Environmental Message of 8-2-79

This directs the Secretary of Transportation to assure that federal transportation funds are used to promote energy conservation.

12. Executive Order 12185, 12-17-79

This order directs each federal agency to effectuate conservation of petroleum and natural gas.

13. Federal Highway Administration (FHWA) Notice 5520.4, 3-21-80

This policy provides broad direction on energy conservation for the federal aid highway program and to identify areas that possess the greatest area for fuel conservation.

California Law and Regulation

1. California Environmental Quality Act (CEQA) of 1970

This act specifically requires that an energy analysis be made as part of an Environmental Impact Report (EIR) for a project.

2. California Department of Transportation, Policy and Procedure No. 78-17, 10-10-78

This policy is to assure that the Department is utilizing nonrenewable resources most efficiently in order to minimize their consumption by the transportation program.

APPENDIX C

ROADWAY ENERGY CONSUMPTION

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APPENDIX C

ROADWAY ENERGY CONSUMPTION

C1 Introduction

This chapter presents various methodologies for determining the energy consumption for highway projects. Included are energy factors and discussion of direct and indirect vehicle energy for light duty vehicles, medium trucks, heavy trucks and buses; roadway maintenance energy and roadway construction energy. Also included is an example problem showing how these factors are used.

C2 Direct Vehicle Energy

Three different methods of determining the fuel consumption of light duty vehicles, medium trucks and heavy trucks have been devised. The first method is highly detailed and allows the analyst to discretely examine the individual effect of roadway geometrics and traffic patterns on fuel consumption. The second method is specifically applicable to urban congestion where only the travel time or average speed is known, and individual effects of each slowdown or stop cannot be determined. The third method is used where only the total VMT of the project is known. These three methods may be utilized in combination with one another to make use of different levels of information available to the energy analyst. A fourth separate method is used for buses due to the different types of information available for a transit energy analysis.

For the purposes of this investigation, light duty vehicles are classified as all vehicles with two axles and four tires. This includes both passenger vehicles and pickups weighing under 8500 lb. Medium trucks are two axle and six tired vehicles weighing between 8500 and 19500 lb. Heavy trucks are defined as vehicles having three or more axles or weighing over 19,500 lb.

Discrete Fuel Consumption Method

The first vehicle fuel consumption methodology is similar to that used in "Energy and Transportation Systems" E&TS(1). It is a disaggregate method where each change in the roadway geometrics or traffic patterns is modeled separately. It is most applicable for project level studies where a high degree of information is available regarding the proposed undertaking.

This method basically consists of dividing the roadway up into segments or "links" where the traffic characteristics are fairly consistent. Knowing the speed and grade on the link, a base fuel consumption rate is obtained for each vehicle type (Tables C:1:1 to C:1:3). This base rate may then be modified by correction factors for cold starts (Table C:6) or other miscellaneous variables (Table C:7) as necessary*. The base rate is multiplied by the length of the link to obtain the link's base fuel consumption. The additional fuel due to curvature, slowdowns and/or stops is

*Contrary to the old E&TS, recent research has shown virtually no correlation between fuel consumption and pavement surface roughness, so no general purpose correction factor is used for common highway pavement surface conditions.

added to this base fuel consumption by using the factors in Tables C:2:1 through C:3:3. The sum is multiplied by a future year correction factor (Tables C:5:1 to C:5:3) to account for changes in fuel efficiency between the base year (1980) and the projected year of the analysis. This value, multiplied by the number of vehicles on the link per year, will yield the annual fuel consumption.

The total fuel consumption consists of both gasoline and diesel fuel. The total gallons of diesel can be obtained by multiplying the percent of diesel (Tables C:5:1 to C:5:3) in the fuel mix for the study year by the total fuel consumed. The remainder is gasoline.

Urban Fuel Consumption Method

The second direct fuel consumption methodology is used for urban traffic situations where it is difficult to identify the speed profile of the average vehicle. This method uses the <u>average</u> speed of the vehicle, and already accounts for the slowdowns and stops normally experienced in urban traffic. It is especially useful for situations where congestion induces delay beyond the normal travel time. This may be applicable for both project and system level studies.

For the urban fuel consumption method, the base year fuel consumption rates presented here are only dependent on the weight of the vehicle and the vehicle's average speed.*

*The average speed may be calculated from the attempted speed and actual delay using the following formula:

$$\text{distance} \;/\; \left(\frac{\text{distance}}{\text{attempted speed}} + \text{delay}\right) = \text{Average Speed}$$

The weight of the average on-road light duty vehicle (LDV) in 1980 has been calculated to be 3938 pounds and the urban fuel consumption rates presented in Table C:4 are based on this weight. Table C:4 also presents a formula to calculate the fuel consumption rates for LDVs with other base vehicle weights. The fuel consumption rates for medium and heavy trucks are based on the average weight of vehicles in this class and no formula exists to modify them for specific vehicles of different vehicle weights.

Table C:4 shows the urban fuel consumption rates and the formula used to calculate them for LDVs and heavy trucks. These rates multiplied by the vehicle's VMT and the future year correction factors from Tables C:5:1 to C:5:3 will yield the total fuel consumption for any given time period between 1980 and 2005. This total fuel quantity can then be multiplied by the percent of diesel (Tables C:5:1 to C:5:3) to further differentiate between gasoline and diesel.

It should be noted that the Urban Fuel Consumption Method is only valid for relatively flat (0% grade) roadway sections. No data exist for nonflat conditions. We might suggest calculating a grade correction factor from Tables C:1:1 to C:1:3 by taking the fuel rate for the grade and speed desired and dividing it by the rate for the same speed at 0 grade. This grade correction factor could then be multiplied by the appropriate urban fuel consumption rate to get the urban consumption at grade.

VMT Fuel Consumption Method

The third direct fuel consumption methodology is used when nothing is known about the transportation system other than the vehicle's total VMT. This method is most applicable for use with large macroscale regional or subregional transportation models which will often output only the total VMT by mode. Generally, it would not be applicable for a project level study of roadway vehicles.

Tables C:5:1 to C:5:3 give the average on-the-road fleet fuel efficiency for each vehicle type. These fuel efficiencies are simply divided into the VMT to obtain the total fuel consumption which may then be separated into gasoline and diesel using the percent of diesel column in these tables.

Direct Energy-Buses

The direct fuel consumption for buses is calculated differently from that of the other vehicle types, mostly because there is no data base similar to that of the above vehicles to call upon. For the purpose of this report, the fuel consumption rate for buses is contingent on the following parameters: bus type, load factor, route type and the use of air conditioning.

Tables C:8 to C:10 give the fuel consumption rate of a number of makes and models of buses under three load factors: empty, 20 passengers, and full. The fuel consumption rates are further refined into three route types: Central

Business District*, Arterial Streets**, and Commuter***, and whether the buses are air conditioned (A.C.) or not.

Table C:11 gives the average of the fuel consumption rates for the three major bus types: Advanced Design Bus (ADB), New Look (NL), and Articulated (Art). The equations given below can be used to modify the fuel consumption rate on the CBD route for all bus types to something other than seven stops per mile. This is done by taking the fuel consumption rates given in Table C:11 and dividing them by the appropriate factor below.

CBD Correction Factor (A.C.) = $3.81 \times e^{(-0.1915xn)}$

CBD Correction Factor (no A.C.) = $3.38 \times e^{(-0.1738xn)}$

where n = stops per mile
e = natural logarithm

*CBD Route: 7 acceleration/stops per mile between zero and 20 mph; average speed = 12.9 mph.

**ART Route: 2 acceleration/stops per mile between zero and 40 mph; average speed = 26.7 mph.

***Com Route: 1 acceleration/stop per 4 miles between zero and 55 mph; average speed = 46.5 mph.

Indirect Energy-Vehicles

Indirect vehicle energy can be broken down into the following four basic components: oil, tires, general maintenance and repair, and manufacturing energy. The amount of energy expended on a per mile basis for these last three components will change with the pavement surface condition. Therefore these factors have to be multiplied by a correction factor if the pavement has a different pavement serviceability index (PSI) value from the base value of 3.5. The base values of the indirect energy components and their correction factors are given in Tables C:12:1 to C:12:3.

Indirect vehicle energy for buses is just broken down by manufacturing and total maintenance. These values are given in Table C:13.

Indirect Energy-Roadway Maintenance

The energy involved in roadway maintenance can be determined by identifying the type of pavement (PCC/AC) and the area type (urban/rural). Table C:14 gives the maintenance energy values on a Btu per lane-mile per year basis. These figures are valid for routine maintenance only: patching, crack sealing, lighting, landscape maintenance, etc. Major rehabilitation projects (such as overlays, slab replacement, etc.) done by outside contractors should be considered as construction projects.

Indirect Energy-Roadway Construction

There are two basic methods used for calculating roadway construction energy: the process analysis approach and the input/output approach. The process analysis approach follows the construction process along from start to finish and assigns an energy value for every material and operational step in that process. This method is useful in that it identifies energy intensive steps and it allows the analyst to determine the individual effects of changes in design or other underlying assumptions. The input-output approach simply assigns an energy-to-dollar ratio for every sector of the economy, such as roadway construction (we have modified these original factors to some extent to allow further differentiation of highway projects). Input-output is useful because it is quick and easy and because preliminary cost data are often the only information available at the time of EIR preparation.

C3 Process Analysis Approach

The energy necessary to construct a project can be broken down in the following manner: materials energy (the energy necessary to produce asphalt, portland cement, aggregate, etc.) operations energy (for mixing, placing, compacting, etc.) and transportation energy (taking materials to and from the job site). By summing the energy for the specific mix designs, construction methods and transport distances used on the job, the total construction energy can be determined.

The energy equivalent of the basic construction materials are given in Appendix G. Table C:15 shows the direct energy used to operate various types of construction equipment. Table C:16 gives estimates of the energy to complete various construction operations. The transportation energy for construction materials is calculated from Table C:17. Estimates of the total energy to produce various construction items in-place are given in Tables C:18 and C:19. The values in these tables assume certain mix designs and construction techniques and do not include the transportation energy, which can be quite variable. An example of the process analysis method of construction energy analysis is given in Appendix D.

C4 Input-Output Approach

The input-output is considerably faster and less accurate than the process analysis approach. It involves simply reducing the cost estimates for each type of facility in a construction project down to their 1977 level by multiplying them by the Highway Construction Price Index in Table C:21. These 1977 dollar costs are then multiplied by the appropriate Btu/$ ratio from Table C:20 to obtain the construction energy.

TABLE C:1:1

FREE FLOW FUEL CONSUMPTION FOR SPEED AND GRADE (GAL/1000 MI.)

BASE YEAR 1980 - LIGHT DUTY VEHICLE

(REF. 3,4,5,7)

	SPEED IN MILES PER HOUR													
GRADE	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00	55.00	60.00	65.00	70.00
8	127.93	127.03	110.25	96.86	91.60	85.87	93.79	100.69	109.67	118.79	128.25	135.17	144.74	153.90
7	121.07	120.17	94.99	88.94	83.45	77.80	84.14	89.30	97.62	106.27	115.96	123.37	131.91	140.73
6	115.99	115.08	92.46	84.64	79.33	73.36	77.79	81.60	88.94	96.69	106.26	113.91	122.24	130.22
5	112.55	111.08	90.42	81.56	76.60	70.44	74.19	77.33	83.42	89.72	98.85	105.89	113.22	120.58
4	109.64	108.72	91.48	77.93	73.54	67.92	71.46	74.21	78.59	83.10	88.71	97.49	105.48	113.22
3	106.18	105.82	91.14	74.54	70.95	65.58	68.80	71.39	73.99	76.87	83.95	89.10	97.93	106.66
2	101.88	100.95	86.47	69.48	66.21	61.41	64.50	66.88	68.28	70.06	76.04	80.40	89.98	99.30
1	92.97	93.16	78.33	63.23	59.05	54.58	57.25	59.30	59.78	61.26	66.78	70.93	79.18	87.51
0	85.50	83.98	68.33	52.33	48.39	46.50	47.02	47.84	50.99	54.08	58.14	62.45	69.73	77.15
-1	76.79	76.95	58.55	39.88	37.52	35.05	38.40	41.28	43.17	45.22	50.47	54.63	60.09	66.76
-2	71.10	71.23	52.91	34.89	32.25	29.17	32.86	36.19	37.07	38.07	42.71	46.78	51.92	57.82
-3	67.24	67.35	50.47	33.07	29.82	26.48	29.54	32.18	33.10	34.23	38.71	42.38	47.99	53.53
-4	64.58	64.68	49.22	33.50	29.62	25.54	27.46	29.20	30.08	31.06	35.46	38.96	44.63	50.07
-5	63.28	63.37	48.53	33.68	29.02	24.51	26.02	27.31	27.71	28.19	32.28	35.87	41.49	46.89
-6	63.49	63.58	48.68	33.45	28.61	23.75	24.61	25.23	25.77	26.20	31.37	32.67	37.23	41.55
-7	64.02	64.11	48.30	32.62	27.99	23.02	23.28	23.40	23.58	23.52	26.57	29.02	32.83	36.62
-8	64.76	64.86	48.45	31.81	26.97	22.26	21.93	22.06	20.71	20.36	23.32	25.03	28.76	31.66

TABLE C:1:2

FREE FLOW FUEL CONSUMPTION FOR SPEED AND GRADE (GAL/1000 MI.)

BASE YEAR 1980 - MEDIUM TRUCK

(REF. 3,4,5,7)

GRADE	SPEED IN MILES PER HOUR													
	5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00	55.00	60.00	65.00	70.00
8	416.00	406.00	330.00	263.00	247.00	231.00	238.00	248.00	223.00	203.00	202.00	201.00	204.00	216.00
7	389.00	380.00	306.00	242.00	230.00	219.00	228.00	240.00	217.00	197.00	198.00	198.00	201.00	214.00
6	362.00	354.00	288.00	230.00	220.00	212.00	221.00	232.00	211.00	194.00	194.00	194.00	198.00	211.00
5	343.00	335.00	228.00	222.00	213.00	204.00	210.00	218.00	201.00	188.00	179.00	189.00	194.00	206.00
4	324.00	317.00	243.00	215.00	206.00	198.00	200.00	204.00	192.00	182.00	176.00	182.00	187.00	200.00
3	305.00	298.00	249.00	206.00	197.00	189.00	187.00	187.00	179.00	174.00	171.00	174.00	180.00	192.00
2	281.00	275.00	230.00	192.00	182.00	173.00	170.00	147.00	145.00	143.00	143.00	166.00	171.00	184.00
1	249.00	243.00	202.00	164.00	151.00	138.00	141.00	146.00	151.00	150.00	153.00	154.00	161.00	174.00
0	212.00	207.00	167.00	132.00	121.00	112.00	113.00	115.00	123.00	133.00	139.00	144.00	150.00	163.00
-1	150.00	147.00	126.00	108.00	101.00	94.40	84.10	79.30	93.10	108.00	120.00	130.00	135.00	147.00
-2	121.00	118.00	109.00	101.00	91.20	82.60	73.10	65.10	73.80	83.70	99.70	115.00	122.00	135.00
-3	121.00	118.00	107.00	97.80	86.60	74.20	65.70	57.10	64.10	72.20	88.30	103.00	110.00	121.00
-4	124.00	121.00	109.00	98.80	84.80	71.60	60.50	50.80	58.00	66.10	79.10	92.00	98.50	110.00
-5	127.00	124.00	110.00	99.70	83.00	67.00	56.50	47.20	53.20	59.90	71.70	83.30	90.70	102.00
-6	130.00	127.00	112.00	101.00	81.10	62.40	53.40	45.50	50.10	55.50	66.40	76.30	83.70	94.30
-7	131.00	128.00	112.00	98.00	78.40	58.80	50.20	42.80	45.70	49.30	60.30	70.30	79.40	91.60
-8	133.00	130.00	110.00	94.20	74.30	55.10	47.50	41.00	42.40	44.70	56.80	67.70	75.90	87.90

TABLE C:1:3

FREE FLOW FUEL CONSUMPTION FOR SPEED AND GRADE (GAL/1000 MI.)

BASE YEAR 1980 - HEAVY TRUCK

(REF. 3,4,5,6,7)

GRADE	SPEED IN MILES PER HOUR 5.00	10.00	15.00	20.00	25.00	30.00	35.00	40.00	45.00	50.00	55.00	60.00	65.00	70.00
8	802.47	686.44	568.47	452.45	471.42	492.63	454.86	414.46	394.54	378.69	399.74	413.22	429.60	453.71
7	728.16	635.23	529.61	430.74	448.80	468.56	435.57	401.49	380.38	358.02	381.93	397.75	408.98	429.31
6	668.35	585.09	501.20	416.32	430.76	447.44	421.29	393.96	372.11	348.99	371.93	387.75	392.77	407.15
5	606.98	541.86	507.97	408.20	411.09	435.48	412.11	389.01	365.51	342.19	344.59	379.70	381.66	392.52
4	566.47	508.93	454.00	398.97	408.31	426.10	405.25	381.87	357.63	333.20	355.43	370.00	349.79	378.31
3	517.84	474.89	431.47	387.72	398.19	410.64	392.03	371.97	344.62	320.54	342.60	356.83	353.56	359.10
2	463.38	429.56	394.75	360.20	349.09	379.05	341.20	341.99	315.53	288.08	312.65	330.01	323.76	324.41
1	423.31	380.52	339.32	297.84	304.85	312.67	285.26	257.94	242.73	228.49	242.05	251.44	257.43	268.19
0	382.97	313.12	253.80	195.20	190.14	185.25	182.43	179.87	178.25	177.80	180.81	184.80	189.10	194.20
-1	103.66	82.05	61.16	40.63	38.23	54.11	60.52	62.42	68.92	88.88	88.74	87.01	90.01	89.04
-2	77.13	55.64	38.13	18.50	16.65	14.80	11.10	8.88	11.10	18.46	18.58	18.79	28.04	34.91
-3	55.52	35.52	24.42	13.32	11.84	10.36	6.10	5.55	6.84	8.14	9.25	10.36	14.27	15.00
-4	40.70	30.34	20.14	9.99	8.69	7.40	5.73	4.07	5.55	7.03	8.07	9.10	9.25	9.62
-5	34.78	25.90	17.02	8.14	6.84	5.55	4.25	2.96	4.81	4.44	7.33	7.95	8.14	8.51
-6	28.86	21.46	14.06	4.44	5.36	4.07	3.33	2.59	4.44	6.29	4.59	6.84	7.03	7.40
-7	23.86	17.76	11.65	5.55	4.07	2.59	2.40	2.22	4.07	5.92	5.77	5.59	5.55	5.92
-8	17.20	12.95	8.69	4.44	3.14	1.85	1.85	1.85	3.70	5.55	5.07	4.55	4.44	5.18

TABLE C:2:1

EXCESS FUEL CONSUMPTION FOR SPEED CHANGE CYCLE (GAL/1000 CYC)

BASE YEAR 1980 - LIGHT DUTY VEHICLE

(REF. 3 AND AUTHORS)

MIN. SPEED OF CYCLE, MPH

MAX. SPEED OF CYCLE, MPH

SPD	0	5	10	15	20	25	30	35	40	45	50	55	60	65
5	1.126													
10	2.190	1.064												
15	3.315	2.100	1.125											
20	4.622	3.496	2.432	1.307										
25	6.000	4.954	3.890	2.765	1.458									
30	7.710	6.584	5.521	4.396	3.089	1.630								
35	9.923	8.797	7.734	6.609	5.302	3.843	2.213							
40	12.354	11.227	10.164	9.039	7.732	6.273	4.643	2.430						
45	14.975	13.849	12.706	11.661	10.353	8.895	7.265	5.052	2.622					
50	17.000	16.762	15.690	14.573	13.266	11.808	10.178	7.965	5.534	2.913				
55	21.190	20.064	19.000	17.875	16.568	15.110	13.480	11.267	8.836	6.215	3.302			
60	25.026	23.900	22.036	21.711	20.404	18.946	17.316	15.103	12.673	10.051	7.138	3.836		
65	29.519	28.393	27.329	26.204	24.897	23.439	21.809	19.596	17.165	14.544	11.631	8.329	4.493	
70	35.708	34.581	33.518	32.393	31.086	29.627	27.997	25.784	23.354	20.732	17.820	14.518	10.682	6.189

TABLE C:2:2
EXCESS FUEL CONSUMPTION FOR SPEED CHANGE CYCLE (GAL/1000 CYC)
BASE YEAR 1980 – MEDIUM TRUCK
(REF. 3 AND AUTHORS)

MIN. SPEED OF CYCLE, MPH

MAX. SPEED OF CYCLE, MPH

SPD	0	5	10	15	20	25	30	35	40	45	50	55	60	65
5	2.964													
10	5.952	2.988												
15	9.580	6.617	3.620											
20	14.376	11.412	8.424	4.795										
25	20.327	17.363	14.375	10.746	5.951									
30	27.798	24.826	21.838	18.210	13.414	7.463								
35	37.296	34.333	31.344	27.716	22.921	16.970	9.506							
40	48.637	45.673	42.685	39.057	34.261	28.310	20.847	11.341						
45	61.983	58.940	55.951	52.323	47.520	41.577	34.113	24.607	13.266					
50	76.882	73.118	70.130	66.502	61.706	55.755	48.292	38.706	27.445	14.179				
55	90.651	87.688	84.699	81.071	76.276	70.325	62.861	53.355	42.014	28.740	14.560			
60	106.118	103.154	100.166	96.538	91.742	85.791	78.328	68.022	57.401	44.215	30.036	15.467		
65	123.129	120.165	117.177	113.548	108.753	102.802	95.339	85.832	74.492	61.226	47.047	32.478	17.011	
70	140.197	137.233	134.245	130.616	125.821	119.070	112.407	102.900	91.560	78.294	64.119	49.546	34.079	17.060

TABLE C:2:3
EXCESS FUEL CONSUMPTION FOR SPEED CHANGE CYCLE (GAL/1000 CYC)
BASE YEAR 1980 - HEAVY TRUCK
(REF. 3 AND AUTHORS)

MIN. SPEED OF CYCLE, MPH

MAX. SPEED OF CYCLE, MPH

SPD	0	5	10	15	20	25	30	35	40	45	50	55	60	65
5	7.177													
10	14.143	6.966												
15	21.049	14.672	7.706											
20	31.474	24.296	17.331	9.625										
25	42.217	35.040	28.074	20.368	10.743									
30	54.450	47.273	40.307	32.601	22.977	12.233								
35	68.707	61.530	54.564	46.858	37.234	26.490	14.257							
40	85.262	78.084	71.119	63.412	53.788	43.044	30.811	16.554						
45	104.847	97.669	90.704	82.998	73.373	62.629	50.396	36.139	19.585					
50	126.697	119.520	112.554	104.848	95.224	84.409	72.247	57.990	41.436	21.851				
55	148.978	141.801	134.835	127.129	117.504	106.761	94.529	80.271	63.716	44.131	22.281			
60	171.719	164.542	157.576	149.870	140.245	129.502	117.269	103.012	86.457	66.872	45.022	22.741		
65	195.209	188.031	181.065	173.359	163.735	152.991	140.758	126.501	109.947	90.362	68.511	46.231	23.490	
70	219.917	212.739	205.774	198.067	188.443	177.699	165.466	151.209	134.655	115.070	93.219	70.939	48.198	24.700

TABLE C:3:1
EXCESS FUEL CONSUMPTION ON HORIZONTAL CURVES (GAL/1000 MI.)
BASE YEAR 1980 – LIGHT DUTY VEHICLE
(REF. 3)

SPEED	DEGREE OF CURVATURE																
MPH	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	12.0	14.0	16.0	18.0	20.0	25.0	30.0
5	0.0	0.2	0.3	0.6	0.8	1.0	1.2	1.2	1.1	1.4	1.4	1.3	1.3	1.3	1.3	1.3	1.2
10	0.0	0.2	0.4	0.7	0.9	1.1	1.4	1.3	1.3	1.6	1.5	1.4	1.4	1.3	1.2	1.1	1.0
15	0.0	0.2	0.4	0.7	0.8	1.0	1.2	1.1	1.1	1.3	1.1	1.0	0.9	0.8	0.6	0.4	0.2
20	0.0	0.1	0.3	0.6	0.7	0.8	0.9	0.8	0.7	0.8	0.6	0.5	0.3	0.2	0.1	0.0	0.1
25	0.0	0.1	0.2	0.4	0.4	0.5	0.5	0.4	0.3	0.3	0.2	0.1	0.0	0.0	0.1	0.6	1.5
30	0.0	0.0	0.1	0.2	0.2	0.2	0.1	0.1	0.0	0.0	0.0	0.1	0.3	0.5	0.9	2.3	4.4
35	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.1	0.4	1.0	1.8	3.0	4.4	9.4	
40	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.6	0.8	2.0	3.7	4.0	9.0	12.5		
45	0.0	0.0	0.0	0.0	0.1	0.2	0.4	0.9	1.5	1.9	2.9	4.4	10.2				
50	0.0	0.0	0.1	0.1	0.3	0.6	1.0	1.7	2.7	3.8	4.5	11.7					
55	0.0	0.1	0.3	0.5	1.0	1.8	2.7	4.4	6.6	8.5	15.8						
60	0.1	0.3	0.6	1.1	2.1	3.5	5.2	8.1	12.2	14.1							
65	0.1	0.8	1.2	2.3	4.2	6.7	10.1	14.3	23.8	30.0							
70	0.2	1.0	2.3	4.2	7.8	12.4	19.5	28.3									

TABLE C:3:2
EXCESS FUEL CONSUMPTION ON HORIZONTAL CURVES (GAL/1000 MI.)
BASE YEAR 1980 - MEDIUM TRUCK
(REF. 3)

SPEED	DEGREE OF CURVATURE																
MPH	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	12.0	14.0	16.0	18.0	20.0	25.0	30.0
5	0.2	0.7	1.7	3.0	3.8	4.6	5.6	5.6	5.6	4.6	4.4	4.5	4.4	4.4	4.3	4.1	4.0
10	0.2	0.7	1.5	2.7	3.4	4.1	5.0	4.8	4.7	5.6	5.4	5.1	4.9	4.7	4.5	3.9	3.4
15	0.1	0.6	1.3	2.3	2.8	3.3	4.0	3.7	3.8	4.2	3.7	3.3	2.9	2.5	2.1	1.4	0.8
20	0.1	0.4	1.0	1.7	2.1	2.4	2.8	2.5	2.2	2.5	1.9	1.4	1.0	0.6	0.3	0.0	0.2
25	0.1	0.3	0.6	1.1	1.2	1.3	1.5	1.1	0.8	0.9	0.4	0.1	0.0	0.0	0.1	1.6	4.1
30	0.0	0.1	0.3	0.5	0.5	0.5	0.5	0.2	0.1	0.1	0.0	0.3	0.8	1.7	3.0	7.7	14.7
35	0.0	0.1	0.1	0.2	0.1	0.1	0.0	0.0	0.1	0.2	1.1	2.6	4.8	7.8	11.6	24.7	
40	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.7	1.5	2.0	5.0	9.4	15.4	23.0	32.1		
45	0.0	0.0	0.0	0.1	0.3	0.7	1.3	2.6	4.8	8.8	11.9	20.3	29.7				
50	0.0	0.1	0.2	0.3	0.8	1.8	2.3	4.1	6.3	8.2	15.3	23.3					
55	0.0	0.2	0.5	0.8	1.7	2.8	4.3	7.0	10.4	13.3	21.3						
60	0.1	0.4	0.8	1.5	2.9	4.7	7.1	11.1	15.5	19.5							
65	0.2	0.6	1.4	2.6	4.7	7.6	11.4	17.1	24.4	31.4							
70	0.3	1.0	2.4	4.4	7.9	12.7	18.7	27.6									

TABLE C:3:3

EXCESS FUEL CONSUMPTION ON HORIZONTAL CURVES (GAL/1000 MI.)

BASE YEAR 1980 - HEAVY TRUCK

(REF. 3)

SPEED	DEGREE OF CURVATURE																
MPH	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	12.0	14.0	16.0	18.0	20.0	25.0	30.0
5	0.2	0.8	1.8	3.2	4.1	5.1	6.1	6.1	6.1	7.2	7.2	7.1	7.0	6.9	6.9	6.7	6.5
10	0.3	1.2	2.8	5.0	6.3	7.7	9.3	9.1	8.8	10.5	10.1	9.4	9.2	8.8	8.3	7.4	6.4
15	0.3	1.4	3.1	5.5	6.8	8.2	9.7	9.1	8.6	10.1	9.0	8.0	7.0	6.1	5.2	3.4	1.9
20	0.3	1.3	2.9	5.3	6.2	7.3	8.4	7.4	6.5	7.6	5.7	4.2	2.9	1.8	1.0	0.0	0.5
25	0.3	1.0	2.3	4.1	4.6	5.0	5.6	4.3	3.1	3.5	1.7	0.5	0.0	0.2	1.0	6.1	15.5
30	0.2	0.6	1.5	2.6	2.5	2.5	2.4	1.2	0.4	0.4	0.1	1.3	4.1	8.5	14.7	37.6	72.1
35	0.0	0.2	0.4	0.8	0.5	0.3	0.2	0.0	0.5	0.7	3.9	9.5	17.7	28.8	42.7	90.7	
40	0.0	0.0	0.0	0.0	0.0	0.2	0.5	1.7	3.8	5.1	12.6	23.7	38.7	58.0	82.1		
45	0.0	0.0	0.1	0.2	0.7	1.6	2.9	6.0	10.3	13.4	27.3	46.7	73.1				
50	0.1	0.3	0.6	1.0	2.4	4.4	7.0	12.2	19.0	24.4	48.0	79.5					
55	0.2	0.9	2.0	3.6	7.2	12.3	18.0	30.5	45.3	58.3	112.8						
60	0.5	2.0	4.6	8.4	15.9	26.1	39.2	61.5	93.9	128.8							
65	0.9	3.8	8.0	16.0	29.3	47.8	70.9	108.9	148.8	167.7							
70	1.7	4.9	14.0	29.4	53.3	83.7	118.7	159.1									

TABLE C:4

URBAN FUEL CONSUMPTION

LIGHT DUTY VEHICLE

(REFERENCES 11,12,13,14,15)

$FCR = (A + C / V) \times 1000$ WHERE:

FCR = FUEL CONSUMPTION RATE (GAL/2000 MI)

$A = 9.278 \times 10^{-3} + 8.445 \times 10^{-6} \times$ VEH. WT.

$C = -2.618 \times 10^{-1} + 2.161 \times 10^{-4} \times$ VEH. WT.

V = VELOCITY, MPH

BASE YEAR	ON ROAD INERTIAL VEH. WT.(LB)	FUEL CONSUMPTION RATE AT STATED VELOCITIES									
		5	10	15	20	25	30	35	40	45	50
1980	3938	160.4	101.4	81.8	72.0	66.1	62.2	59.4	57.3	55.6	54.3

MEDIUM TRUCK

(REFERENCE 18)

$FCR = 1000 / (0.48 + 1.12 \times SQR(V))$ WHERE: FCR = FUEL CONSUMP. RATE (GAL/1000 MI)

V = VELOCITY, MPH

BASE YEAR	VEH. WT. LB	FUEL CONSUMPTION RATE AT STATED VELOCITIES									
		5	10	15	20	25	30	35	40	45	50
1980	8.5 - 19.5K	335.1	248.6	207.6	182.2	164.5	151.2	140.7	132.2	125.1	119.1

HEAVY TRUCK

(REFERENCE 18)

$FCR = (2.1 / V + 0.14) \times 1000$ WHERE: FCR = FUEL CONSUMP. RATE (GAL/1000 MI)

V = VELOCITY, MPH

BASE YEAR	VEH. WT. LB	FUEL CONSUMPTION RATE AT STATED VELOCITIES									
		5	10	15	20	25	30	35	40	45	50
1980	> 19.5K	560.0	350.0	280.0	245.0	224.0	210.0	200.0	192.5	186.7	182.0

TABLE C:5:1

PROJECTED FUTURE YEAR FUEL EFFICIENCY

LIGHT DUTY VEHICLE

****

(REFERENCES 7,8,9)

CALENDAR YEAR	FUEL COR. FACTOR	ON ROAD FLEET MPG	NEW MODEL FLEET MPG	PERCENT DIESEL
1980	1	14.24	18.46	.6
1981	.96	14.83	20.77	.9
1982	.92	15.48	22.05	1.1
1983	.874	16.3	23.08	1.8
1984	.825	17.26	24.29	2.6
1985	.779	18.27	25.49	3.6
1986	.733	19.42	26.67	4.8
1987	.691	20.62	27.78	5.9
1988	.655	21.74	28.99	6.9
1989	.624	22.83	30.12	8
1990	.592	24.04	31.03	8.9
1991	.562	25.35	32.1	9.9
1992	.537	26.5	33.1	10.8
1993	.518	27.5	34.02	11.5
1994	.497	28.65	34.75	12.3
1995	.481	29.59	35.08	12.7
1996	.466	30.55	35.05	13.1
1997	.454	31.4	35.03	13.7
1998	.445	32	35	14
1999	.436	32.65	34.98	14.3
2000	.431	33.04	34.95	14.4
2001	.424	33.56	34.92	14.8
2002	.422	33.78	34.9	14.8
2003	.419	34.01	34.87	14.9
2004	.416	34.25	34.85	14.9
2005	.415	34.35	34.82	14.9

TABLE C:5:2

PROJECTED FUTURE YEAR FUEL EFFICIENCY

MEDIUM TRUCK

(REFERENCES 7,8,9)

CALENDAR YEAR	FUEL COR. FACTOR	ON ROAD FLEET MPG	NEW MODEL FLEET MPG	PERCENT DIESEL
1980	1	8.22	9.87	.3
1981	.97	8.47	10.44	.3
1982	.937	8.77	10.87	.9
1983	.901	9.12	11.2	2.4
1984	.864	9.51	11.62	4.5
1985	.829	9.91	12.01	7
1986	.797	10.31	12.37	9.3
1987	.768	10.7	12.63	11.9
1988	.744	11.05	12.96	14.4
1989	.724	11.36	13.2	17
1990	.709	11.6	13.35	19.7
1991	.693	11.86	13.47	22.1
1992	.678	12.12	13.55	24
1993	.668	12.3	13.6	25.7
1994	.658	12.5	13.66	27.2
1995	.649	12.67	13.7	28.5
1996	.641	12.82	13.74	29.8
1997	.635	12.95	13.76	30.7
1998	.629	13.07	13.78	31.6
1999	.624	13.18	13.8	32.4
2000	.622	13.21	13.82	33
2001	.617	13.33	13.85	33.5
2002	.613	13.42	13.87	34
2003	.611	13.46	13.89	34.4
2004	.608	13.51	13.9	34.7
2005	.606	13.57	13.91	35

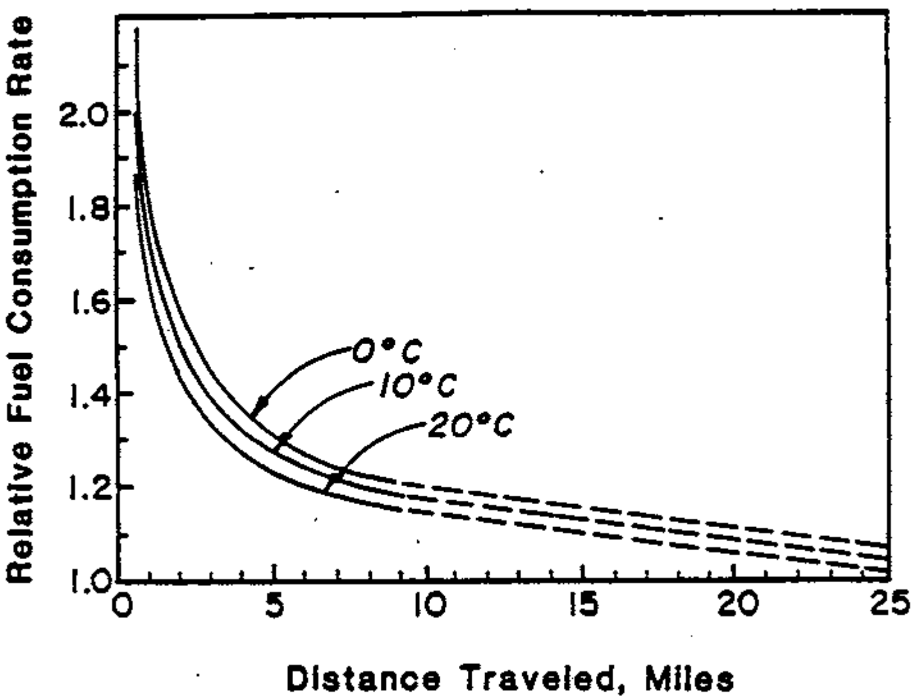
TABLE C:5:3

PROJECTED FUTURE YEAR FUEL EFFICIENCY

HEAVY TRUCK

(REFERENCES 7,8,9)

CALENDAR YEAR	FUEL COR. FACTOR	ON ROAD FLEET MPG	NEW MODEL FLEET MPG	PERCENT DIESEL
1980	1	5.17	5.67	78.6
1981	.987	5.24	5.84	80.2
1982	.974	5.31	5.97	81.6
1983	.956	5.41	6.15	83.3
1984	.935	5.53	6.28	85.2
1985	.913	5.66	6.49	87.1
1986	.887	5.83	6.65	88.6
1987	.863	5.99	6.8	90
1988	.841	6.15	6.85	91.3
1989	.822	6.29	7.09	92.6
1990	.809	6.39	7.19	93.6
1991	.797	6.49	7.25	94.4
1992	.783	6.6	7.31	94.9
1993	.772	6.7	7.37	95.4
1994	.759	6.81	7.4	95.8
1995	.747	6.92	7.42	96.1
1996	.739	7	7.44	96.5
1997	.733	7.05	7.46	96.6
1998	.725	7.13	7.48	96.8
1999	.719	7.19	7.51	97
2000	.715	7.23	7.5	97.1
2001	.711	7.27	7.55	97.4
2002	.706	7.32	7.57	97.5
2003	.703	7.35	7.58	97.6
2004	.701	7.37	7.59	97.7
2005	.698	7.41	7.6	97.7



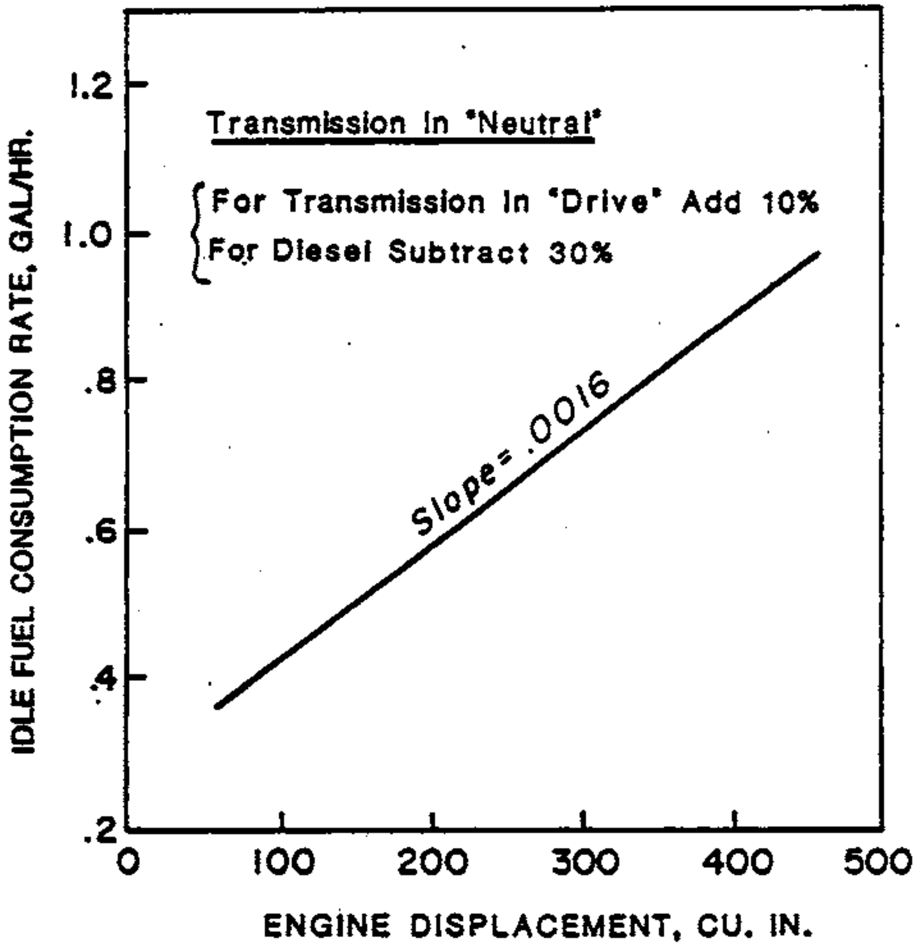
Ref. 30

Fig. C:1 COLD START FUEL CONSUMPTION-AUTO

TABLE C:6

COLD START FUEL CONSUMPTION-AUTO

Trip Distance (mile)	Cold/Warm Start Ratio 0°C	10°C	20°C
1	1.84	1.76	1.67
2	1.62	1.54	1.45
3	1.47	1.40	1.35
4	1.37	1.32	1.28
5	1.31	1.28	1.23
10	1.20	1.18	1.15
15	1.16	1.13	1.11
20	1.11	1.08	1.06
25	1.06	1.04	1.02



Ref. 28, 29, 12, 21, 30

Fig. C:2 IDLE FUEL CONSUMPTION VS GASOLINE ENGINE DISPLACEMENT

TABLE C:7

MISCELLANEOUS DIRECT ENERGY FACTORS-AUTO

Acceleration Rate

Fuel consumption increases 10.4% when acceleration rate increases from 1.0 mph/sec to 4.0 mph/sec (Ref. 35).

Driver Characteristics

Driving Technique	Change in Fuel Consumption	Change in Speed	Ref.
Minimize Stops	-16.1%	+3.39	20
Drive Very Cautiously	-7.4%	-7.2	20
Reduce Accels and Decels	-6.8%	-4.2	20
Minimize Trip Time	+9.0%	+15.7	20
Use Vigorous Acceleration	+14.0%	+11.9	20
Drive Economically	-23%	-15%	19
Add Passenger	+2 to 6%	--	19

"Older male drivers use less fuel than younger men, the opposite is true for women" (Ref. 19).

All Values are % Change in Fuel Consumption

Accessories	20 mph	30 mph	40 mph	50 mph	60 mph	70 mph	80 mph	Ref.
Power Steering	--	2.4	2.1	2.0	2.0	2.0	2.2	36
Air Conditioning	14.4	10.7	7.5	5.5	5.3	5.3	4.5	16
Windows Open	-2.6	1.8	1.9	1.8	1.0	2.1	2.2	16

	City Driving	Highway Driving	Combined	Ref.
Air Conditioning, 80°F	6.5	4.1	5.6	16
Air Conditioning, 90°F	8.9	10.2	9.4	16
Air Conditioning, 110°F	13.9	17.6	15.3	16

TABLE C:7 (Continued)

MISCELLANEOUS DIRECT ENERGY FACTORS-AUTO

Engine

	% Change in Fuel Consumption City	Highway	Ref.
One Spark Plug Misfiring	13	15	40
Air/Fuel Ratio too Rich	11	12	40
Ignition Timing Retarded 8°	6	4	40
Idle Air/Fuel Rich	1	-1	41
Plugged PCV	4	3	40
Choke Rich	2	1	41
Idle RPM High	4	2	42
Distributor Vacuum Low	1	1	40,41
Idle Air/Fuel Lean	<.5	<.5	40
Ignition Timing Advanced 5°	-2	-1	42
Air Pump Disabled	-1	-1	41
Choke Heater Disconnected	<.5	-2	41
Idle RPM Low	-3	<.5	40
Put in New Plugs	-2.5 to -5		43
Tuneup	-9 to -15		43

Elevation

	City	Highway	Ref.
<500 ft	+0.4%	-0.1%	16
500-1000 ft	0.0	0.0	16
1000-2000 ft	-0.4	+0.1	16
2000-5000 ft	-1.6	+0.5	16
>5000 ft	-3.1	+1.0	16

All Values are % Change in Fuel Consumption

Pavement Surface

	Dry	Wet	Snowy	Ref.
Unsurfaced	20	30	35	16
Gravel	15	18	20	16
Low Load Asphalt	4	5	10	16
PCC, High Load AC	0	3	7	16

TABLE C:7 (Continued)

MISCELLANEOUS DIRECT ENERGY FACTORS-AUTO

All Values are % Change in Fuel Consumption

Temperature

	Small Car	Large Car	Ref.
<10°F	+44.5	+17.1	16
10-20	33.0	13.4	16
20-30	26.3	11.4	16
30-40	20.2	8.7	16
40-50	14.7	6.5	16
50-60	9.6	4.4	16
60-70	5.0	2.4	16
70-80	.8	.4	16
80-90	-3.1	-1.5	16
90-100	-6.7	-3.3	16
>100	-10.7	-5.5	16

Tires

	Increase One Letter	Increase One Inch	Both 1 Inch and 1 Letter	Ref.
Bias Ply	-0.8	-1.1	-1.9	38
Radials	-0.8	-1.1	-1.9	38
Bias to Radials	-4.3	-4.5	-5.3	38

Bias to Radials Switch Only:	-3.5	38
Bias to Radials Switch Only:	-2.0 to -2.5	39
Inflation Pressure:	-0.55% per psi	16

Transmission

Switch from Automatic to Manual	-4.5 to -7.3	16
Switch from Automatic to Manual	-14.0 to -15.5	39

Wind

Wind Speed (mph)	City Driving Small Car	City Driving Large Car	Highway Driving Small Car	Highway Driving Large Car	Ref.
<3	0.0	0.0	0.0	0.0	16
4-7	0.4	0.3	1.9	1.5	16
8-12	1.4	1.1	6.2	4.8	16
13-18	2.1	1.6	9.7	7.5	16
19-24	2.9	2.2	13.0	9.0	16
≥25	3.8	2.9	17.2	13.2	16

TABLE C:8

BASELINE BUS COMPARISONS WITH
SEATED CAPACITIES

Manufacturer	Model	Type	Capacity	Fuel Economy MPG: Non-Air Conditioned			Air Conditioned		
				CBD**	ART**	COM**	CBD	ART	COM
Flexible	870	ADB	49	2.88	3.13	4.69	2.43	2.64	3.96
Flyer	DG01	New Look	51	3.28	2.79	5.20	2.57	2.15	5.33
Gillig	Phantom	ADB/New Look	49	3.33	3.57	5.02	3.05	3.24	4.55
GM-Canada*	5307A	New Look	53	N/A	N/A	N/A	2.21	2.42	3.70
GM-Canada*	5307N	New Look	53	3.34	3.14	4.79	N/A	N/A	N/A
GMC	RTS	ADB	47	2.68	3.32	4.40	2.33	2.89	3.83
Neoplan	Atlantis	New Look	48	3.17	3.46	5.03	2.65	2.90	4.16
Neoplan	N412	ADB	42	3.51	3.64	5.12	2.95	3.11	5.93
Neoplan	N421	Articulated	59	2.61	2.71	3.97	2.18	2.29	3.40
Crown-Ikarus	286	Articulated	74	2.36	2.56	3.81	1.92	2.24	3.41

*Data not directly comparable since A/C available only with larger V8-71 engine
**CBD: Central Business District; ART: Arterial; COM: Commuter

(Ref. 22)

TABLE C:9

BASELINE BUS COMPARISONS WITH
20 PASSENGERS

Manufacturer	Model	Type	Capacity	Fuel Economy MPG — Non-Air Conditioned CBD**	ART**	COM**	Air Conditioned CBD	ART	COM
Flexible	870	ADB	49	3.06	3.47	5.11	2.59	2.93	4.37
Flyer	DG01	New Look	51	3.70	3.44	5.21	2.85	2.44	5.25
Gillig	Phantom	ADB/New Look	49	3.63	3.97	5.51	3.28	3.60	5.02
GM-Canada*	5307A	New Look	53	N/A	N/A	N/A	2.41	2.89	3.77
GM-Canada*	5307N	New Look	53	3.81	3.82	4.89	N/A	N/A	N/A
GMC	RTS	ADB	47	2.85	3.69	4.73	2.46	3.22	4.16
Neoplan	Atlantis	New Look	48	3.32	3.77	5.41	2.79	3.16	4.57
Neoplan	N412	ADB	42	3.74	3.93	5.44	3.08	3.34	6.23
Neoplan	N421	Articulated	59	2.79	3.06	4.30	2.33	2.60	3.72
Crown-Ikarus	286	Articulated	74	2.63	3.01	4.45	2.11	2.61	3.95

*Data not directly comparable since A/C available only with larger V8-71 engine
**CBD: Central Business District; ART: Arterial; COM: Commuter

(Ref. 22)

TABLE C:10

BASELINE BUS COMPARISONS WITH NO PASSENGERS

Manufacturer	Model	Type	Capacity	Fuel Economy MPG Non-Air Conditioned CBD**	ART**	COM**	Air Conditioned CBD	ART	COM
Flexible	870	ADB	49	3.21	3.75	5.42	2.73	3.16	4.66
Flyer	DG01	New Look	51	4.00	3.89	5.23	3.06	2.87	5.23
Gillig	Phantom	ADB/New Look	49	3.88	4.29	5.87	3.45	3.88	5.37
GM-Canada*	5307A	New Look	53	N/A	N/A	N/A	2.54	3.21	3.82
GM-Canada*	5307N	New Look	53	4.16	4.30	4.97	N/A	N/A	N/A
GMC	RTS	ADB	47	3.01	4.00	4.98	2.57	3.48	4.39
Neoplan	Atlantis	New Look	48	3.48	4.08	5.78	2.94	3.42	4.92
Neoplan	N412	ADB	42	3.98	4.21	5.75	3.22	3.57	6.53
Neoplan	N421	Articulated	59	2.89	3.26	4.47	2.42	2.78	3.88
Crown-Ikarus	286	Articulated	74	2.74	3.21	4.70	2.18	2.76	4.16

*Data not directly comparable since A/C available only with larger V8-71 engine
**CBD: Central Business District; 7 0-20 mph acceleration/stops per mile; average speed 12.9 mph
ART: Arterial; 2 0-40 mph acceleration/stops per mile; average speed 26.7 mph
COM: Commuter; 1 0-55 mph acceleration/stops per 4 miles; average speed 46.5 mph

(Ref. 22)

TABLE C:11

AVERAGE FUEL CONSUMPTION BY BUS TYPE

Type	Average Capacity	Gallons/1000 Miles Non-Air Conditioned CBD*	ART*	COM*	Air Conditioned CBD	ART	COM
ADB	47	284.09	246.31	181.82	334.45	284.09	190.84
New Look	51	257.73	241.55	183.15	333.33	299.40	207.04
Articulated	66	355.87	309.60	218.34	434.78	361.01	248.76
ADB	47	301.20	265.25	192.31	350.88	305.81	202.02
New Look	51	276.24	266.67	190.11	353.36	331.13	215.05
Articulated	66	369.00	328.95	228.31	450.45	383.14	260.42
ADB	47	322.58	292.40	243.90	371.75	336.70	218.82
New Look	51	304.88	308.64	199.60	381.68	373.13	225.23
Articulated	66	401.61	378.79	257.07	487.80	440.53	293.26

*CBD: Central Business District; ART: Arterial; COM: Commuter

See Discussion, Page C-65

CBD Correction Factor (A.C.) = $3.81 \times e^{(-0.1915xn)}$

CBD Correction Factor (no A.C.) = $3.38 \times e^{(-0.1738xn)}$

where n = stops per mile
e = natural logarithm

(Ref. 22)

TABLE C:12:1

INDIRECT VEHICLE ENERGY-LIGHT DUTY VEHICLE

Oil Energy = .0014 quart/mi x 220,000 Btu/quart = 308 Btu/mi

Tire Energy = (4 tires x 3.16 x 10^6 Btu/tire)/40,000 mi = 316 Btu/mi

Maint & Repair Energy = \$.04217(1980\$)/mi x $\left(\frac{1.00[1972\$]}{2.74[1980\$]}\right)$ 32,819 Btu/1972 \$ = 505 Btu/mi

Manufacturing Energy = 139.9 x 10^6 Btu/100,000 mi = 1399 Btu/mi

Light Duty Vehicles Adjustment Factors for Roadway Surface Condition

Pavement Serviceability Index	Tire Adjustment Factor	Maintenance Adjustment Factor	Mfg. Depreciation Adjustment Factor
1.0	2.40	2.30	1.14
1.5	1.97	1.98	1.09
2.0	1.64	1.71	1.06
2.5	1.37	1.37	1.04
3.0	1.16	1.15	1.02
3.5	1.00	1.00	1.00
4.0	0.86	0.90	0.99
4.5	0.76	0.83	0.98

TABLE C:12:2

INDIRECT VEHICLE ENERGY-MEDIUM TRUCK

Oil Energy = .0027 quart/mi x 220,000 Btu/quart = 594 Btu/mi

Tire Energy = (4 tires x 4.58 x 10^6 Btu/tire)/50,000 mi = 366 Btu/mi

Maint & Repair Energy = \$.099(1980\$)/mi x $\left(\frac{1.00[1972\$]}{2.74[1980\$]}\right)$ 32,819 Btu/1972 \$ = 1186 Btu/mi

Manufacturing Energy = 367.7 x 10^6 Btu/200,000 mi = 1839 Btu/mi

Medium Duty Vehicles Adjustment Factors for Roadway Surface Condition

Pavement Serviceability Index	Tire Adjustment Factor	Maintenance Adjustment Factor	Mfg. Depreciation Adjustment Factor
1.0	1.67	1.73	1.33
1.5	1.44	1.48	1.23
2.0	1.27	1.30	1.15
2.5	1.16	1.17	1.09
3.0	1.07	1.07	1.04
3.5	1.00	1.00	1.00
4.0	0.95	0.94	0.97
4.5	0.92	0.90	0.94

TABLE C:12:3

INDIRECT VEHICLE ENERGY-HEAVY TRUCK

Oil Energy = .0058 quart/mi x 206,800 Btu/quart = 1199 Btu/mi

Tire Energy = (4 tires x 1.27 x 10^7 Btu/tire)/70,000 mi = 725 Btu/mi

Maint & Repair Energy = $.14315(1980$)/mi x $\left(\frac{1.00[1972\$]}{2.74[1980\$]}\right)$ 32,819 Btu/1972 $ = 1714 Btu/mi

Manufacturing Energy = 500.2 x 10^6 Btu/400,000 mi = 1251 Btu/mi

Heavy Duty Vehicles Adjustment Factors for Roadway Surface Condition

Pavement Serviceability Index	Tire Adjustment Factor	Maintenance Adjustment Factor	Mfg. Depreciation Adjustment Factor
1.0	1.67	2.35	1.32
1.5	1.44	1.82	1.22
2.0	1.27	1.50	1.14
2.5	1.16	1.27	1.09
3.0	1.07	1.11	1.04
3.5	1.00	1.00	1.00
4.0	0.95	0.92	0.97
4.5	0.92	0.86	0.94

TABLE C:13

INDIRECT VEHICLE ENERGY-BUS

Manufacturing Energy = 1040.5 x 10^6 Btu/300,000 mi = 3468 Btu/mi

Maintenance Energy (includes everthing but manufacturing) = 13,142 Btu/mi (Ref. 44)

TABLE C:14

ROADWAY MAINTENANCE ENERGY

Pavement Type	Annual Energy Consumption Btu per Lane-Mile Urban	Rural
Portland cement concrete	1.634×10^{8}	6.61×10^{7}
Asphalt concrete	1.776×10^{8}	8.03×10^{7}

Ref. 24 and authors

TABLE C:15

EQUIPMENT OPERATING ENERGY

Equipment Types	Gal/hr	Btu/hr	Ref.
1. Asphalt concrete grinder, Rotomill PR250, rated production 22 cu yd/hr 53,000 Btu/cu yd	8	1,180,800	29
2. Asphalt concrete grinder, Rotomill PR750, rated production 55 cu yd/hr 34,000 Btu/cu yd	12.6	1,860,000	29
3. Asphalt concrete paver	4.50	664,200	2
4. Asphalt concrete paver, 4 cu yd	3.2	472,320	29
5. Asphalt distributor tank truck 2.7 mi/gal - 53,220 Btu/mi	-	-	29
6. Backhoe, Trencher, gasoline 1.35 gal/cu yd - 194,000 Btu/cu yd	-	-	29
7. Broom, mechanical	1.0	143,700	30
8. Compactor/tractors, Cat 815, sheepsfoot	9.1	1,343,160	43
9. Crushing/screening plant	5.0	738,000	30
10. Dozer, track type	3.0	442,800	30
11. Dozer, Caterpillar D-5	4.2	619,920	43
12. Dozer, Caterpillar D-8	8.2	1,210,320	29
13. Excavator, Caterpillar 235	8.0	1,180,800	43
14. Grader, 23,000 lb Diesel	0.05	7,380	30
15. Grader, Caterpillar 12F	2.9	428,040	29
16. Grader, Caterpillar 12G	4.6	678,960	43
17. Loader, gas, 200 ton/hr	7.0	1,006,000	2

TABLE C:15 (Continued)

EQUIPMENT OPERATING ENERGY

Equipment Types	Gal/hr	Btu/hr	Ref.
18. Loader, gasoline, front end, 1.5 cu yd capacity	0.04	5,800	30
19. Loader, diesel, front end, 2 cu yd capacity	0.05	7,380	30
20. Loader, wheel type, diesel, front end, 8 cu yd capacity	5.6	826,560	29
21. Loader, wheel type, Caterpillar 988, 8 cu yd capacity	13.2	1,948,320	43
22. Mower, landscaping	0.4	57,480	30
23. Mower, R/W	1.0	143,700	30
24. Rollers	0.8	118,080	30
25. Rollers	4.5	664,200	2
26. Roller, Tandem, Model Hyster C-350	2.0	295,200	29
27. Roller, vibratory, 19 tons, Dynapack CC-50	6.0	885,600	29
28. Scraper, Caterpillar 631D, 21 cu yd capacity	15.8	2,332,080	43
29. Spreader, self propelled	2.4	354,240	30
30. Striping machine, self-contained, gas	1.0	143,700	30
31. Striping machine, hand, gas	0.5	71,850	30
32. Tractor, farm type, gas	3.0	431,000	30
33. Water truck, 4 mi/gal, 36,900 Btu/mi	-	-	29

TABLE C:16

CONSTRUCTION OPERATION ENERGY

		Ref.
Asphaltic Concrete		
Plant Operations		
Asphalt Storage	9,200 Btu/ton	2
Cold Feed	5,440 Btu/ton	2
Dryer & Exhaust	5,480 Btu/ton	2
Pugmill Mixing Plant	4,510 Btu/ton	2
Dryer Drum Mixing Plant	740 Btu/ton	2
Mobile Plant Setup & Removal	14,060 Btu/ton	29
Peripheral Plant Operation	63,980 Btu/ton	29
Dry & Heat Aggregate	221,000-347,000 Btu/ton	30
Remove 1% moisture from aggregate	29,900 Btu/ton	2
Raise Aggregate 1°F	480 Btu/ton	2
Road Operations		
Traveling Plant (windrow) Mixing	3,170 Btu/ton	2
Blade Mixing	35 Btu/sq yd pass	
	420 Btu/sq yd in	2
Spread & Compact (hot mix)	17,700 Btu/ton	2
Rolling (cold mix)	130 Btu/sq yd	2
Placement	40,700 Btu/ton	31
Earthwork		
Excavation, earth	64,300 Btu/cu yd	31
Excavation, rock	83,400 Btu/cu yd	31
Excavation, other	75,000 Btu/cu yd	31
Borrow	40,000 Btu/cu yd	32
Loose Riprap	83,400 Btu/cu yd	32
Granular Backfill	170,000 Btu/cu yd	32

TABLE C:16 (Continued)

CONSTRUCTION OPERATION ENERGY

		Ref.
Portland Cement Concrete		
Plant Operations		
Loader	4,720 Btu/ton	2
Conveyor	300 Btu/ton	2
Mixing & Other Plant Operations	1,920 Btu/ton	2
Production (total)	62,900 Btu/cu yd	31
Road Operations		
Placing, Consolidating, Finishing	2,800 Btu/ton	2
Placement	65,500 Btu/cu yd	31
Miscellaneous		
Aggregate Spreader	10 Btu/sq yd	2
Aggregate Stabilization (mixing)	10,000 Btu/sq yd	32
Asphalt Distributor		
Asphalt Cement	600 Btu/gal	2
Asphalt Emulsion	160 Btu/gal	2
Centrally Prepared Stabilized Mixes	7,900 Btu/ton	2
Concrete Barrier Construction	43,900 Btu/lf	32
Guardrail Construction	33,000 Btu/lf	32

TABLE C:17

TRANSPORT ENERGY

	Btu/Ton-Mile Gas Truck	Btu/Ton-Mile Diesel Truck	Ref.
Trucks, fully loaded one-direction return empty			
2 axle, 6 tire	12,670		2
3 axle,	4,900	4,040	2
3 axle, comb.	8,450	6,200	2
4 axle, comb.	5,770	3,470	2
5 axle, comb.	3,335	2,095	2
5 axle, comb.	mountain terrain	2,140	29

Various vehicles	mpg	Btu/mi	Ref.
Automobile	17.3	8,300	30
Station wagon	16.11	8,920	30
Pickup	10.9	13,180	30
Maintenance truck - 1 ton	8.0	13,450	30
Maintenance truck - Gas	4.7	30,570	30
Maintenance truck - Diesel	5.2	28,400	30
Maintenance truck - 2 axle	5.0	29,520	30
Truck tractor	4.6	32,000	30
Distributor truck - gas	4.0	36,900	30

TABLE C:18

ENERGY FOR
ROADWAY CONSTRUCTION ITEMS, IN PLACE*

			Ref.
Asphalt Concrete (5%)	145 lb/cf	1,942,000 Btu/ton	Authors
Asphalt Concrete (6%)	145 lb/cf	2,256,000 Btu/ton	Authors
Base, aggregate, uncrushed	133 lb/cf	37,000 Btu/ton	32
Base, aggregate, crushed	148 lb/cf	95,000 Btu/ton	32
Base, asphaltic concrete (5%)	145 lb/cf	1,942,000 Btu/ton	Authors, 46
Base, asphaltic concrete (3%)	135 lb/cf	1,290,000 Btu/ton	Authors, 46
Base, cement treated (5%)		371,000 Btu/ton	Authors, 46
Base, lean concrete (4 sack)		1,380,000 Btu/ton	Authors, 46
Base, lime treated (4%)		397,000 Btu/ton	Authors, 46
Portland Cement Concrete:			
4 sack		1,446,000 Btu/ton	Authors, 46
5 sack		1,768,000 Btu/ton	Authors, 46
6 sack		1,928,000 Btu/ton	Authors, 46
7 sack		2,409,000 Btu/ton	Authors, 46
Pavement:			32
PCC 9 in.		484,000 Btu/sq yd	Authors
			32
PCC 10 in.		537,000 Btu/sq yd	Authors

*Note: This does not include the energy necessary to transport the materials from the point of manufacture to the work site. This should be added using the factors in Table C:17.

TABLE C:19

ENERGY FOR
STRUCTURAL CONSTRUCTION ITEMS
(Does not include placement)

		Ref.
Bridge Railing		
Railing	8.4×10^5 Btu/lf	Authors
Piles		
Class 1	12.89×10^5 Btu/lf	Authors
Class 2	11.54×10^5 Btu/lf	Authors
16 inch cast in place	2.61×10^5 Btu/lf	Authors
Class 45	1.68×10^5 Btu/lf	Authors
Class 70	1.68×10^5 Btu/lf	Authors

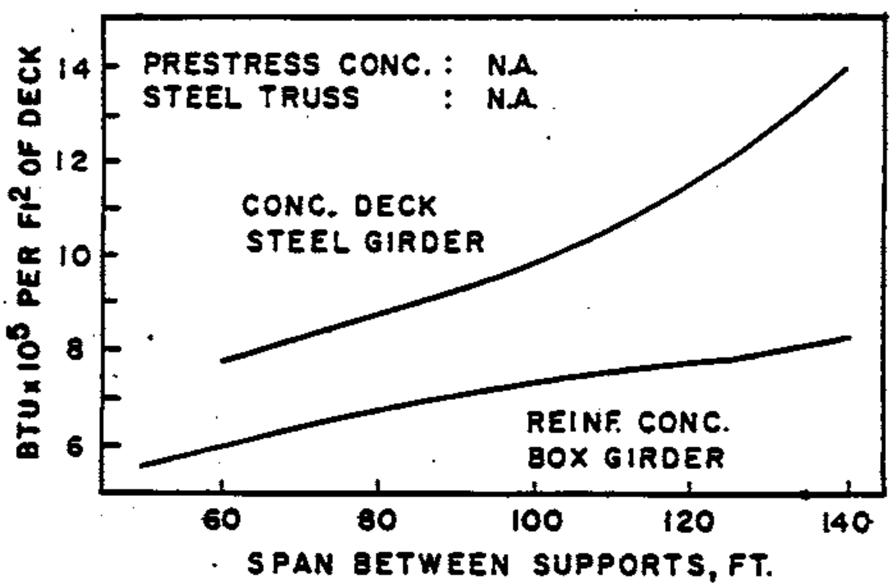


Fig. C:3 Energy of bridge superstructure materials (Add 30% for placement energy).

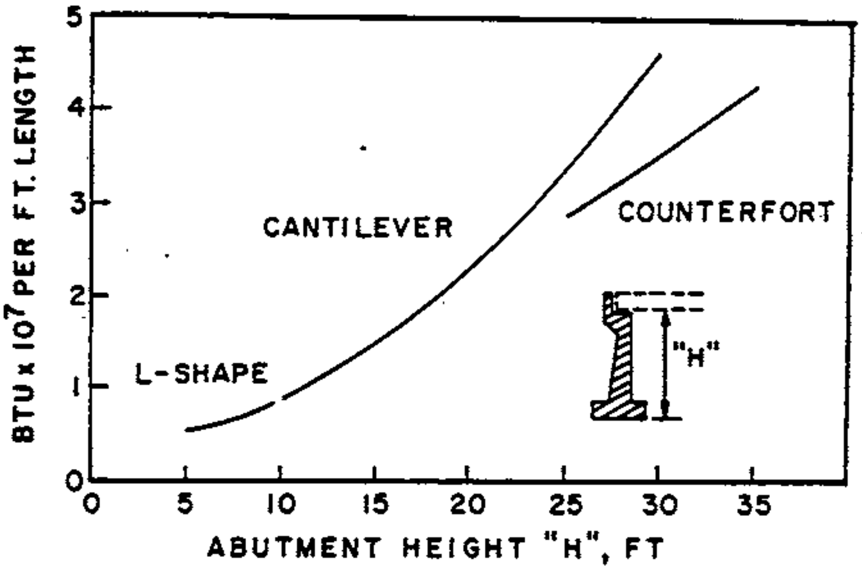


Fig. C:4 Energy of bridge abutment materials
(Add 30% for placement energy).

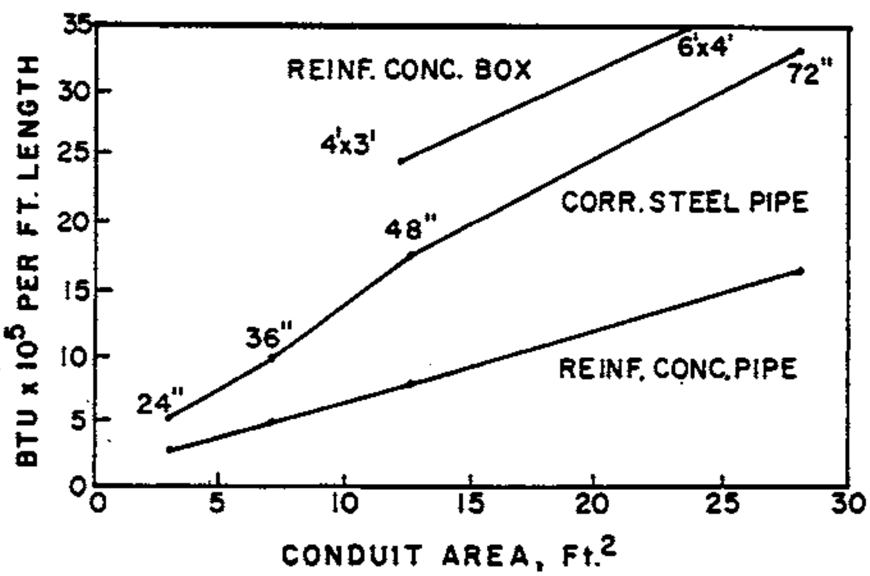


Fig. C:5 Energy consumed for culverts in-place.

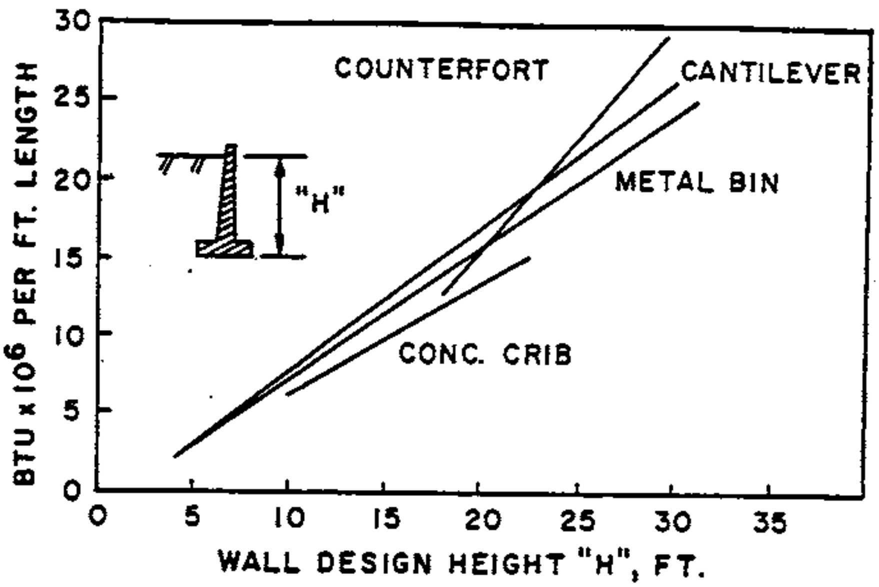


Fig. C:6 Energy consumed for retaining walls in-place.

TABLE C:20

CONSTRUCTION ENERGY FACTORS - BTU/1977$
(INPUT-OUTPUT METHOD)

Type of Facility	Project Energy Factor Btu/$	References
Rural Freeway	$6.92x10^4$	31,47
Rural Conventional Highway	$6.60x10^4$	31,47
Rural Freeway Widen	$4.32x10^4$	31,47
Rural Conventional Highway Widen	$4.65x10^4$	31,47
Urban Freeway	$2.75x10^4$	31,47
Urban Conventional Highway	$2.51x10^4$	31,47
Urban Freeway Widen	$2.46x10^4$	31,47
Urban Conventional Highway Widen	$2.33x10^4$	31,47
Interchange	$7.01x10^4$	31,46,47
Blanket	$3.46x10^4$	31,47
Bridge Steel Girder	$3.04x10^4$	31,46,47
Bridge Concrete Box Girder	$2.81x10^4$	31,46,47
Landscape Planting	$1.23x10^4$	31,47
Lighting Signals	$1.18x10^4$	31,47

TABLE C:21

HIGHWAY CONSTRUCTION PRICE INDEX

Year	Factor
1973	0.56
1974	0.83
1975	0.99
1976	0.86
1977	1.00
1978	1.14
1979	1.46
1980	1.54
1981	1.76
1982	1.55
1983	1.59

(Ref. 48)

C5 REFERENCES

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C6 COMMENTARY

General Comments

Many of the values for the energy factors reported in this section have previously not appeared in the published literature. They represent an extensive research effort to update as many factors as possible to post-1980 conditions. Due to the numerous gaps and inconsistencies in the transportation energy literature, oftentimes divergent data bases, analysis methodologies and assessment techniques have been to be combined to produce the values reported herein. Complete documentation of all the calculation procedures used here would expand the volume of this document many fold. In this commentary, an attempt has been made to present the various basis of the methods used to derive the energy factors and, if necessary, notes regarding their limitations. Complete documentation is available upon request for most of these factors. The authors would appreciate comments or criticism sent to the Transportation Laboratory in Sacramento.

It should be noted that a large percentage of the energy factors presented in this report and other references originated from a relatively small number of basic research papers. In the past, the vast majority of information available on construction energy originated from some assumptions made by one private institution(2). Virtually all of direct energy factors used by various researchers in the last 10 years were derived originally from one paper (Claffy, Paul J., "Running Costs of Motor Vehicles as Affected by Road Design and Traffic," NCHRP Report III [1971]. In this current report, an attempt has been made to trace all energy factors back to their original source, if possible, so that the concerned reader can determine their applicability toward any specific situation.

Tables C:1:1 to C:1:3
Fuel Consumption for Speed and Grade

Speed and grade fuel consumption tables were obtained from Reference 3 for compact, midsize, and large passenger vehicles as well as pickup, 2 axle single unit, 3 axle single unit, 4 axle semi and 5 axle semi trucks. Similar tables were derived for mini and subcompacts using data from Reference 4. The mini, subcompact, compact, midsize, large and pickup classes were normalized to 1980 conditions by dividing the fuel consumption tables by the test vehicle's model EPA gallons per mile (GPM) and multiplying by the respective 1980 vehicle class GPM. These normalized tables were combined into the composite 1980 LDV using sale weighted market shares from Reference 5. The composite 1980 fleet was translated to the 1980 on-the-road fleet using information from Reference 7.

The 3 axle, 4 axle and 5 axle trucks were combined into the heavy truck classification using truck body type distributions from Reference 6. The 2 axle single unit data were used as is.

Tables C:2:1 to C:2:3
Excess Fuel Consumption for Speed Change Cycles

These tables are based on an acceleration/deceleration fuel consumption model developed in Reference 3. Although some problems were discovered with some of the numerical algorithms used in this reference, these problems were corrected after discussions with the authors. This algorithm is based on empirically derived fuel consumption rates of a nonlinear acceleration model (the acceleration rate is contingent on the instantaneous speed) and a stepwise linear deceleration model (there are two consistent deceleration rates, depending on the speed.) It is doubtful that the numeric values used in this model would be precisely accurate for different acceleration/deceleration rates.

The method of combining disaggregate fuel consumption rates by EPA vehicle classification into the three vehicle types used is similar to that used by speed and grade tables above.

Tables C:3:1 to C:3:3
<u>Excess Fuel Consumption on Horizontal Curves</u>

Reference 3 devised a method of determining the energy dissipated due to tire slip on horizontal curves. Caltrans has created a computer algorithm to reproduce this method. The values output by this method are contingent on a number of input parameters. Below is a list of curve superelevations used to generate these tables. These are consistent with the superelevations used in the California Highway Design Manual.

Degree of Curve	Radius(ft)	Superelevation(ft/ft)
1	5730	.02
2	2865	.04
3	1910	.06
4	1432	.08
5	1146	.09
6	955	.10
7	819	.11
8	716	.11
9	637	.11
10	573	.12
12	477	.12
14	409	.12
16	358	.12
18	318	.12
20	286	.12
25	229	.12
30	191	.12

The method used to combine the fuel consumption rates output by this algorithm into the three vehicle classes is similar to that described above.

Table C:4

Urban Fuel Consumption

Numerous reports(11,12) have shown a linear relationship between fuel consumption and the time it takes to drive a given distance in urban conditions. Caltrans used this work, along with papers by Fred Wagner(13,14), to derive the coefficients used in this linear relationship as a function of weight for LDVs. The average weights of the new vehicle fleet for past years were obtained from References 14 and 15. These vehicle weights were used to calculate VMT averaged on-the-road vehicle weight for 1980 using VMT vs age data from Reference 17. The weight shown is an "inertial" weight which include an average 300 lb load for passengers and baggage.

The urban fuel consumption tables for medium and heavy trucks were taken directly from Reference 18.

It should be noted that the data base from which these fuel rates were derived specifically state that they are applicable 1) for speeds only under 40 mph and 2) for urban city (non-highway) conditions. No statistically validated data base has been developed for congestion at highway speed. Preliminary investigations from Caltrans District personnel seem to substantiate use of these factors for freeway conditions.

Tables C:5:1 to C:5:3
Projected Future Year Fuel Consumption Rates

All of the factors used in these tables were taken directly from Reference 7 for federal vehicles and References 8 and 9 for California vehicles. Both of these references are outputs of highly disaggregate computer models that take into account such things as: the technological feasibility of future development of more fuel efficient models in each vehicle classification, the social acceptability and probable purchases of each vehicle type, the probable survival rate by vehicle type, the vehicles declining VMT with age, the correlations between the vehicles EPA mileage and the on-the-road mileage, etc. Both models output the total VMT and fuel usage by class for most of the year from which these tables were derived.

It should be noted that the vehicle classifications are defined somewhat differently for the California and federal vehicles. The California Energy Commission, who developed References 8 and 9, define medium trucks as vehicles between 10,000 and 19,500 lb instead of the 8,500 to 19,500 lb classification used for the federal medium trucks. Reference 10 indicates that the majority of vehicles in the 8,500-10,000 lb range are 6 tired, 2 axle trucks which is the criteria used for medium trucks in the visual ADT counts from which the roadway vehicle mixes are usually determined. This is why they have been included in the medium truck classification for federal vehicles. The California Energy Commission puts the 8,500-10,000 lb truck in the same truck class as pickups. Here, pickups have been included in the light duty vehicle class because they are often used interchangeably with passenger vehicles in function. These differences may help explain some of the apparent abnormalities in the California medium truck data.

The fuel correction factors for each year in these tables is simply the on-road fleet MPG for that year divided by the on-road fleet MPG for 1980.

Table C:7

Miscellaneous Direct Energy Factors-Auto

General Comments: There are a number of conditions affecting fuel economy which usually are not specifically accounted for in large generalized data bases such as the ones used to generate most of the factors in this appendix. These factors may affect only a few individual vehicles in specific situations. They are presented here for the sake of completeness. For the most part, these factors represent a few isolated studies on specific vehicles. No attempt has been made to statistically validate them to the entire vehicle fleet.

Acceleration - Vehicles exhibited a wide degree of variation in their fuel consumption rate with acceleration.

Driver Characteristics - Reference 19 is based on British data. Reference 20 is based only on urban data.

Pavement Surface - Recent research has shown that there is virtually no change in direct fuel consumption with the pavement surface conditions normally experienced by roadway traffic. Wisconsin DOT showed a 3% change in fuel economy between a serviceability index of 0.9 and 4.4(21). Other researchers have concluded that even this small an effect cannot be validated(3).

Tables C:8 to C:11
Direct Energy-Buses

The bus fuel efficiencies shown in these tables are based on a computer program written for the National Cooperative Transit Research & Development Program. They represent the fuel efficiencies of the most likely engine, transmission and rear axle ratio combinations for each bus model. For applications where the bus characteristics are known more specifically, Reference 22 should be consulted directly.

The CBD correction factors for other than seven stops per mile were derived from Reference 18 which used a computer program similar to the above.

Tables C:12:1 to C:12:4

Indirect Vehicle Energy

General Notes - The indirect vehicle energy in these tables is shown to vary only with pavement surface roughness. Reference 3 contains a disaggregate data base to determine the indirect energy due to oil consumption, tire wear, maintenance and repair, and depreciation as a function of speed, grade, curvature, and accel/decel cycles for all three major vehicle classifications. However, due to numerical problems in the algorithms used to generate this data base, this information was not used.

Oil Consumption Energy - Base oil consumption rates (which include oil changes) were obtained from Reference 3 with a vehicle mix derived from References 5 and 6.

Tire Wear Energy - The energy to produce tires is from Appendix G.

Maintenance and Repair Energy - The cost per mile in 1980 dollars was derived from Reference 3. The inflation factors used to deflate the costs to 1977 dollars are from Table C:21. The energy to dollars ratio for vehicle repair is from Reference 24.

Manufacturing Energy - In order to reduce the number of hand calculations, a computer program was developed to determine the manufacturing energy of vehicles and other items. This program is based on the factors in Appendix G and the methodology of Reference 25. The program sums the energy of the various materials and fabrication process used in the vehicles manufacture. It also determines the quantity of this energy which is electrically based and the quantity which is premium fuel (gas and oil) based, although these numbers are not used at this time.

Tables C:22 and C:23 show example outputs of this program. Table C:22 gives the manufacturing energy breakdown for a composite 1980 vehicle, while Table C:23 shows the manufacturing energy for a projected year 2005 vehicle. Vehicle weights are from Table C:4, while the percentage material breakdowns are based on References 26, 27 and 28. As can be seen, even though light duty vehicles will become lighter in future years, they will be utilizing more energy intensive materials, so the overall manufacturing energy will remain virtually constant.

A similar analysis was done for most other major vehicle types.

Roadway Surface Adjustment Factors - These were taken directly from Reference 3.

Table C:14
Roadway Maintenance Energy

The energy equivalent of all the materials and resources used for maintenance of the California Highway System in 1980 was determined by using a combination of the input/output and process analysis approach. The pavement management accounting system allowed this energy consumption to be broken down by pavement type (PCC/AC) and a further distinction was made for urban/rural, with the majority of

TABLE C:22

COMPOSITE YEAR 1980 LIGHT DUTY AUTO MANUFACTURING ENERGY
ALL ENERGY QUANITIES ARE IN UNITS OF MILLONS OF BTU'S

MANUFACTURING PROCESS	STEP NUM	TONS	PROCESS ENERGY	PREMIUM ENERGY	ELECT ENERGY
MAT: STEEL : CARBON	1	1.136	45.19	14.78	7.41
FAB : STEEL COLD ROLL	2	0.604	3.11	0.94	1.86
FAB : STEEL PRESS FORM	3	0.024	0.07	0.02	0.07
FAB : STEEL ELEPLATE	4	0.127	0.48	0.18	0.41
FAB : STEEL STAMP	5	0.441	0.26	0.07	0.26
FAB : STEEL EXTRUS	6	0.010	0.05	0.02	0.03
FAB : STEEL DRAW	7	0.024	0.30	0.09	0.18
FAB : STEEL IND HARD	8	0.123	0.06	0.02	0.06
FAB : STEEL Q & T	9	0.356	0.96	0.80	0.21
FAB : STEEL FORG	10	0.019	0.30	0.13	0.23
MAT: HSLAS	11	0.086	4.98	1.90	0.99
MAT: PIG IRON	12	0.262	2.77	0.63	0.23
FAB : IRON CAST	13	0.262	2.93	0.79	0.87
MAT: ALUMINUM	14	0.062	14.65	4.99	11.09
FAB : ALUM CAST	15	0.025	0.27	0.07	0.26
FAB : ALUM EXTRUS	16	0.037	0.49	0.17	0.44
MAT: COPPER	17	0.017	2.18	1.36	0.85
FAB : COPPER DRAW	18	0.017	0.24	0.09	0.20
MAT: LEAD	19	0.016	1.10	0.47	0.43
FAB : LEAD ROLLING	20	0.016	0.05	0.02	0.04
MAT: ZINK	21	0.010	0.68	0.29	0.27
FAB : ZINK FORG	22	0.010	0.15	0.07	0.12
MAT: GLASS	23	0.058	1.21	0.70	0.18
MAT: RUBBER	24	0.081	11.92	11.00	1.22
FAB : INJ MOLD	25	0.081	1.21	0.68	0.73
MAT: HD POLYETHYLENE	26	0.091	8.56	7.97	0.78
FAB : INJ MOLD	27	0.091	1.36	0.76	0.81
MAT: FRP	28	0.000	0.00	0.00	0.00
FAB : FRP FORMATION	29	0.000	0.00	0.00	0.00
MAT: HRP	30	0.000	0.00	0.00	0.00
FAB : HRP FORMATION	31	0.000	0.00	0.00	0.00
MAT: POLYSTYRENE	32	0.115	15.90	14.90	1.08
FAB : INJ MOLD	33	0.115	1.72	0.97	1.03
CUMULATIVE SUBTOTAL		1.934	123.13	64.91	32.34
TOTAL FABRICATION ENERGY SO FAR IS : 14.001604					
FAB : ENERGY OVERHEAD	34	0.000	6.30	2.93	0.98
ASSEM: AUTO	35	0.000	10.40	6.70	2.16

TOTAL TONS	TOTAL ENERGY	TOT PREM ENERGY	TOT ELECT ENERGY
1.933768	139.835594	74.534012	35.479284

TABLE C:23

PROJECTED YEAR 2005 LIGHT DUTY AUTO MANUFACTURING ENERGY
ALL ENERGY QUANITIES ARE IN UNITS OF MILLONS OF BTU'S

MANUFACTURING PROCESS	STEP NUM	TONS	PROCESS ENERGY	PREMIUM ENERGY	ELECT ENERGY
MAT: STEEL : CARBON	1	0.233	9.26	3.03	1.52
FAB : STEEL COLD ROLL	2	0.124	0.64	0.19	0.38
FAB : STEEL PRESS FORM	3	0.005	0.01	0.00	0.01
FAB : STEEL ELEPLATE	4	0.026	0.10	0.04	0.08
FAB : STEEL STAMP	5	0.090	0.05	0.01	0.05
FAB : STEEL EXTRUS	6	0.002	0.01	0.00	0.01
FAB : STEEL DRAW	7	0.005	0.06	0.02	0.04
FAB : STEEL IND HARD	8	0.025	0.01	0.00	0.01
FAB : STEEL Q & T	9	0.073	0.20	0.16	0.04
FAB : STEEL FORG	10	0.004	0.06	0.03	0.05
MAT: HSLAS	11	0.257	14.87	5.68	2.94
MAT: PIG IRON	12	0.061	0.64	0.15	0.05
FAB : IRON CAST	13	0.061	0.68	0.18	0.20
MAT: ALUMINUM	14	0.240	56.57	19.29	42.82
FAB : ALUM CAST	15	0.096	1.03	0.29	1.02
FAB : ALUM EXTRUS	16	0.144	1.91	0.67	1.71
MAT: COPPER	17	0.010	1.29	0.81	0.51
FAB : COPPER DRAW	18	0.010	0.14	0.06	0.12
MAT: LEAD	19	0.013	0.94	0.40	0.37
FAB : LEAD ROLLING	20	0.013	0.05	0.02	0.03
MAT: ZINK	21	0.007	0.50	0.21	0.20
FAB : ZINK FORG	22	0.007	0.11	0.05	0.09
MAT: GLASS	23	0.043	0.91	0.53	0.13
MAT: RUBBER	24	0.065	9.54	8.81	0.97
FAB : INJ MOLD	25	0.065	0.97	0.55	0.58
MAT: HD POLYETHYLENE	26	0.060	5.66	5.28	0.52
FAB : INJ MOLD	27	0.060	0.90	0.51	0.54
MAT: FRP	28	0.006	0.49	0.42	0.05
FAB : FRP FORMATION	29	0.006	0.18	0.10	0.11
MAT: HRP	30	0.008	0.91	0.79	0.07
FAB : HRP FORMATION	31	0.008	0.35	0.20	0.21
MAT: POLYSTYRENE	32	0.108	14.91	13.97	1.01
FAB : INJ MOLD	33	0.108	1.61	0.91	0.97
CUMULATIVE SUBTOTAL		1.112	125.58	63.35	57.43
TOTAL FABRICATION ENERGY SO FAR IS : 9.074904					
FAB : ENERGY OVERHEAD	34	0.000	4.08	1.90	0.63
ASSEM: AUTO	35	0.000	10.40	6.70	2.16

TOTAL TONS	TOTAL ENERGY	TOT PREM ENERGY	TOT ELECT ENERGY
1.1115	140.059027	71.9478	60.22159

landscaping and lighting energy being attributed to the urban highways.

Table C:15

Equipment Operating Energy

Information from Reference 24 was obtained from field records of equipment used for an AC recycling project. Reference 6 is an actual equipment manufacturers handbook. Energy values from Reference 30 appear to be consistently lower than the rest. This is probably due to the fact that this information was taken originally from various state departments of transportation and probably represents the hourly consumption rates based on the time a piece of equipment was assigned to a task or project, and not necessarily the time the equipment was actually used.

Table C:16

Construction Operations Energy

Information from Reference 2 is almost completely theoretical assuming 100% productivity, and may not be applicable in real world situations. Values from References 29 and 30 apparently are from actual field operations of specific equipment. References 31 and 32 appear to be based on average fuel consumption values per bid item of actual construction projects. They probably include peripheral equipment energy for pickups, sweepers, cranes, etc.

Table C:17

Transport Energy

Most of these values were taken from a reference that quotes them originally from the FHWA.

Table C:18
Energy For Roadway Construction Items, In-Place

Most of these energy values were derived from the preceding tables, making certain assumptions regarding mix design and construction techniques. None of these values includes the energy necessary to transport the materials to the job site. This should be individually calculated for each job.

Table C:20
Construction Energy Factors-Btu/1977$ (Input-Output Method)

Energy values were based primarily on Reference 31 with engineering judgment used to modify the factors to California conditions.

Table C:21
Highway Construction Price Index

These values are based on the California "Highway Construction Cost Index", formerly the "Price Index for Selected Highway Construction Items", Reference 47.

C7 Example Problem

A project has been proposed to construct a highway bypass around a city from Point A to Point E. Currently, eastbound traffic enters the city at Point A and travels for two miles on one of the city's major arterials. The posted speed limit is 35 mph, but traffic is slowed by signalized intersections which result in three stops and two speed cycle changes from 35 to 20 mph. Westbound traffic has two stops and one speed cycle change from 35 mph to 25 mph. This section contains .5 mile of +3% grade and .25 mile of 10 degree curve. The pavement has a serviceability index of 3.0, and the combined ADT for both directions is 28,000. At Point B, the ADT increases to 32,000 and the average speed decreases to 20 mph as the route passes through a one mile flat section of urban CBD. This portion of the route has a serviceability index of 2.5. At Point D, the ADT drops to 28,000 again and traffic returns to free-flowing for the remaining two miles to Point E. At the time of the analysis, no data are available regarding the speed, traffic conditions, or specific roadway geometrics for this last section.

Alternative 1

It is proposed to build a new 4.5 mile, two-lane, bypass along a shorter but more hilly route. From Point A to Point C will be 1.5 miles containing one mile of +4% grade and .8 mile of 5 degree curve. From Point C to Point E will be 3.0 miles containing 1.25 miles of -2.0% grade and 1.6 miles of 4 degree curve. The ADT for the entire bypass is projected at 24,000; traffic would be free-flowing at 55 mph. The bypass being a new pavement would have a serviceability index of 3.5 and the project is estimated to cost $6,000,000 (in 1980 dollars).

Alternative 2

It is proposed that no improvements be made in the area (a no-build alternative). The existing roadway will receive only normal maintenance. Future traffic predictions indicate the same ADT and vehicle mix for the entire study period.

Perform an energy analysis comparing the two alternatives over a 20 year study period from beginning of 1985 to end of 2004. Use the federal vehicle fuel consumption rates. Calculate the total direct and indirect energy consumption by each alternative. It has been calculated that with the bypass, the city's arterial route would still retain a traffic of 4,350 vehicles per day. The vehicle mix for all traffic is 80% light duty vehicle, 10% medium vehicle and 10% heavy vehicle.

ALTERNATIVE #1

BUILD A BYPASS

DIRECT ENERGY CALCULATION WORKSHEET

[If the only information available is the segment length and ADT, then use the lines that are followed by "S" (special case)]

1 Study Period: Begin 1985 to End 2004; 20 Years

Line	Item	Formula	A to C	C to E	E to C	C to A
2	Points		A to C	C to E	E to C	C to A
3	Lane Segment #		1E	2E	2W	1W
4	Length of Segment (miles)		1.5	3.0	3.0	1.5
5	Type of Traffic Flow		F. Flow	F. Flow	F. Flow	F. Flow
6	Grade (%)		4	-2	+2	-4
7	Length of Grade (miles)		1.0	1.25	1.25	1.0
8	Curvature (degree)		5	4	4	5
9	Lengths of Curves (miles)		0.8	1.6	1.6	0.8
10	Speed Change Cycles		None	None	None	None
11	Average Speed, mph		55	55	55	55
12	Average Daily Traffic		12,000	12,000	12,000	12,000
13	Percent Light Duty Vehicle (LDV)		80	80	80	80
14	Number of LDV	[Lines 12x13]/100	9600	9600	9600	9600
15	Constant Speed 0% Grade Consumption Rate	(C-1-1)	58.1	58.1	58.1	58.1
16	Constant Speed at Grade Consumption Rate	(C-1-1)	88.7	42.7	76.0	35.5
17	Consumption Rate for Speed Change Cycles	(C-2-1)	0	0	0	0
18	Curvature Consumption Rate	(C-3-1)	1.0	0.5	0.5	1.0
19	Base Urban Fuel Consumption Rate	(C-4)	N/A	N/A	N/A	N/A
20	Fuel Consumed 0% Grade	[Lines (4-7)x14x15]/1000	279.1	976.8	976.8	279.1
21	Fuel Consumed at Grade	[Lines 7x14x16]/1000	851.6	512.5	912.5	340.4
22	Fuel Consumed Speed Change	[Lines 14x17]/1000	0	0	0	0
23	Fuel Consumed Curvature	[Lines 9x14x18]/1000	7.7	7.7	7.7	7.7
24	Base Urban Fuel Consumed	[Lines 4x14x19]/1000	N/A	N/A	N/A	N/A
25	Study Period Fuel Consumption	[Lines 20+21+22+23 or 24]x(365)x(years)	8.31E6	10.93E6	13.85E6	4.58E6
26	Study Period Average Base Fuel Correction factor	(C-5-1)	0.529	0.529	0.529	0.529
26S	Study Period Average On-Road Consumption Rate	[Line 26]/14.24[a]	N/A	N/A	N/A	N/A
27	Adjusted Fuel Consumption	[Lines 25x26] or [Lines 4x14x26S]x(365)x(years)	4.40E6	5.78E6	7.33E6	2.42E6
28	Percent Diesel - Study Period Average	(C-5-1)	11.21	11.21	11.21	11.21
29	Gallons Diesel	[Lines 27x28]/100	0.49E6	0.65E6	0.82E6	0.27E6
30	Gallons Gas	[Lines 27-29]	3.91E6	5.13E6	6.51E6	2.15E6
31	Percent Medium Truck (MT)		10	10	10	10
32	Number of Medium Truck	[Lines 12x31]/100	1200	1200	1200	1200
33	Constant Speed 0% Grade Consumption Rate	(C-1-2)	139.0	139.0	139.0	139.0
34	Constant Speed at Grade Consumption Rate	(C-1-2)	176.0	99.7	163.0	79.1
35	Consumption Rate for Speed Change Cycles	(C-2-2)	0	0	0	0
36	Curvature Consumption Rate	(C-3-2)	1.7	0.8	0.8	1.7
37	Base Urban Fuel Consumption Rate	(C-4)	N/A	N/A	N/A	N/A
38	Fuel Consumed 0% Grade	[Lines (4-7)x32x33]/1000	83.4	291.9	291.9	83.4
39	Fuel Consumed at Grade	[Lines 7x32x34]/1000	211.2	149.6	244.5	94.9
40	Fuel Consumed Speed Change	[Lines 32x35]/1000	0	0	0	0
41	Fuel Consumed Curvature	[Lines 9x32x36]/1000	1.6	1.5	1.5	1.6
42	Base Urban Fuel Consumed	[Lines 4x32x37]/1000	N/A	N/A	N/A	N/A
43	Study Period Fuel Consumption	[Lines 38+39+40+41 or 42]x(365)x(years)	2.16E6	3.23E6	3.93E6	1.31E6
44	Study Period Average Base Fuel Correction factor	(C-5-2)	0.68	0.68	0.68	0.68
44S	Study Period Average On-Road Consumption Rate	[Line 44]/8.22[a]	N/A	N/A	N/A	N/A
45	Adjusted Fuel Consumption	[Lines 43x44] or [Lines 4x32x44S]x(365)x(years)	1.47E6	2.20E6	2.67E6	0.89E6
46	Percent Diesel - Study Period Average	(C-5-2)	25.05	25.05	25.05	25.05
47	Gallons Diesel	[Lines 45x46]/100	0.37E6	0.55E6	0.67E6	0.22E6
48	Gallons Gas	[Lines 45-47]	1.10E6	1.65E6	2.00E6	0.67E6
49	Percent Heavy Truck (HT)		10	10	10	10
50	Number of Heavy Truck	[Lines 12x49]/100	1200	1200	1200	1200
51	Constant Speed 0% Grade Consumption Rate	(C-1-3)	180.81	180.81	180.81	180.81
52	Constant Speed at Grade Consumption Rate	(C-1-3)	355.43	18.85	312.65	8.07
53	Consumption Rate for Speed Change Cycles	(C-2-3)	0	0	0	0
54	Curvature Consumption Rate	(C-3-3)	7.2	3.6	3.6	7.2
55	Base Urban Fuel Consumption Rate	(C-4)	N/A	N/A	N/A	N/A
56	Fuel Consumed 0% Grade	[Lines (4-7)x50x51]/1000	108.5	379.7	379.7	108.5
57	Fuel Consumed at Grade	[Lines 7x50x52]/1000	426.5	27.9	469.0	9.6
58	Fuel Consumed Speed Change	[Lines 50x53]/1000	0	0	0	0
59	Fuel Consumed Curvature	[Lines 9x50x54]/1000	6.9	6.9	6.9	6.9
60	Base Urban Fuel Consumed	[Lines 4x50x55]/1000	N/A	N/A	N/A	N/A
61	Study Period Fuel Consumption	[Lines 56+57+58+59 or 60]x(365)x(years)	3.96E6	3.03E6	6.25E6	0.91E6
62	Study Period Average Base Fuel Correction factor	(C-5-3)	0.773	0.773	0.773	0.773
62S	Study Period Average On-Road Consumption Rate	[Line 62]/5.17[a]	N/A	N/A	N/A	N/A
63	Adjusted Fuel Consumption	[Lines 61x62] or [Lines 4x50x62S]x(365)x(years)	3.06E6	2.34E6	4.83E6	0.70E6
64	Percent Diesel - Study Period Average	(C-5-3)	94.70	94.70	94.70	94.70
65	Gallons Diesel	[Lines 63x64]/100	2.90E6	2.22E6	4.57E6	0.66E6
66	Gallons Gas	[Lines 63-65]	0.16E6	0.12E6	0.26E6	0.04E6

Line	Item	Formula	Value
67	Study Period Fuel Diesel	[Lines 29+47+65]	2.23E6 + 1.81E6 + 10.35E6 = 14.39E6 gallons
68	Study Period Fuel Gas	[Lines 30+48+66]	17.70E6 + 5.42E6 + 0.58E6 = 23.70E6 gallons
69	Study Period Energy Diesel	[Line 67] x 147,600	= 2.12E12 Btu
70	Study Period Energy Gas	[Line 68] x 143,700	= 3.41E12 Btu
71	Subtotal Btu	[Lines 69+70]	= 5.53E12 Btu
72	Energy Consumed on Existing Route[b]		= 2.70E12 Btu
73	Total Direct Energy		= 8.23E12 Btu

a 14.24, 8.22, 5.17 are base year 1980 MPG of LDV, MT and HT, respectively, from Table C:5
b See No. 2 Calculation Detail
N/A Not Applicable

ALTERNATIVE #1

BUILD A BYPASS

INDIRECT ENERGY CALCULATION WORKSHEET

1 Study Period: Begin 1985 to End 2004; 20 Years

2	Points		A to C	C to E	E to C	C to A
3	Lane Segment		1E	2E	2W	1W
4	Length of Section		1.5	3.0	3.0	1.5
5	Pavement Serviceability Index*		3.5	3.5	3.5	3.5
6	Average Daily Traffic		12,000	12,000	12,000	12,000
7	Percent Light Duty Vehicle (LDV)		80	80	80	80
8	Number of LDV	[Lines 6x7]/100	9600	9600	9600	9600
9	Annual Vehicle Miles Traveled	[Lines 4x8]x365	5.26E6	10.51E6	10.51E6	5.26E6
10	Oil Energy Per Mile	308	308.0	308.0	308.0	308.0
11	Tire Energy Per Mile	316x(adj.fact.) (C-12-1)	316.0	316.0	316.0	316.0
12	Maintenance Repair Energy Per Mile	505x(adj.fact.) (C-12-1)	505.0	505.0	505.0	505.0
13	Manufacturing Energy Per Mile	1399x(adj.fact.) (C-12-1)	1399.0	1399.0	1399.0	1399.0
14	Annual Energy Consumed Btu/mile	[Lines 10+11+12+13]	2528.0	2528.0	2528.0	2528.0
15	LDV Energy Consumed During Study Period	[Lines 9x14]x(years)	0.27E12	0.53E12	0.53E12	0.27E12
16	Percent Medium Truck (MT)		10	10	10	10
17	Number of Medium Truck	[Lines 6x16]/100	1200	1200	1200	1200
18	Annual Vehicle Miles Traveled	[Lines 4x17]x365	0.66E6	1.31E6	1.31E6	0.66E6
19	Oil Energy Per Mile	594	594.0	594.0	594.0	594.0
20	Tire Energy Per Mile	366x(adj.fact.) (C-12-2)	366.0	366.0	366.0	366.0
21	Maintenance & Repair Energy Per Mile	1186x(adj.fact.) (C-12-2)	1186.0	1186.0	1186.0	1186.0
22	Manufacturing Energy Per Mile	1839x(adj.fact.) (C-12-2)	1839.0	1839.0	1839.0	1839.0
23	Annual Energy Consumed Btu/mile	[Lines 19+20+21+22]	3985.0	3985.0	3985.0	3985.0
24	MT Energy Consumed During Study Period	[Lines 18x23]x(years)	0.05E12	0.10E12	0.10E12	0.05E12
25	Percent Heavy Truck (HT)		10	10	10	10
26	Number of Heavy Truck	[Lines 6x25]/100	1200	1200	1200	1200
27	Annual Vehicle Miles Traveled	[Lines 4x26]x365	0.66E6	1.31E6	1.31E6	0.66E6
28	Oil Energy Per Mile	1199	1199.0	1199.0	1199.0	1199.0
29	Tire Energy Per Mile	725x(adj.fact.) (C-12-3)	725.0	725.0	725.0	725.0
30	Maintenance Repair Energy Per Mile	1714x(adj.fact.) (C-12-3)	1714.0	1714.0	1714.0	1714.0
31	Manufacturing Energy Per Mile	1251x(adj.fact.) (C-12-3)	1251.0	1251.0	1251.0	1251.0
32	Annual Energy Consumed Btu/mile	[Lines 28+29+30+31]	4889.0	4889.0	4889.0	4889.0
33	HT Energy Consumed During Study Period	[Lines 27x32]x(years)	0.06E12	0.13E12	0.13E12	0.06E12

34	Subtotal Indirect Energy Due to Vehicles .. [Lines 15+ 24+ 33]	1.6E12 + 0.30E12 + 0.38E12 = 2.28E12 Btu
35	Percent Vehicles Using Existing Road**	= 30.2
36	Indirect Energy Due to Vehicles Using Existing Road ...[Line 35]/100x(3.22E6)***	= 0.97E12 Btu
37	Total Indirect Energy Due to Vehicles ..... [Lines 34+36]	= 3.25E12 Btu
38	Annual Maintenance Energy per Lane-Mile of Existing ACP . (C-14)	17.76E7 Btu
39	Total Lane-Miles of Existing Road	10.0 miles
40	Energy Consumed for Existing Road Maintenance During Study Period [Lines 38x39]x(years)	= 0.04E12 Btu
41	Annual Maintenance Energy per Lane-Mile of New ACP ...... (C-14)	8.03E7 Btu
42	Total Lane-Miles of New Highway	9.0 miles
43	Energy Consumed for New Highway Maintenance During Study Period [Lines 41+42]x(years)	= 0.01E12 Btu
44	Total Indirect Energy ..... [Lines 37+40+43]	= 3.30E12 Btu
45	Energy per Construction Dollar ..... (C-20)	6.60E4 Btu
46	Energy Consumed for Construction of New ACP Highway [Line 45xCost/(Highway Construction Price Index)****]	= 0.26E12 Btu

*If pavement serviceability index unknown, use 3.5
**See No. 1 Calculation Details
***See Alternative #2, Indirect Energy Worksheet, Line 34
****Highway Construction Price Index = 1.54 (Base Year 1977, Table C:21)

ALTERNATIVE #2

NO BUILD

DIRECT ENERGY CALCULATION WORKSHEET

[If the only information available is the segment length and ADT, then use the lines that are followed by "S" (special case)]

1 Study Period: Begin 1985 to End 2004; 20 Years

Line	Item	A to B	B to D	D to E	E to D	D to B	B to A
2	Points	A to B	B to D	D to E	E to D	D to B	B to A
3	Lane Segment #	1E	2E	3E	3W	2W	1WE
4	Length of Segment (miles)	2.0	1.0	2.0	2.0	1.0	2.0
5	Type of Traffic Flow	F. Flow	Congest.	F. Flow	F. Flow	Congest.	F. Flow
6	Grade (%)	+3.0	0	Unknown	Unknown	0	-3.0
7	Length of Grade (miles)	0.5	0	*	*	0	0.5
8	Curvature (degree)	10.0	0	*	*	0	10.0
9	Lengths of Curves (miles)	0.25	0	*	*	0	0.25
10	Speed Change Cycles	5[a]	N/A	*	*	N/A	3[b]
11	Average Speed, mph	35	20	*	*	20	35
12	Average Daily Traffic	14,000	16,000	14,000	14,000	16,000	14,000
13	Percent Light Duty Vehicle (LDV)	80	80	80	80	80	80
14	Number of LDV [Lines 12x13]/100	11,200	12,800	11,200	11,200	12,800	11,200
15	Constant Speed 0% Grade Consumption Rate (C-1-1)	47.0	N/A	N/A	N/A	N/A	47.0
16	Constant Speed at Grade Consumption Rate (C-1-1)	68.8	*	*	*	*	29.5
17	Consumption Rate for Speed Change Cycles (C-2-1)	40.4	*	*	*	*	23.7
18	Curvature Consumption Rate (C-3-1)	0.1	*	*	*	*	0.1
19	Base Urban Fuel Consumption Rate (C-4)	N/A	72.0	*	*	72.0	N/A
20	Fuel Consumed 0% Grade [Lines (4-7)x14x15]/1000	789.9	N/A	*	*	N/A	789.9
21	Fuel Consumed at Grade [Lines 7x14x16]/1000	385.3	*	*	*	*	165.4
22	Fuel Consumed Speed Change [Lines 14x17]/1000	452.1	*	*	*	*	265.3
23	Fuel Consumed Curvature [Lines 9x14x18]/1000	0.3	*	*	*	*	0.3
24	Base Urban Fuel Consumed [Lines 4x14x19]/1000	N/A	921.5	*	*	921.5	N/A
25	Study Period Fuel Consumption . [Lines 20+21+22+23 or 24]x(365)x(yrs)	11.88E6	6.73E6	*	*	6.73E6	8.91E6
26	Study Period Average Base Fuel Correction factor . (C-5-1)	0.529	0.529	0.529	0.529	0.529	0.529
26S	Study Period Average On-Road Consumption Rate .... [Line 26]/14.24[c]	N/A	N/A	0.0371	0.0371	N/A	N/A
27	Adjusted Fuel Consumption [Lines 25x26] or [Lines 4x14x26S]x(365)x(yrs)	6.29E6	3.56E6	6.07E6	6.07E6	3.56E6	4.71E6
28	Percent Diesel - Study Period Average (C-5-1)	11.21	11.21	11.21	11.21	11.21	11.21
29	Gallons Diesel [Lines 27x28]/100	0.71E6	0.40E6	0.68E6	0.68E6	0.40E6	0.53E6
30	Gallons Gas [Lines 27-29]	5.58E6	3.16E6	5.39E6	5.39E6	3.16E6	4.19E6
31	Percent Medium Truck (MT)	10	10	10	10	10	10
32	Number of Medium Truck [Lines 12x31]/100	1400	1600	1400	1400	1600	1400
33	Constant Speed 0% Grade Consumption Rate (C-1-2)	113.0	N/A	N/A	N/A	N/A	113.0
34	Constant Speed at Grade Consumption Rate (C-1-2)	187.0	*	*	*	*	65.9
35	Consumption Rate for Speed Change Cycles (C-2-2)	157.7	*	*	*	*	91.6
36	Curvature Consumption Rate (C-3-2)	0.2	*	*	*	*	0.2
37	Base Urban Fuel Consumption Rate (C-4)	N/A	182.19	*	*	182.19	N/A
38	Fuel Consumed 0% Grade [Lines (4-7)x32x33]/1000	237.3	N/A	*	*	N/A	237.3
39	Fuel Consumed at Grade [Lines 7x32x34]/1000	130.9	*	*	*	*	46.1
40	Fuel Consumed Speed Change [Lines 32x35]/1000	220.8	*	*	*	*	128.2
41	Fuel Consumed Curvature [Lines 9x32x36]/1000	0.1	*	*	*	*	0.1
42	Base Urban Fuel Consumed [Lines 4x32x37]/1000	N/A	291.5	*	*	291.5	N/A
43	Study Period Fuel Consumption . [Lines 38+39+40+41 or 42]x(365)x(yrs)	4.30E6	2.13E6	*	*	2.13E6	3.01E6
44	Study Period Average Base Fuel Correction factor . (C-5-2)	0.680	0.680	0.680	0.680	0.680	0.680
44S	Study Period Average On-Road Consumption Rate .... [Line 44]/8.22[c]	N/A	N/A	0.0827	0.0827	N/A	N/A
45	Adjusted Fuel Consumption [Lines 43x44] or [Lines 4x32x44S]x(365)x(yrs)	2.92E6	1.45E6	1.69E6	1.69E6	1.45E6	2.05E6
46	Percent Diesel - Study Period Average (C-5-2)	25.05	25.05	25.05	25.05	25.05	25.05
47	Gallons Diesel [Lines 45x46]/100	0.73E6	0.36E6	0.42E6	0.42E6	0.36E6	0.51E6
48	Gallons Gas [Lines 45-47]	2.19E6	1.09E6	1.27E6	1.27E6	1.09E6	1.54E6
49	Percent Heavy Truck (HT)	10	10	10	10	10	10
50	Number of Heavy Truck [Lines 12x49]/100	1400	1600	1400	1400	1600	1400
51	Constant Speed 0% Grade Consumption Rate (C-1-3)	182.4	N/A	N/A	N/A	N/A	182.4
52	Constant Speed at Grade Consumption Rate (C-1-3)	392.0	*	*	*	*	6.1
53	Consumption Rate for Speed Change Cycles (C-2-3)	280.6	*	*	*	*	163.9
54	Curvature Consumption Rate (C-3-3)	0.7	*	*	*	*	0.7
55	Base Urban Fuel Consumption Rate (C-4)	N/A	245.0	*	*	245.0	N/A
56	Fuel Consumed 0% Grade [Lines (4-7)x50x51]/1000	383.1	N/A	*	*	N/A	383.1
57	Fuel Consumed at Grade [Lines 7x50x52]/1000	274.4	*	*	*	*	4.3
58	Fuel Consumed Speed Change [Lines 50x53]/1000	392.8	*	*	*	*	229.5
59	Fuel Consumed Curvature [Lines 9x50x54]/1000	0.2	*	*	*	*	0.2
60	Base Urban Fuel Consumed [Lines 4x50x55]/1000	N/A	392.0	*	*	392.0	N/A
61	Study Period Fuel Consumption . [Lines 56+57+58+59 or 60]x(365)x(yrs)	7.67E6	2.86E6	*	*	2.86E6	4.50E6
62	Study Period Average Base Fuel Correction factor . (C-5-3)	0.772	0.772	0.772	0.772	0.772	0.772
62S	Study Period Average On-Road Consumption Rate .... [Line 62]/5.17[c]	N/A	N/A	0.149	0.149	N/A	N/A
63	Adjusted Fuel Consumption [Lines 61x62] or [Lines 4x50x62S]x(365)x(years)	5.92E6	2.21E6	3.05E6	3.05E6	2.21E6	3.48E6
64	Percent Diesel - Study Period Average (C-5-3)	94.70	94.70	94.70	94.70	94.70	94.70
65	Gallons Diesel [Lines 63x64]/100	5.61E6	2.09E6	2.89E6	2.89E6	2.09E6	3.30E6
66	Gallons Gas [Lines 63-65]	0.32E6	0.12E6	0.16E6	0.16E6	0.12E6	0.18E6

67 Study Period Fuel Diesel ...... [Lines 29+47+65] .... 3.40E6 + 2.80E6 + 18.87E6 = 25.07E6 gallons
68 Study Period Fuel Gas .... [Lines 30+48+66] .... 26.87E6 + 8.45E6 + 1.06E6 = 36.38E6 gallons
69 Study Period Energy Diesel..... [Line 67] x (147,600) .... = 3.70E12 Btu
70 Study Period Energy Gas .... [Line 68] x (143,700) .... = 5.23E12 Btu
71 Total Direct Energy .... [Lines 69+70] .... = 8.93E12 Btu

a Three cycles of 35/0 and two cycles of 35/20
b Two cycles of 35/0 and one cycle of 35/25
c 14.24, 8.22, 5.17 are base year 1980 MPG of LDV, MT and HT, respectively, from Table C:5
N/A Not Applicable

ALTERNATIVE #2

NO BUILD

INDIRECT ENERGY CALCULATION WORKSHEET

1 Study Period: Begin 1985 to End 2004; 20 Years

2	Points		A to B	B to D	D to E	E to D	D to B	B to A
3	Lane Segment		1E	2E	3E	3W	2W	1W
4	Length of Section		2.0	1.0	2.0	2.0	1.0	2.0
5	Pavement Serviceability Index*		3	2.5	Unknown	Unknown	2.5	3
6	Average Daily Traffic		14,000	16,000	14,000	14,000	16,000	14,000
7	Percent Light Duty Vehicle (LDV)		80	80	80	80	80	80
8	Number of LDV	[Lines 6x7]/100	11,200	12,800	11,200	11,200	12,800	11,200
9	Annual Vehicle Miles Traveled	[Lines 4x8]x365	8.18E6	4.67E6	8.18E6	8.18E6	4.67E6	8.18E6
10	Oil Energy Per Mile	308	308.0	308.0	308.0	308.0	308.0	308.0
11	Tire Energy Per Mile	316x(adj.fact.) (C-12-1).	367.0	433.0	316.0	316.0	433.0	367.0
12	Maintenance Repair Energy Per Mile	505x(adj.fact.) (C-12-1).	581.0	692.0	505.0	505.0	692.0	581.0
13	Manufacturing Energy Per Mile	1399x(adj.fact.) (C-12-1).	1427.0	1455.0	1399.0	1399.0	1455.0	1427.0
14	Annual Energy Consumed Btu/mile	[Lines 10+11+12+13]	2683.0	2888.0	2528.0	2528.0	2888.0	2683.0
15	LDV Energy Consumed During Study Period	[Lines 9x14]x(years)	0.44E12	0.27E12	0.41E12	0.41E12	0.27E12	0.44E12
16	Percent Medium Truck (MT)		10	10	10	10	10	10
17	Number of Medium Truck	[Lines 6x16]/100	1400	1600	1400	1400	1600	1400
18	Annual Vehicle Miles Traveled	[Lines 4x17]x365	1.02E6	0.58E6	1.02E6	1.02E6	0.58E6	1.02E6
19	Oil Energy Per Mile	594	594.0	594.0	594.0	594.0	594.0	594.0
20	Tire Energy Per Mile	366x(adj.fact.) (C-12-2).	392.0	425.0	366.0	366.0	425.0	392.0
21	Maintenance & Repair Energy Per Mile	1186x(adj.fact.) (C-12-2).	1269.0	1388.0	1188.0	1188.0	1388.0	1269.0
22	Manufacturing Energy Per Mile	1839x(adj.fact.) (C-12-2).	1913.0	2005.0	1839.0	1839.0	2005.0	1913.0
23	Annual Energy Consumed Btu/mile	[Lines 19+20+21+22]	4168.0	4412.0	3987.0	3987.0	4412.0	4168.0
24	MT Energy Consumed During Study Period	[Lines 18x23]x(years)	0.09E12	0.05E12	0.08E12	0.08E12	0.05E12	0.09E12
25	Percent Heavy Truck (HT)		10	10	10	10	10	10
26	Number of Heavy Truck	[Lines 6x25]/100	1400	1600	1400	1400	1600	1400
27	Annual Vehicle Miles Traveled	[Lines 4x26]x365	1.02E6	0.58E6	1.02E6	1.02E6	0.58E6	1.02E6
28	Oil Energy Per Mile	1199	1199.0	1199.0	1199.0	1199.0	1199.0	1199.0
29	Tire Energy Per Mile	725x(adj.fact.) (C-12-3).	776.0	841.0	725.0	725.0	841.0	776.0
30	Maintenance Repair Energy Per Mile	1714x(adj.fact.) (C-12-3).	1903.0	2177.0	1714.0	1714.0	2177.0	1903.0
31	Manufacturing Energy Per Mile	1251x(adj.fact.) (C-12-3).	1301.0	1364.0	1251.0	1251.0	1364.0	1301.0
32	Annual Energy Consumed Btu/mile	[Lines 28+29+30+31]	5179.0	5581.0	4889.0	4889.0	5581.0	5179.0
33	HT Energy Consumed During Study Period	[Lines 27x32]x(years)	0.11E12	0.06E12	0.10E12	0.10E12	0.06E12	0.11E12

34 Total Indirect Energy Due to Vehicles .... [Lines 15+ 24+ 33] .... 2.24E12 + 0.44E12 + 0.54E12 = 3.22E12 Btu

35 Annual Maintenance Energy per Lane-Mile of ACP .... (C-14) .... 17.76E7 Btu

36 Total Lane-Miles of Existing Road .... 10.0 miles

37 Energy Consumed for Existing Road Maintenance During Study Period (Lines 35x36]x(years) .... = 0.04E12 Btu

38 Total Indirect Energy (Lines 34+37) .... = 3.26E12 Btu

*If pavement serviceability index unknown, use 3.5

SUMMARY

Description	Alt. #1 (build)	Alt. #2 (no build)	Compare to "No Build"
Direct Energy (Btu)	$8.23x10^{12}$	$8.93x10^{12}$	- 7.8%
Indirect Energy (Btu)	$3.30x10^{12}$	$3.26x10^{12}$	+ 1.2%
Construction Energy (Btu)	$0.26x10^{12}$	0	—
Total Energy (Btu)	$11.79x10^{12}$	$12.19x10^{12}$	- 3.3%
[Equivalent Barrels of oil per day (approx.)*]	279.0	288.0	
Annual Direct Energy (Btu)	$0.412x10^{12}$	$0.447x10^{12}$	$-35x10^9$
Annual Vehicle Miles Traveled	$(39.6+15.9)x10^6$	$52.5x10^6$	+ 5.7%
Btu per VMT	10,620.0	11,610.0	- 8.5%
Annual Vehicles Traveled	$(4.40+1.59)x10^6$	$5.25x10^6$	+14.1%

Years to Pay Back the Construction Energy............$0.26x10^{12}/35x10^9$ = 7.4 years

*One barrel of oil = $5.8x10^6$ Btu

CALCULATION DETAILS

1/ Energy consumed on existing route.

Daily vehicles (no build): $\frac{\text{total lines}[9+18+27]}{\text{total length}}$ /365

$= \frac{52.54x10^6}{10} x \frac{1}{365}$ = 14,390 vehicles

Percent vehicles using existing street after bypass built: $\frac{4,350}{14,390}$ = 30.2%

2/ Energy consumed on existing street after bypass built: $8.93x10^{12}x30.2\% = 2.70x10^{12}$ Btu

APPENDIX D

PAVEMENT RECYCLING ENERGY ANALYSIS

APPENDIX D

Pavement Recycling

This Appendix contains an example energy analysis comparing the energy consumption of an asphalt concrete recycling process to that of a conventional asphalt overlay using new material. Energy factors necessary for the analysis are found in Appendix C, D and G.

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D1 General Operation of AC Recycling

Pavement recycling has recently received a good deal of attention due to its potential for saving energy and conserving scarce resources. Although it is possible to recycle both portland cement concrete (PCC) and asphalt concrete (AC) pavements, recycling as used here refers only to AC pavements.

The most common methods of recycling AC pavements are: Central hot plant, cold in-place and hot surface scarifying. Surface recycling is usually confined to reworking only the top one inch of pavement. This report is concerned with only central hot plant and cold in-place recycling. In both of these methods, from one to six inches of existing AC is commonly removed. A full description of each method is beyond the scope of this report; interested readers should consult References DR4, 5, 6 or 7. All recycling processes consist of at least three basic operations, (1) removal of the existing material to be recycled, (2) processing this salvaged material into a paving mixture, and (3) relaying the recycled mix.

1. Removal of the existing AC can be accomplished by scarifying, planing or milling. Each of these operations can be performed either at ambient temperature or after the pavement has been heated.

2. Once the old AC is removed, it can be transported to a central plant or processed in place. In either case, processing usually involves pulverizing and grading the salvaged material, adding new aggregate and binder as required and mixing. The mixing operation can be performed with a cold mix at ambient temperature or after the material has been heated. It should be noted that cold recycling by itself (without a hot-mix overlay) is only applicable to very low traffic roads.

3. To place a cold recycled mixture usually requires extra compactive effort through the use of a special paving machine, such as a Midland Paver, and a heavy vibratory roller. To place a hot recycled mix requires only conventional AC paving and compaction equipment.

The overall energy consumption for recycling AC will be contingent on the exact method used, as well as the mix design and pavement thickness. One recent report (DR7) shows the energy saved by recycling as ranging between 70 and 7,730 gallons of diesel fuel per lane mile. Although much of this range may be attributed to an inconsistent analysis methodology, which in large part is due to a lack of accepted guidelines, obviously a considerable degree of variability does exist.

The following example illustrates how the energy intensiveness of AC recycling can be calculated. A cold in-place mix with a central hot plant overlay is used in the calculation. This strategy will provide both protection from reflective cracking and good surface durability. The recycling scheme is then compared to the energy intensity of a conventional AC overlay.

It is often useful to break construction energy down into three basic categories of: (1) materials, (2) hauling, and (3) processing.

1. The materials energy is the energy necessary to produce the basic construction materials before they reach the job site.

2. The hauling energy is the energy necessary to transport the material. This can vary greatly depending on the distance from job to plant site.

3.   The processing energy is the fuel energy required by the contractor's equipment to produce and place the completed job.

This energy breakdown convention is used in the summary table presented for the example problem.

D2 Example of AC Pavement Recycling Energy Analysis

A section of rural AC pavement has undergone sufficient deterioration to require improvement. Two pavement rehabilitation strategies will be considered. Comparison will be made on a Btu/yd^2 basis.

Alternative 1 - (Recycle existing pavement)

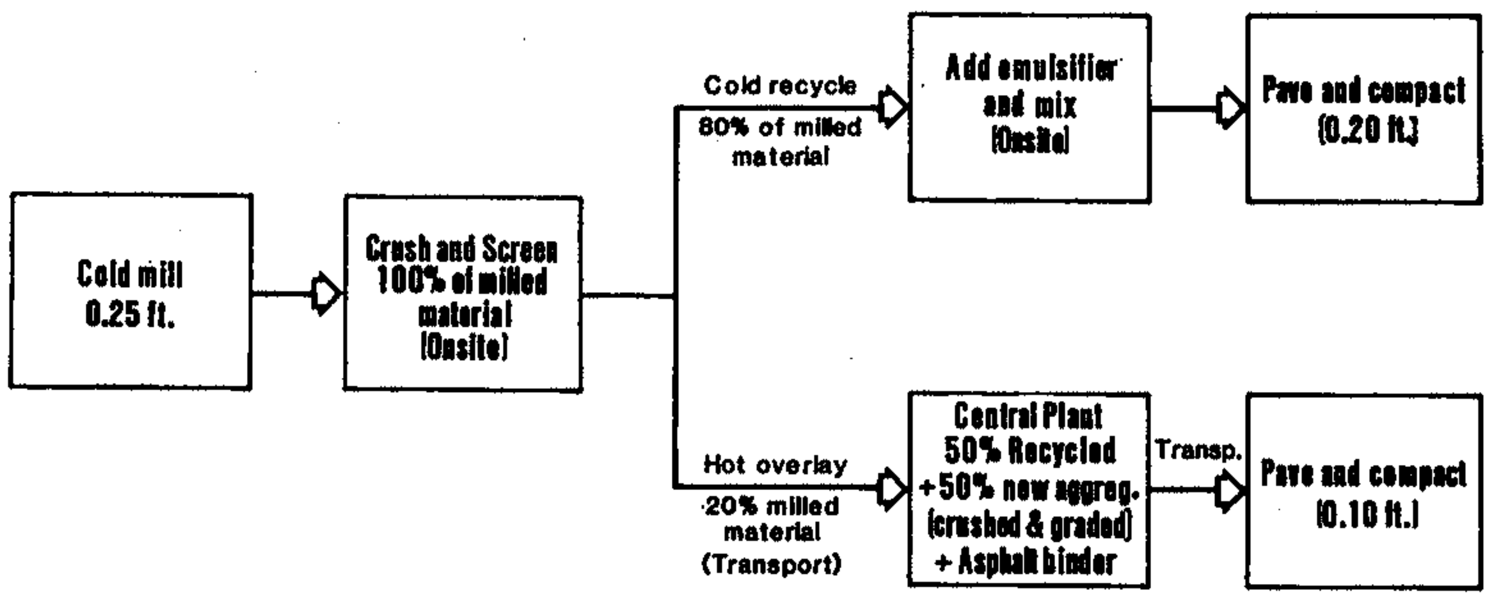
A combination of hot and cold recycling methods will be used in this alternative. The top 0.25 foot of the existing pavement will be removed by cold milling. This material will then be crushed at the site by a mobile crusher. Eighty percent of the crushed material will then be processed by a traveling mixer and paving plant. The mixer plant will add 1.5 percent of an emulsified softening agent to the mix. This portion of the recycled AC, when placed and recompacted, forms a mat approximately 0.20 foot thick. The remaining 20 percent of the milled AC will be transported to a centrally located hot mix plant. New aggregate and asphalt binder will be added in proportion to make a 50 percent recycled and 50 percent new hot mix. This mix is then laid as the surface course approximately 0.10 foot thick. Figure D-I shows the Recycling Flow Chart.

Alternative 2 - (New AC overlay)

Alternative 2 is to overlay the existing surface with a 0.15 foot thick mat of AC made from virgin materials.

Energy Analysis Alternative 1

The factors used in this analysis are shown in Table D-1 of this Appendix.



RECYCLING FLOW CHART

Figure D-1

Cold Milling Energy Consumption

Cold Milling (D4.1) 2,700 (Btu/yd^2/in.)

2,700(Btu/yd^2/in.) x .25(ft) x 12(in./ft) = 8,100 Btu/yd^2

Cold Recycling .80(8,100) = 6,480 Btu/yd^2

Cold Mixing Energy Consumption

The milled material must be elevated onto a mobile crushing and screening plant. It is assumed that the plant is mounted on a Caterpillar 126 grader or equivalent piece of equipment. The grader has a fuel (diesel) consumption rate of 3.3 gal/hr at low load factor (2). The plant has a production rate of 175 ton/hr. One hundred percent of the milled material will have to be screened but only 10 percent of it needs to be crushed. The salvaged AC will be relatively easy to crush, with energy consumption similar to that of a pugmill.

Grader $\dfrac{3.3\ (\text{gal/hr}) \times 147600\ (\text{Btu/gal})}{175\ (\text{ton/hr})} = 2783\ (\text{Btu/ton})$

Elevate Material (D4.2)	=	8200 Btu/ton
Screen Material (D4.2)	=	480 Btu/ton
Crush Material (D4.2) .1 x 2200	=	220
		11683 Btu/ton

$$\frac{11683(\text{Btu/ton}) \times 135(\text{lb/ft}^3) \times 9(\text{ft}^2/\text{yd}^2) \times 0.25(\text{ft})}{2000(\text{lb/ton})} = 1774\ \text{Btu/yd}^2$$

After being crushed and screened, the material will be placed in windrows to be picked up by the mixer paving plant. The asphalt emulsion used for cold recycling usually contains a significant amount of rejuvenating agent. The rejuvenating agent is chemically similar to diesel fuel oil. It will be assumed that the energy content of the emulsified asphalt used for recycling is 10 percent greater than ordinary emulsified asphalt.

Elevate Material (D4.2)	=	8,200 Btu/ton
Traveling Mixer (D4.2)	=	3,200 Btu/ton
Paving Machine (D4.2)	=	3,800 Btu/ton
		15,200 Btu/ton

$$\frac{15{,}200(\text{Btu/ton})\times 135(\text{lb/ft}^3)\times 9(\text{ft}^2/\text{yd}^2)\times .2(\text{ft})}{2000\ (\text{lb/ton})} = 1{,}847\ \text{Btu/yd}^2$$

Emulsifier

$1.5\% \times 1.10 \times 1.95 \times 10^7\ (\text{Btu/ton}) = 321{,}750\ \text{Btu/ton}$

$$\frac{321{,}750(\text{Btu/ton})\times 135(\text{lb/ft})\times 9(\text{ft/yd}^2)\times 0.2}{2000\ (\text{lb/ton})} = 39{,}093\ \text{Btu/yd}^2$$

Compaction Energy Consumption

Compacting (D4.2) 130 $\text{Btu/yd}^2/\text{in.}$

$130\ (\text{Btu/yd}^2/\text{in.}) \times .2\ (\text{ft}) \times 12\ (\text{in./ft}) = 312\ \text{Btu/yd}^2$

Total Energy Consumption for Cold Recycling

cold milling		6,480
(crushing and screening)	.8(1774) =	1,419
mixing and paving		1,847
emulsifier		39,093
compaction		312
		49,151 Btu/yd^2

Hot Mix Energy Consumption

Twenty percent of the cold milling operation was performed to provide reclaimed AC for the hot mix.

Milling $.20(8100 \text{ Btu/yd}^2) = 1620 \text{ Btu/yd}^2$

$$\frac{1620 \text{ (Btu/yd}^2\text{) } 2000 \text{ (lb)}}{135 \text{ (lb.ft}^3\text{) x } 9 \text{ (ft}^2\text{/yd}^2\text{) x } 0.1 \text{ ft}} = 26{,}667 \text{ Btu/ton}$$

Crush and Grade Aggregate

The new aggregate to be added to the recycled AC mix will have to be crushed and screened to size. Energy values vary between 16,000 and 75,000 Btu/ton (D4.3) for this operation. A value of 40,000 Btu/ton will be assumed in the analysis. One-half ton of new aggregate is needed for every ton of 50-50 mix.

$$40{,}000 \text{ (Btu/ton) x } .5 = 20{,}000 \text{ Btu/ton}$$

Plant Generator Energy Consumption

This is the fuel required to run the diesel generators for the mixer, vibrators, feed belts, etc. Total energy consumption for these operations is 11,660 Btu/ton (D4.3) for a conventional mix. The extra equipment necessary to process a recycled AC mix will require an additional 25 percent more energy.

$$11,660 \text{ (Btu/ton)} \times 1.25 = 14,575 \text{ Btu/ton}$$

Burner Fuel Energy Consumption

Field measurements have shown that about 1.5 gallons of diesel are needed for each ton of recycled mix (Ref. 1).

$$1.5 \text{ (gal/ton)} \quad 147,600 \text{ (Btu/gal)} = 221,400 \text{ Btu/ton}$$

Peripheral Plant Operations

This item includes fuel needed to operate loaders, asphalt heaters, pumps and compressors.

Peripheral plant operation (Ref. 1) 63,980 Btu/ton

Additional Asphalt Energy

Three percent new asphalt binder will be required for each ton of recycled AC hot mix. Asphalt has an equivalent energy of 3.14×10^7 (Btu/ton).

$$3.14 \times 10^7 \text{ (Btu/ton)} \times .03 = 942,000 \text{ Btu/ton}$$

Grading, Paving and Compaction

The grading, paving and compaction of the recycled hot mix can be accomplished with the use of conventional paving equipment. This is estimated at 17,700 (Btu/ton).

Transportation Energy

The milled material will have to be hauled from the job site to the central plant. After being combined with the new aggregate and binder to form the new mix, it will be hauled back to the job site. For every ton of hot mix hauled to the job site, half a ton of milled material is transported back to the hot mix plant. This prevents going back empty. Therefore 1.5 times the energy intensity value for a 5 axle combination truck will be used.

5 axle combination truck 2,096 Btu/ton/mile (GR.3)

$$2{,}096\ (\text{Btu/ton/mile}) \times 1.5 = 3144\ \text{Btu/ton/mile}$$

$$\frac{3144(\text{Btu/ton/mile}) \times 135(\text{lb/ft}^3) \times 9(\text{ft}^2/\text{yd}^2) \times 0.1\ \text{ft}}{2000\ \text{lb/ton}} = 191\ \text{Btu/yd}^2/\text{mile}$$

Total Energy Consumption for Hot Mix Recycling

cold milling	26,667
crushing and grade new aggregate	20,000
plant generator	14,575
burner fuel	221,400
peripheral plant operation	63,980
additional asphalt	942,000
grading, paving and compaction	17,700
	1,306,322 Btu/ton

$$\frac{1{,}306{,}322(\text{Btu/ton}) \times 135(\text{lb/ft}^3) \times 9(\text{ft}^2/\text{yd}^2) \times .1(\text{ft})}{2000(\text{lb/ton})} = 79{,}359 \text{ Btu/yd}^2$$

+ crush and grade recycled material: 0.2(1774) = 355

79,714

Total Energy for Recycling Operation

Cold mix	49,151
Hot mix	79,714
	128,865 Btu/yd^2

128,865 (Btu/yd^2) + [191 (Btu/yd^2/mile) x haul distance]

Energy Analysis Alternative 2

The energy factors in this analysis are based on the same factors cited for the recycled hot mix.

	Btu/ton
Crush and grade aggregate (D4.3)	40,000
Plant generator (D4.3)	11,660
Burner fuel (Ref. 1)	221,400
Peripheral plant operation (Ref. 1)	63,980
Asphalt (6%)	
3.14×10^7 (Btu/ton) x .06 =	1,884,000
Grading, paving and compaction	17,700
	2,238,740 Btu/ton

$$\frac{2{,}238{,}740(\text{Btu/ton}) \times 135(\text{lb/ft}^3) \times 9(\text{ft}^2/\text{yd}^2) \times 0.15 \text{ ft}}{2000 (\text{lb/ton})} = 204{,}005 \text{ Btu/yd}^2$$

Transportation

$$\frac{2{,}096(\text{Btu/ton/mile})\ 135(\text{lb/ft}^3)\text{x}9(\text{ft}^2/\text{yd}^2)\text{x}.15(\text{ft})}{2000(\text{lb/ton})} = 191\ \text{Btu/yd}^2\text{/mile}$$

Total Energy for Overlay

204,005 (Btu/yd^2) + [191 Btu/yd^2/mile x haul distance]

Summary

Although both the recycling strategy and the virgin overlay consume approximately the same amount of processing energy, the summary table indicates that recycling does conserve a considerable quantity of materials energy. Under the particular scenario we have used here, both alternatives would have the same transportation energy consumption. However, if the aggregate source was not immediately adjacent to the hot mix plant and the virgin aggregate had to be hauled in from a considerable distance, the energy savings due to recycling would be even more substantial.

The results of this analysis may differ somewhat from those of other authors(4,5,6). This analysis attempted to use as many energy factors derived from real world sources(1) as possible. Also, this analysis uses an energy value for asphalt equivalent to the amount of fuel produced if the asphalt were refined into fuel products, rather than using the total heating value of asphalt(8) or the (much less) amount of energy required to heat and store asphalt (Ref. 3). See Appendix G.

It must be emphasized that the energy quantities presented in the summary table are only valid for the specific mix design, placement thickness and construction methods assumed for this project. Every project should be analyzed on an individual basis.

Energy Summary in Btu/yd^2

	Operation	Alternative 1 Cold Mix 0.2 ft	Alternative 1 Hot Mix 0.1 ft	Alternative 1 Recycle	Alternative 2 New Overlay 0.15 ft
Processing					
	Cold Milling	6,480	1,620	8,100	
	Crush and Grade Milled Material	1,419	355	1,774	
	Mixer, Paver Equip.	1,847		1,847	
	Crush and Grade New Aggregate		1,215	1,215	3,645
	Plant Generator		885	885	1,063
	Burner Fuel		13,450	13,450	20,175
	Peripheral Plant Operation		3,887	3,887	5,830
	Grading, Paving and Compaction	312	1,075	1,387	1,613
		10,058	22,487	32,545	31,741
Materials					
	Emulsifier	39,093		39,093	
	Additional Asphalt		57,227	57,227	171,680
		39,093	57,227	96,320	171,680
Hauling					
	Transportation		HD x 191	HD x 191	HD x 191
	*		HD x 191	HD x 191	HD x 191
			128,900 + 191 x HD		203,400 +191 x HD

*HD = Average Haul Distance (mi)

D3 REFERENCES

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2. "Caterpillar Performance Handbook," Caterpillar Tractor Company, Peoria, Illinois, October 1980.

3. "Energy Requirements for Roadway Pavements," The Asphalt Institute Information Series 173, November 1979.

4. J. Epps et al, Guidelines for Recycling Pavement Materials, NCHRP Report 224, September 1980.

5. "Recycling Materials for Highways," NCHRP Synthesis 54, Transportation Research Board, 1978.

6. W. Halstead, "Energy Use and Conservation in Highway Construction and Maintenance," Virginia Highway and Transportation Research Council, May 1978, Report #VHTRC 78-R42.

7. "National Seminar on Asphalt Pavement Recycling," Dallas, Texas, October 14-16, 1980, sponsored by TRB.

8. W. Halstead, "Energy Involved in Construction Materials and Procedures," NCHRP Synthesis 85, TAB, 1981.

D4 AC Recycling Energy Factors

Table D-1

Section			Reference
4.1	Pavement Removal		
	Heater Planer	19,000-30,000 Btu/yd-3/4 in	GR5
	Heater Scarifier	10,000-20,000 Btu/yd-3/4 in	GR5
	Hot Milling	5,000-9,000 Btu/yd in	GR5
	Cold Milling	700-2,500 Btu/yd in	GR5
	Cold Milling	2,700 Btu/yd in	GR1
4.2	Cold Mix Operations		
	Mobile Material Elevator	8,200 Btu/ton	GR1
	Screen Material	480 Btu/ton	GR4
	AC Crushing (same as pug mill mixing)	2,200 Btu/ton	GR4
	Traveling Mixing Plant	3,200 Btu/ton	GR3
	Paving	3,800 Btu/ton	GR1
	Rolling	130 Btu/yd^2 in	GR3
4.3	Hot Mix Operation		
	Crush, Grade Aggregate	16,000-75,000 Btu/ton	GR3
	Plant Generator Energy	11,660 Btu/ton	GR4
	Burner Fuel	221,400 Btu/ton	GR1
	Peripheral Plant Operations	63,980 Btu/ton	GR1
	Grading, Paving, Compacting	17,700 Btu/ton	GR3

D5 Commentary

Energy values from Reference 1 represent actual fuel consumption values gathered in the field specifically for a recycling job. In many cases, they include peripheral equipment energy for such items as pickups, sweepers, water trucks, grease trucks, etc., and therefore are more representative of realistic operating conditions. Energy values from References 2, 3 and 4 are primarily based on theoretical assumptions due to the general lack of empirical data. All energy values have been adjusted to include the refining energy necessary to produce the fuel used in the equipment.

APPENDIX E

LIGHT RAIL TRANSIT ENERGY ANALYSIS

This appendix contains an example energy study for a light rail transit (LRT) project. The factors necessary to perform this analysis and those for heavy rail systems are shown in Appendices C, D and E.

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E1 Energy Analysis for Light Rail Transit (LRT)

The energy analysis for a light rail system has many similarities to that of a highway project. It involves the comparison of the "build" and the "no-build" alternatives.

The construction of a light rail system has both positive and negative effects on the transportation energy consumption. A positive effect is that where no non-roadway system previously existed, the majority of the LRT ridership will be attracted from people who formerly used bus or auto as their primary means of transportation. In some situations, the bus riders will be forced to use a combination of bus and rail system because the bus will no longer parallel the rail system to the same destination.

As a result of this modal shift, the average daily vehicle miles traveled (VMT) by auto and bus should decline, thereby saving fuel. This decline in VMT would also result in less congestion on the highways, thus reducing the direct energy demands of other vehicles as well. This reduction in direct energy consumption must be balanced against the negative effects of the energy consumed by construction and maintenance of the LRT system. Manufacturing, maintaining and operating the light rail vehicles will also consume additional energy.

With the no-build situation, there are both positive and negative effects to be considered. There is no initial construction energy expended; however, the VMT will continue to increase with congestion increasing accordingly. The existing roadway system may eventually have to be renovated to meet future traffic demands.

Due to the numerous assumptions required for a study of this type and the uncertainty of vehicle performance and modal shifts in the future, judgment must be exercised in interpreting the conclusions and results presented. The quantitative values presented should be viewed as a state of the art estimate of future energy use.

E2 Example Light Rail Transit Energy Study

To meet transportation demands, a large metropolitan city is considering either increasing its existing bus fleet or instituting a new light rail system and renovating its existing bus system.

Alternative 1. Build

It is proposed to construct an integrated LRT-bus system in two major traffic corridors of a city. Light Rail Vehicles (LRV) will provide line-haul service in the two corridors to the downtown area. The LRT system will include 24.3 miles of track (including 5.4 miles of double track) and 27 stations. Three stations in each corridor will be coordinated with the Regional Transit Bus (RTB) System so as to provide an efficient mixed mode transit option. In addition, about half of the stations will include lighted parking space. LRV's will be powered from an overhead catenary system supplied from 20 one-megawatt substations located at approximately one-mile intervals. LRV's will be double-ended and able to operate alone or in trains up to four vehicles in length. The vehicles will seat between 65 and 75 persons with crush load capacity of 180 passengers. All will be equipped with heating and air conditioning. Most of the line will occupy existing railroad right-of-way and make use of existing structures to cross surface arterials. The existing bus system will require 6 million dollars to renovate its maintenance facility.

Alternative 2. No-Build

It is proposed not to construct a LRT system, but to expand the existing bus service. The bus maintenance facility will have to be expanded at a cost of 14.4 million dollars.

Currently, transportation alternatives available to the city's residents are almost exclusively dependent on the petroleum industry for energy. This energy is basically in the form of gasoline and diesel fuels for autos, trucks, buses and trains. The proposed LRT System offers residents a new mode of travel and one that is not totally dependent on petroleum. It will use electrical energy for propulsion that will be supplied from the national electrical grid which produces its electricity from hydro, nuclear, coal, gas, petroleum and other sources.

This study investigates direct (propulsion) and indirect (nonpropulsion) energy uses for the build and no build situation. It uses the best obtainable or estimated values for the project.

The following table (Table 1) identifies those areas which have been determined to have an effect on the net energy analysis of a build situation. This report is separated into direct and indirect energy components and the analysis investigates each component individually.

TABLE E-1

SUMMARY TABLE OF ENERGY ANALYSIS

1. Direct

   A. Autos
   B. Transit bus
   C. LRV

2. Indirect

   A. Construction
      °track work
      °structures
      °electric substations
      °overhead electrical
      °signals
      °stations, stops and terminals
      °parking
      °maintenance facilities (bus and LRV)

   B. Manufacturing
      °autos
      °LRV
      °transit bus

   C. Maintenance
      °autos
      °LRV
      °transit bus

For this investigation, the overall conversion efficiency from a power generation plant to the electrically-powered vehicles was estimated to be 27.4 percent. This efficiency factor includes typical estimates for losses due to generation of electrical power, transmission of electricity through electrical networks to LRT substations and conversion of alternating current to direct current (AC/DC).

The average efficiency for all electrical power generated in the United States in 1980 was 31.5 percent. Similarly, the average electrical transmission efficiency for this period was 91.6 percent(1). Older methods of AC/DC conversion produced efficiencies ranging from 85 percent to 95 percent, while the efficiency of newer methods of conversion ranges from 93 percent to 97 percent. This analysis assumes a 95 percent AC/DC conversion efficiency.

Together they result in a combined efficiency of 27.4 percent, which requires the expenditure of 12,458 Btu to produce 1 kwh. This conversion is used in the following calculations for direct and indirect electrical energy use.

It is worthwhile noting that a large portion of the electrical power used by a light rail system is consumed in the late afternoon and early evening. This is the p.m. rush hour peak where the LRV and their air conditioning units will be operating at full loading. If the LRT system is set up in a utility district with limited generation capacity, this additional p.m. peak power consumption may induce brownouts in the surrounding residential communities (public transportation systems are usually given highest priority during a brownout). Alternately, this additional power consumption may cause the utility to purchase load matching generation units to be used only during these p.m. peaks. Such units are usually relatively inexpensive but fuel intensive — such as gas turbines without waste heat recovery — and may have generation efficiencies of only around 20 percent. If a sizable portion of the LRT operating energy is generated from such low efficiency load matching units, then the overall electrical conversion efficiency used in the energy calculations should reflect this.

In determining and comparing total energy usage between alternatives, it is important to base comparisons on systems providing equivalent services. In the case of a person commuting to work by automobile, his energy consumption begins the moment he starts his engine at his home and ends when he arrives at his parking location at work. Assuming he then walks to his work location, his total modal energy consists entirely of gasoline to propel his car to work.

In contrast, a person commuting to work by light rail, in most cases, is confronted with the problem of initially getting to the LRT station. In some cases, the commuter is able to walk or ride a bicycle and expends little or an unmeasurable amount of energy. In most cases, he will be transported by a car, bus or some other motorized vehicle. If he then walks to his work location after traveling on the LRT system, his total modal energy would consist of a portion of the LRV propulsion energy and also the energy he used to get to the LRT station. The portion of energy required to move LRT passengers to LRT terminals is termed "access" energy. If he used energy going from the terminal to his work location, it would be termed "egress" energy.

In comparing total modal energy, the energy used for access and egress must be considered. Vehicle miles traveled for access to each mode are included in total modal VMT figures which are presented in Tables 3 and 4.

The LRT construction energy was estimated from best available preliminary information on the system. A lack of detailed information precluded a thorough process analysis for the entire system. Instead, most of the energy calculations were performed using preliminary cost estimates (including 20 percent contingencies) and dollar to energy conversion factors for the various construction items (Appendix C). For some items, such as track work and overhead electrical wiring, a process analysis approach was used.

The construction energy for the LRT system includes the manufacturing energy of the materials and the direct energy necessary to transport and place those materials.

The construction energy does not include direct energy used by the work force to commute between home and work. It is assumed that the work force would be working elsewhere if not on LRT construction work. At any rate, the work force energy is estimated to be about 1 percent of total construction energy. (Assuming 200 persons, traveling 20 miles per workday, at 20 mpg, for 1-1/2 years.)

Due to difficulties in making accurate projections of future conditions, an analysis will be made for one "typical year" and extrapolated over the entire life of the project (50 years). This "typical year" is the year 2000.

E2.1 Direct Energy

Although total energy requirements of a transportation system include both direct and indirect components, the single most important factor is direct vehicle (propulsion) energy. This component can account for up to 60 percent of total system energy. Private auto consumption alone can account for over 90 percent of the total direct energy. Therefore it is critical that these components be assigned values that are as reliable as possible. Values of vehicle operating intensity are presented in Table 2.

Automobile fleet average fuel efficiency of manufactured vehicles as mandated by Congress in 1975(2) must increase from the 18 mpg in 1978 to 27.5 mpg by 1985. Fuel economy should rise above 27.5 mpg beyond 1985 and federal estimates indicate that by the study year 2000, the on-road fleet average will reach 33.04 mpg. The on-the-road fleet is comprised mostly of less efficient vehicles from previous years as well as new manufactured vehicles.

Projected bus operating energy intensity is not expected to vary considerably from today's values and is used without adjustment.

TABLE E-2

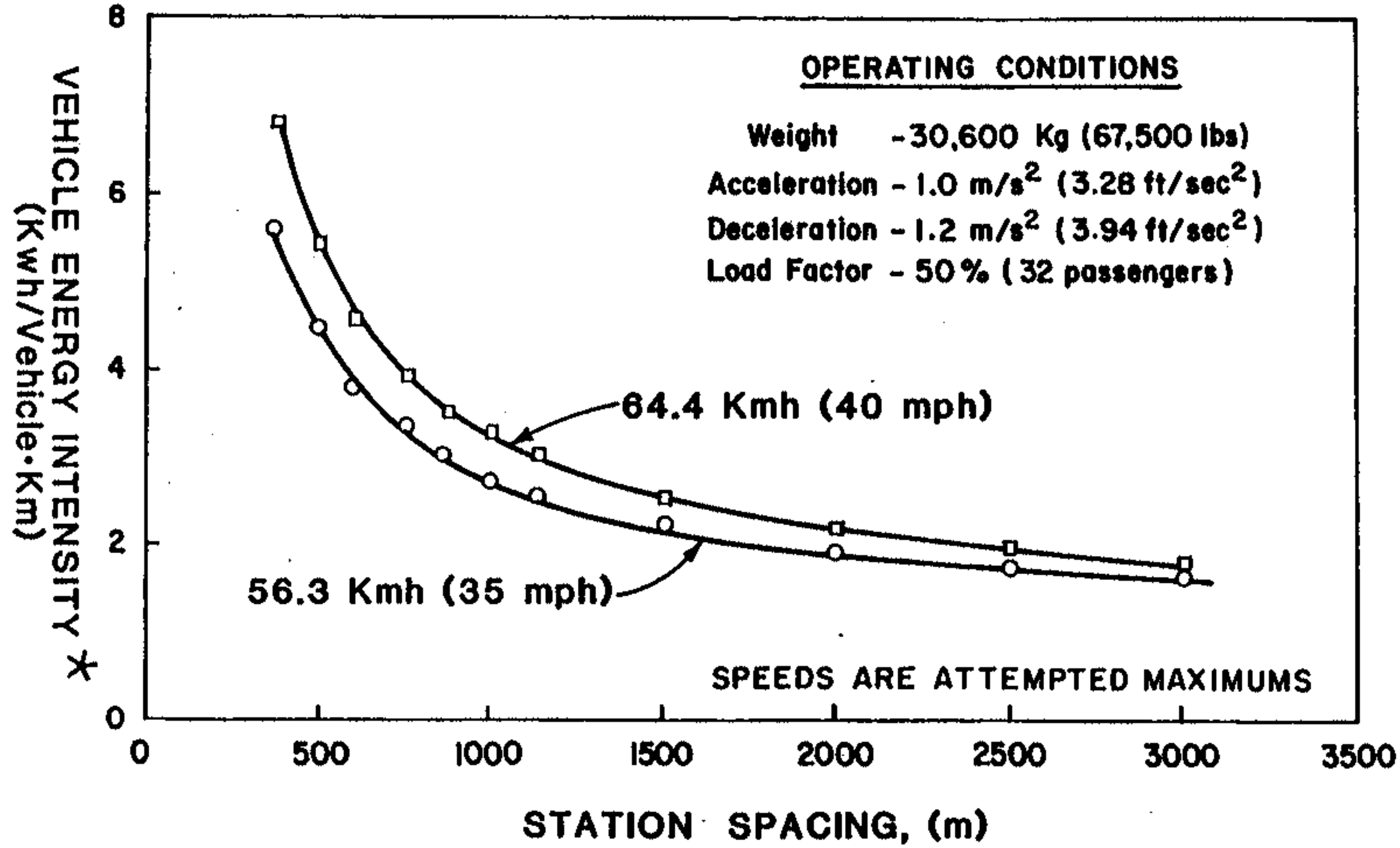
ON ROAD VEHICLE PERFORMANCE[1]

Vehicle	Fuel Economy (mpg)
Automobile	
1980	14.24
1985	18.27
2000	33.04
Advanced Design Bus (ADB)	3.77
Articulated Bus (ART)	3.04

[1](Appendix C)

A computer model(3) has been developed to predict the operating energy intensity of current LRT vehicles. Base level performance of a new LRV were predicted with the model to within 5 percent of manufacturers specifications so the model is considered to be accurately validated.

The direct energy consumed to operate a LRV is primarily dependent on four key parameters: weight, acceleration rate, top speed, and station spacing. A typical LRV was used in this analysis. Figure E-1 presents the important characteristics of a typical LRV under assumed operating conditions.



* VEHICLE INTENSITY includes: Energy required for propulsion, auxiliary equipment, heating, air-conditioning, lights; does not include any generation losses.

TYPICAL MODERN LIGHT RAIL VEHICLE ENERGY INTENSITY

FIGURE E-1

A large macroscale traffic assignment computer model was used to determine travel characteristics in the entire metropolitan area. VMT for the build and no-build alternatives includes travel by autos, light and heavy trucks and motorcycles. It is assumed that only autos and motorcycles are influenced by a build alternative and therefore all variations in VMT can be attributed to these two modes. The Caltrans model assigns motorcycles only one percent of total VMT figures which would prove negligible in the overall energy picture. Because of their negligible effect, motorcycle VMT is included with the auto VMT.

Table E-3 shows reported daily auto vehicle trips which are then adjusted to provide daily VMT. Dividing the VMT by the auto fuel economy rate of 33.04 mpg gives daily auto gasoline consumption. These values are then adjusted to reflect daily consumption over the year 2000. Final values are reported in equivalent Btu.

Calculations

Automobile direct energy consumption

No-Build:

$$\frac{24{,}662{,}220 \text{ miles/day} \times 290 \text{ days/year}^{1} \times 143{,}700 \text{ Btu/gal}}{33.04 \text{ miles/gal}} = 31{,}106 \times 10^{9} \text{ Btu}$$

Build:

$$\frac{24{,}653{,}530 \text{ miles/day} \times 290\text{/days/year} \times 143{,}700 \text{ BTU/gal}}{33.04 \text{ miles/gal}} = 31{,}095 \times 10^{9} \text{ Btu/yr}$$

[1] An average value of 290 days/year was used to reflect a 5 1/2 day week plus the addition of some holidays.

TABLE E-3

AUTOMOBILE DIRECT ENERGY CONSUMPTION

Alternative	Daily Auto Vehicle Trips (trips)	Daily Auto VMT[1] (miles)	Daily Auto Gasoline Consumption (gal)	Annual Auto Energy Consumption[2] Gasoline (galx10^6)	Equiv.Btu (Btux10^9)
No Build	2,838,000	24,662,220	896,808	260.07	37,372
Build	2,837,000	24,653,530	896,492	259.98	37,359

1-Vehicle trips times 8.69 miles/trip factor(5)

2-Daily auto gallons times 290 days/year

A procedure similar to the one applied to autos was also applied to buses. Unlike autos, the bus VMT can be more accurately predicted and is therefore reported directly in annual VMT. The bus results are presented in Table E-4. The bus consumption rates are presented in Table E-2.

Calculations

"No-Build":

Articulating Bus (ART)

$$\frac{2,150,960 \text{ miles/year} \times 147,600 \text{ Btu/gal}}{3.04 \text{ miles/gal}} = 104.435 \times 10^9 \text{ Btu/yr}$$

Advanced Design Bus (ADB)

$$\frac{5,531,040 \text{ miles/year} \times 197,600 \text{ Btu/gal}}{3.77 \text{ miles/gal}} = 216.547 \times 10^9 \text{ Btu/yr}$$

$$\text{Total} = 321 \times 10^9 \text{ Btu/yr}$$

Build:

Articulating Bus (ART)

$$\frac{1{,}140{,}224 \text{ miles/year} \times 147{,}600 \text{ Btu/gal}}{3.04 \text{ miles/gal}} = 55.361 \times 10^9 \text{ Btu/yr}$$

Advanced Design Bus (ADB)

$$\frac{5{,}566{,}976 \text{ miles/year} \times 147{,}600 \text{ Btu/gal}}{3.77 \text{ miles/gal}} = 217.95 \times 10^9 \text{ Btu/yr}$$

$$= 273 \text{ Btu}$$

TABLE E-4

BUS DIRECT ENERGY CONSUMPTION

Alternative	Bus Type	Annual Bus[1] VMT (miles)	Annual Bus Energy Consumption Diesel (gallons)	Annual Bus Energy Consumption Equiv. Btu ($Btu \times 10^9$)
No-Build	ART	2,150,960	707,553	104.435
	ADB	5,531,040	1,467,119	216.547
Total		7,682,000	2,174,672	320.982
Build	ART	1,140,224	375,074	55.361
	ADB	5,566,976	1,476,651	217.954
Total		6,707,200	1,851,725	273.315

[1]-(Ref. 4)

The use of average values for car and bus fuel efficiency is justified by the fact that the fleet size is very large. Individual differences in vehicle fuel consumption will tend to cancel out to produce one "system" average. By contrast, LRT systems are small enough that individual differences in the system can cause large differences in their average consumption. Table E-5 shows an example of the wide range of values reported for LRT systems compared to the relatively small range for buses and cars. Because LRT propulsion energy is so dependent on the specific operating conditions of the LRT system, considerably more effort was expended in quantifying this value.

TABLE E-5

AVERAGE MODAL ENERGY INTENSITY

Mode	Btu/Vehicle Mile[1]
Auto	10,400-11,100
Vanpool	13,900-17,900
Bus	26,100-32,900
Light Rail	50,000-100,000

[1]-(Ref. 5)

It has been found that a principal factor in the large variability of reported energy use for LRV's is their high system dependency. As the station spacings for the system is reduced, the energy required for propulsion per vehicle km increases (Figure E-1). This provides for a vehicle intensity which can vary considerably throughout the system even for the same vehicle. The Caltrans LRT computer model(4) was used to simulate the system under an average weekday passenger load (Table E-6). This model assigns passenger loads throughout a typical weekday according to both passenger demand and the availability of LRV's. It is therefore possible to account for varying LRV intensity throughout the system for a normal weekday operation of 16 hours. The model determines total energy consumption in Btu for a typical weekday. It also includes energy required for deadheading operations (nonrevenue type) between the vehicle storage facility and the starting or finishing station.

TABLE E-6

LIGHT RAIL VEHICLE DIRECT ENERGY CONSUMPTION

Component Corridor	Weekday Electrical[1] Consumption (kwh)	Annual Electrical[2] Consumption (kwhx10^6)	Total Annual[3] System Consumption (Btux10^9)	Annual[4] VMT (miles)
North Area	6,973	2.02	25.19	303,880
East Area	8,028	2.33	29.00	349,860
Downtown	4,834	1.40	17.46	210,660
Deadheading	967	.28	3.49	42,140
Total	20,802	6.03	75.14	906,540

[1]-Values obtained from Caltrans LRT Simulation model.

[2]-Weekday values times 290 equivalent weekdays/year.

[3]-Summation of North Area, East Area, Downtown, and Deadheading values multiplied by 12,458 Btu/kwh to account for generation, transmission and AC/DC conversion losses.

[4]-Based on 3,126 LRV miles/weekday as determined by the LRT model and 290 days/year.

Table E-7 presents a summary of all the direct energy for both the build and no-build alternatives.

TABLE E-7

SUMMARY: DIRECT ENERGY CONSUMPTION

Alternate	Annual Vehicle Consumption ($Btu \times 10^9$)	Annual Bus Consumption ($Btu \times 10^9$)	Annual LRV Consumption ($Btu \times 10^9$)
No Build	37,372	321	-0-
Build	37,359	273	75.1
Change From No-Build	13	48	-75.1

E2.2 Indirect Energy

The energy provided for construction of the build alternative constitutes the largest fraction of the total indirect energy required for the LRT system. This energy is expended only once and prior to revenue operations. Therefore, for comparison purposes, an amortized value is used for the year 2000 analysis. A project life of 50 years is used(5).

For convenience in the analysis, the LRT system was separated into eight components as shown below:

Item

- Track Work
- Structures
- Electric Substations
- Overhead Electrical
- Signalling
- Stations, Stops and Terminals
- Parking
- Maintenance Facilities

Track Work

The 18.9 mile long project will have approximately 13.5 miles of single track and 5.4 miles of double track. The total amount of track miles is 24.3.

The track alignment either follows existing railroad right-of-way or is located on city streets. It is assumed that very little grading will be necessary. Excavation and breaking of existing pavement will be necessary for a 6.6 mile section on city street right-of-way, of which 3.4 miles will be repaved after placement of the track. Assuming excavation and breaking of pavement to take the same energy as excavation of soft rock (Appendix C) and the excavation to be 10 feet wide, 3 feet deep, the amount of energy required per track mile (based on 24.3 miles) = 1.0×10^8 Btu. Repaving 3.4 miles will use approximately 4.0×10^8 Btu per track mile. These small amounts were absorbed by the "10% Miscellaneous" and the "30% Placement Energy" in the Track Work Construction energy analysis. Details are provided in Table E-8.

A placement energy of 30 percent of the materials energy was assumed. Various reports and papers(7,8) set this value from 30 to 35.7 percent. The latter value was for construction of the heavier BART rapid rail track. Since this LRT system is lighter and will be mainly on existing railroad right-of-way, the lower figure of 30 percent was used for placement energy.

TABLE E-8

TRACK WORK CONSTRUCTION ENERGY

Item	Density Ton/TM[1]	Process Energy[2] (Btu/Ton)	Item Energy (Btu/TM[1]x10^9)
Rails	201 (113 lb/yd)	3.98×10^7	8.0
Gravel Ballast	3,960 (100 lb/ft^3)	4.8×10^4	0.2
Timber	152 (32 lb/ft^3)	2.13×10^7	3.2
Subtotal			11.4
10% Miscellaneous			1.1
Subtotal Materials			12.5
30% Placement Energy			3.8
Total			16.3

1 TM: Track Mile, from Reference 7

2 (Appendix G)

Structures

The total structural cost amounts to \$15,272,000 (1982 dollars). A ratio of $\frac{1.00(1973\$)}{2.75(1982\$)}$ was used to convert the cost into 1973 dollars (Appendix C). The dollar-to-energy conversion used for structures was 5.01×10^4 Btu per 1973 dollar (Reference 9). Total structures energy amounted to:

$$\frac{1.00(1973\$)}{2.75(1982\$)} \times \$15{,}272{,}000 \times 5.01\times10^4 \text{ Btu/(1973\$)} = 2.782\times10^{11} \text{Btu/1982\$}$$

The structures energy per track mile is:

$$\frac{2.782\times10^{11}(\text{Btu/1982\$})}{24.3 \text{ track miles}} = 11.4\times10^9 \text{ Btu/1982\$/track mile}$$

Electric Substations

Preliminary cost estimates for the one megawatt (MW) substations are \$300,000 each. Twenty substations are planned to be built for \$6,000,000 total. In the absence of further details, it was assumed that 10% of the total cost was for construction of the concrete slab, walls and roof. The remaining 90% of the cost was assumed to be for the electrical equipment, mainly the transformer.

Using dollar-to-energy conversions for the structure (housing) of 5.01×10^4 Btu/(1973\$) (Reference 9) and for transformers(9) of 8.00×10^4 Btu/(1973\$), a weighted conversion factor was calculated as follows:

$$(0.10 \times 5.01\times10^4 \text{ Btu/\$}) + (0.90 \times 8.00\times10^4 \text{ Btu/\$}) = 7.70\times10^4 \text{ Btu/(1973\$)}$$

Energy for the 20 substations was calculated as follows:

$$\frac{1.00(1973\$)}{2.75(1982\$)} \times \$6{,}000{,}000(1982\$) \times 7.70\text{x}10^4 \text{ Btu/(1973\$)} = 16.80\text{x}10^{10} \text{ Btu.}$$

$$\text{Energy} = \frac{16.80\text{x}10^{10} \text{ Btu}}{24.3 \text{ track miles}} = 6.91\text{x}10^9 \text{ Btu/track mile}$$

The energy for supply lines was estimated and added to the substation energy. Preliminary quantities showed the need for 21,850 lf @ $47/ft for the entire project, or $42,261 per track mile. Cost of the overhead electrical distribution system was approximately $19/ft or $100,320 per track mile. Energy was calculated at 2.8x10^9 Btu per track mile of overhead electrical distributions (Table E-9). Assuming a direct proportion between cost and energy, the supply line energy per track mile was calculated as follows:

$$\frac{42{,}261}{100{,}320} \times 2.8\text{x}10^9 \text{ Btu/TM} = 1.8\text{x}10^9 \text{ Btu/TM}$$

$$\text{Substation Energy} = (6.91+1.8)\text{x}10^9 = 8.71\text{x}10^9 \text{ Btu/TM}$$

TABLE E-9

OVERHEAD ELECTRICAL DISTRIBUTION SYSTEM

Item	Density[3] (Ton/TM[1])	Process Energy[2] (Btu/Ton)	Item Energy (Btu/TM[1] $x10^9$)
Trolley Line	5.34	$1.39x10^8$	0.7
Feeder Lines	7.98	$1.39x10^8$	1.1
Cross Street Suspension (Catenary)	2.66	$6.67x10^7$	0.2
Subtotal			2.0
10% Miscellaneous			.2
Subtotal Materials			2.2
30% Placement			.6
Total			2.8

1 TM: Track Mile

2 (Appendix C)

3 (Ref. 7)

Signals

The total cost estimate for signals was $9,102,000 (1982$). This amount includes the following items:

Track Circuits
Impedance Bonds
Signal Power Supply
Wayside Indication Apparatus
Grade Crossing Protection
Turnout Controls
Traffic Control Modifications

The dollar to energy conversion factor used was 2.1079×10^4 Btu/(1973\$) (Reference 9). Total energy needed for construction of signals is:

$$\frac{1.00(1973\$)}{2.75(1982\$)} \times \$9{,}102{,}000(1982\$) \times 2.1079 \times 10^4 \text{ Btu/(1973\$)} = 6.98 \times 10^{10} \text{ Btu}$$

$$\text{Energy per track mile: } = \frac{6.98 \times 10^{10} \text{ Btu}}{24.3 \text{ track miles}} = 2.87 \times 10^9 \text{ Btu/track mile}$$

Stations, Stops and Terminals (without parking)

Three types of passenger facilities are proposed: sheltered, unsheltered and terminals. From preliminary cost estimates, the following inferences were drawn about the distribution of the three types of stations:

a. Six downtown stops @ \$12,000 each = \$72,000. These stops will consist of concrete platforms without shelter.

b. Ten other central city stops @ \$73,000 each = \$730,000. At this cost, the stations were assumed to have some sort of shelter.

c. Nine outlying area stops @ \$715,000 total These stations will also have shelters.

d. Two terminals.

(1)	North Corridor	=	\$1,290,000
(2)	East Corridor	=	1,000,000
	Total	=	\$2,290,000

e. Facilities for handicapped and elderly persons, total = \$1,250,000.

The total estimated cost for the above items = $5,057,000 (1982$). This amount was converted into energy using the dollar to energy conversion factor for structures(9). The total energy for the 27 stations, stops and terminals was calculated at:

$$\frac{1.00(1973\$)}{2.75(1982\$)} \times \$5{,}057{,}000(1982\$) \times 5.01\times10^{4}\ \text{Btu}/(1973\$) = 9.21\times10^{10}\ \text{Btu}$$

$$\text{The energy per track mile is} = \frac{9.21\times10^{10}\ \text{Btu}}{24.3\ \text{track miles}} = 3.79\times10^{9}\ \text{Btu/track mile}$$

Parking

The cost of additional parking is $6,425,000 (1982$). A dollar to energy conversion factor of 6.1615×10^{4} Btu/(1973$) was used. This factor is for asphaltic concrete surfacing (Reference 9).

Energy for parking =

$$\frac{1.00(1973\$)}{2.75(1982\$)} \times \$6{,}425{,}000(1982\$) \times 6.1615\times10^{4}\ \text{Btu}/(1973\$) = 1.44\times10^{11}\ \text{Btu}$$

$$\text{The energy per track mile is} = \frac{1.44\times10^{11}\ \text{Btu}}{24.3\ \text{track miles}} = 5.92\times10^{9}\ \text{Btu/track mile}$$

Maintenance Facilities

The construction energy for the LRV maintenance facility was divided into three categories; the analysis is presented in Table E-10. Except for total cost estimates, information regarding the renovation and building of the bus maintenance facilities was not available. It is assumed that the cost breakdown for the bus facilities will be similar to those in the LRV facility. The ratio of (4.24×10^{9} Btu/TM, for $6 million facility) found in Table

E-10 will be used to determine the construction energy required for the bus maintenance facilities. Details are found in Table E-11.

TABLE E-10

LRV MAINTENANCE FACILITY CONSTRUCTION ENERGY

Item	Cost (1982\$)	Cost (1973\$)[1]	Energy Conversion Btu/(1973\$)	Energy (Btux10^9)
Shop Building	2,000,000	727,273	$5.01x10^4$	36.44
Shop Equipment[2]	1,280,000	-		6.00
Storage Yard	2,700,000	981,818	$6.1615x10^4$	60.49
Total	5,980,000			102.93

$102.93x10^9$ Btu/24.3TM[3] = $4.24x10^9$ Btu/TM

[1] 1982 to 1973 dollar conversion $\frac{1.00(1973\$)}{2.75(1982\$)}$(10)

[2] The shop equipment energy was estimated from a Toronto bus garage(7) at $6.00x10^9$ Btu

[3] TM = Track Mile

TABLE E-11

BUS MAINTENANCE FACILITY CONSTRUCTION ENERGY

Alternative	Facility Cost[1] (Dollars x 10^6) Renovation	New N.E. Facility	Total Cost	Cost[2] Ratio	Energy[3] (Btu/TMx10^9)
No-Build	6.0	8.4	14.4	2.4	10.18
Build	6.0	-0-	6.0	1.0	4.24

1 (Ref. 11)

2 no-build 14.4/6.0 = 2.4; build 6.0/6.0 = 1.0

3 Energy numbers obtained by multiplying cost ratio by (4.24x10^9 Btu/TM) for the LRV maintenance facility found in Table E-10.

In Table E-12 below, a summary of the construction energy is presented.

TABLE E-12

SUMMARY: CONSTRUCTION ENERGY

Item	Energy			
	Build x 10^9		No-Build x 10^9	
	Btu/TM	Btu Total	Btu/TM	Btu Total
Track Work	16.3	396.1		
Structures	11.4	277.0		
Overhead Electrical System	2.8	68.0		
Electric Substations	8.7	211.4		
Signalling	2.9	70.5		
Stations, Stops & Terminals	3.8	92.3		
Parking	5.9	143.4		
Maintenance Facilities: LRV	4.2[2]	102.1		
Bus	4.2[3]	102.1	10.2[3]	247.9
Total	60.2	1462.9	10.2	247.9

[1] TM = Track Mile, based on 24.3 track miles

[2] From Table E-10

[3] From Table E-11

Manufacturing and maintenance energy required to construct and maintain autos, buses, and LRV's are included in the report. This energy is implicitly associated with any transportation mode and its effect on total energy should be identified. Energy intensity for vehicle manufacturing and maintenance is presented in Table E-13. These values are tabulated as Btu per vehicle mile. This study is being evaluated for the study year 2000. VMT figures for each vehicle type, autos, buses and LRV, are presented in Tables E-3, E-4 and E-6, respectively. Table E-14 presents total annual energy consumed by vehicle type for vehicle manufacturing and maintenance in Btu.

TABLE E-13

VEHICLE MANUFACTURING AND MAINTENANCE ENERGY INTENSITY

Vehicle	Usable Life (miles)	Manufacturing[1] Total Energy (Btu)	Manufacturing[1] Energy Per Mile (Btu/mile)	Maintenance[1] Energy Per Mile (Btu/mile)
Automobile	100,000	141×10^6	1,410	1,400
Bus	300,000	$1,041 \times 10^6$	3,470	13,142
LRV	1,240,000[2]	$2,614 \times 10^6$	2,108[3]	7,060[3]

1-Caltrans Vehicle Manufacturing Computer Program (Appendix C)

2-30 year usable life/car x 142.5 car miles/weekday x 290 weekdays/year = 1.24×10^6 miles

3-(Ref. 12)

TABLE E-14

VEHICLE MANUFACTURING AND MAINTENANCE ENERGY[1]

Alternative	Annual Manufacturing Energy (Btux10^9) Auto	Bus	LRV	Annual Maintenance Energy (Btux10^9) Auto	Bus	LRV
No-Build	10,084	26.66	-0-	10,013	100.96	-0-
Build	10,081	23.27	1.91	10,009	88.14	6.4
Change From No-Build	3	3.4	-1.9	4	12.8	-6.4

(1) Annual energy figures obtained by multiplying appropriate VMT figures by respective intensity from Table E-13.

Table E-15 presents a summary of all the indirect energy for both the build and no build alternatives.

TABLE E-15

SUMMARY: INDIRECT ENERGY CONSUMPTION

Alternative	Annual[1] Construction Energy (Btux10^9)	Annual[2] Manufacturing Energy (Btux10^9)	Annual[2] Maintenance Energy (Btux10^9)
No-Build	5.0	10,111	10,114
Build	29.3	10,106	10,104
Change From No-Build	-24.3	5.0	10.0

1-From Table E-12 amortized over 50 years

2-Summation of Auto, Bus and LRV values from Table E-14

Totals of direct and indirect energy for both the build and no-build alternates are presented in Table E-16 below.

TABLE E-16

SUMMARY: DIRECT AND INDIRECT ENERGY CONSUMPTION

Alternative	Direct Energy[1]		Indirect Energy[2]		Total Energy[3]	
	$Btu\times10^9$	(BOE/day)	$Btu\times10^9$	(BOE/day)	$Btu\times10^9$	(BOE/day)
No-Build	37,693	17,805	20,230	9,556	57,923	27,361
Build	37,707	17,812	20,239	9,560	57,946	27,372
Change From No-Build	-14	-7	-9	-4	-23	-11

1-Summation of Direct Energy consumption from Table E-7

2-Summation of Indirect Energy consumption from Table E-15

3-Summation of Direct and Indirect Energy

In summary, the LRT system will cost a negligible 23 billion Btu (11 BOE) in direct and indirect energy for the study year 2000.

E3 Personal Rapid Transit (Light Mass Transit) Fuel Consumption

TABLE E-17

CHARACTERISTICS AND POWER RATING OF SELECTED OPERATIONAL SYSTEMS

System	Seats [Standing] per car	Rated hp/Seat	wt/Seat Tons	Avg. Speed MPH	Energy Consumption
N.Railbus (San Diego Zoo)	75	1.33	.13	25	NA
Airtrans (Dallas Airport)	16 [24]	4.69	.34	12	1.4 kw/veh-mi
Minirail (Montreal)	12	0.78	.05	8	NA
K Monorail (Lancaster, PA)	12	0.42	N.A.	25	NA
Skybus (Tampa Airport)	12 [90]	8.33	1.06	15	NA
Jetrail (Dallas Airport)	6 [4]	1.67	N.A.	30	NA
Peoplemover (Disneyland)	4	2.5	.08	4	NA
ACT (Ford Motor Co.)	10 [20]	12.0	.64	20	NA
StaRRcar (Morgantown, W.VA)	8 [13]	12.5	.43	22	2 kw/veh-mi
Speedwalk* (Moving sidewalk) (L.A. Airport)	[200±]	0.23*	30**	1.4	
Escalator* (Moving stairway)	NA	0.3*	NA	1.4	NA

Reference 19

*Standees only in this system
**Values are: 30 plf (44.6 kg/m)

E4 Direct Fuel Consumption of Trains - General

TABLE E-18

FUEL CONSUMPTION PER THROTTLE POSITION

Diesel-Electric Locomotive	Throttle Position 8	7	6	5	4	3	2	1	Idle	Dynamic Brake
EMD SW1000-1000HP	60	50	40	31	22	13	6	5	3	-
EMD SW1500-1500HP	93	80	62	52	39	25	12	6	4	-
EMD GP/SD7-1500HP	93	75	60	46	34	23	14	6	4	-
EMD GP/SD9-1750HP	108	82	68	52	37	24	13	5	4	-
GE U18B-1800HP	103	85	72	56	42	24	16	11	4	20
EMD GP20-2000HP	116	86	69	55	42	28	14	6	4	-
EMD GP/SD38-2000HP	122	103	83	64	47	31	16	7	5	25
EMD GP30-2250HP	125	102	75	61	45	31	19	7	4	-
GE U23B,C-2300HP	112	92	81	64	48	27	17	12	4	20
EMD SD24-2400HP	144	106	81	61	44	30	18	6	3	-
EMD GP/SD35-2500HP	144	124	96	72	51	35	21	11	5	-
EMD GP-SD40-3000HP	168	146	108	79	57	41	25	7	6	25
GE U30B,C-3000HP	149	127	102	81	62	34	22	16	5	26
GE U33B,C-3300HP	163	138	110	87	65	36	23	16	5	26
GE U36B,C-3600HP	177	150	119	94	69	39	24	16	5	26
EMD SD45-3600HP	194	172	127	92	68	48	28	10	6	25

Reference 13

Diesel Fuel Consumption Rate: gallons per hour

TABLE E-19

TYPICAL DAILY LOCOMOTIVE OPERATION - Diesel Electric

Throttle Position	Delivered Horsepower	Operation (Hours)	Consumption Rate Gal/Hr
8	3100	3.6	168
7	2550	1.0	146
6	2000	1.0	108
5	1450	1.0	79
4	950	1.0	57
3	500	1.0	41
2	200	1.0	25
1	58	1.2	7.5
Idle	0	12.0	5.5
Dyn.Brake	-	1.2	25

Reference 13

TABLE E-20

HORSEPOWER REQUIREMENTS FOR ASCENDING GRADES

Additional horsepower required for gross elevation changes in the track.

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

Reference 14

TABLE E-21

FUEL CONSUMPTION PER HORSEPOWER-TO-WEIGHT RATIO

Relatively Mountainous Territory

Max MPH	Avg MPH	Diesel Fuel Consumption GPM
1.0 Horsepower/Trailing Gross Ton		
70	30.9	8.28
60	30.6	8.09
50	29.7	7.81
40	28.0	7.56
1.5 Horsepower/Trailing Gross Ton		
70	37.6	9.33
60	37.2	8.88
50	35.6	8.43
40	32.5	8.06
3.0 Horsepower/Trailing Gross Ton		
70	47.0	10.42
60	44.3	9.72
50	40.3	9.08
40	35.6	8.53
4.0 Horsepower/Trailing Gross Ton		
70	49.8	12.28
60	46.3	10.91
50	41.4	9.77
40	36.0	9.08
5.0 Horsepower/Trailing Gross Ton		
70	NA	14.29
60	NA	11.9
50	NA	10.47
40	NA	9.92

TABLE E-21 (Continued)

FUEL CONSUMPTION PER HORSEPOWER-TO-WEIGHT RATIO

6.0 Horsepower/Trailing Gross Ton		
70	51.8	16.62
60	47.5	13.74
50	42.1	12.10
40	36.0	11.36
8.0 Horsepower/Trailing Gross Ton		
NA	NA	20.8
10.0 Horsepower/Trailing Gross Ton		
NA	NA	26.0

References 13, 15

E5 Direct Fuel Consumption of Passenger Trains

TABLE E-22

FUEL CONSUMPTION OF TRAINS - SHORT TRIPS

Electric energy 0.17 KWH/seat-mile
[Diesel Fuel Equivalent = 0.013 gal/seat-mile

Reference 17

TABLE E-23

FUEL CONSUMPTION OF SELECTED TRAINS - LONG TRIPS - Diesel Fuel

Route	Distance Miles	Propulsion Type	gal/seat-mile
Seattle-Havre	903	Diesel-Elec.	.009
Atlanta-Wash.	633	Diesel-Elec.	.012
New York-Wash.	284	Gas Turbine	.010
Chicago-St. Louis	227	Electric	.013*

Reference 14

*Equivalent diesel fuel

TABLE E-24

WEIGHT PER SEAT OF SELECTED TRAINS

Train Type	Gross Weight Tons	No of Seats	Gross Weight per Seat Tons
Urban	39.5	50-60	0.72
Intercity	525	382	1.37
Intercity	1000	1400	0.71
Std.Diesel	600	360	1.67

Reference 18

E6 Direct Fuel Consumption of Freight Trains

TABLE E-25

AVERAGE DISTRIBUTION OF GROSS TRAIN WEIGHT

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

Reference 13

TABLE E-26

CARGO WEIGHT DEPENDING ON COMMODITY SHIPPED

Commodity	Tons/Car
Average	54.1
Metallic Ores	77.3
Non-Met. Minerals	73.5
Coal	69.5
Petroleum	55.8
Farm Products	54.3
Wood Products	48.1
Food	38.6
Printed Matter	29.2
Machinery	27.9
Fab. Metal Products	27.4
Leather Products	24.5
Transp. Equipment	22.4
Textile Products	19.9
Instru., Photography	18.4
Apparel	18.1
Rubber or Plastic	16.4
Misc. Mfg. Goods	15.0
Electric Machinery	13.7
Furniture, Fixtures	9.2

Reference 15

TABLE E-27

FUEL CONSUMED IN NORMAL USE - Diesel

Gross Consumption:	0.0020 gal/gross ton-mile
Net Consumption:	0.0049 gal/net ton-mile

Reference 13

E7 Direct Fuel Consumption of Rail Mass Transit

TABLE E-28

FUEL CONSUMED IN NORMAL USE

Characteristics and Energy Consumption of Selected Systems

System	Seats [Standing] per car	Rated hp/Seat	wt/Seat Tons	Energy Consumed** Btu/Seat-mi
Std. Commuter	127 [123]	9.5	.47	NA
Lindenwold	84	7.6	.39	NA
Toronto	83 [NA]	1.9	.35	860
San Francisco*	72 [72]	7.4	.40	850
Philadelphia	56 [NA]	5.8	.43	1075
Cleveland	54 [NA]	3.4	.51	686
Chicago	51 [NA]	3.4	.41	952
New York	47 [NA]	7.3	.84	1208
Montreal	40 [120]	3.9	.75	NA
Tokyo "Alweg"	35 [65]	13.3	.39	NA

References 17, 19, and 20

*BART System
**Standee capacity is not included in computations

E8 Load Factors

TABLE E-29

PASSENGER-RELATED LOAD FACTORS

Rail (conventional and rapid rail transit)

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

References 14, 21, 22, 23

TABLE E-30

RAIL TRANSPORT

All cars	57%
Boxcars	67%
Flatcars	69%
Gondolas	54%
Hoppers	50%

Reference 24

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E10 COMMENTARY

Personal Rapid Transit (Light Mass Transit) Fuel Consumption

General Comments:

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

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

Direct Fuel Consumption of Trains - General

General Comments:

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

Horsepower Requirements for Ascending Grades

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

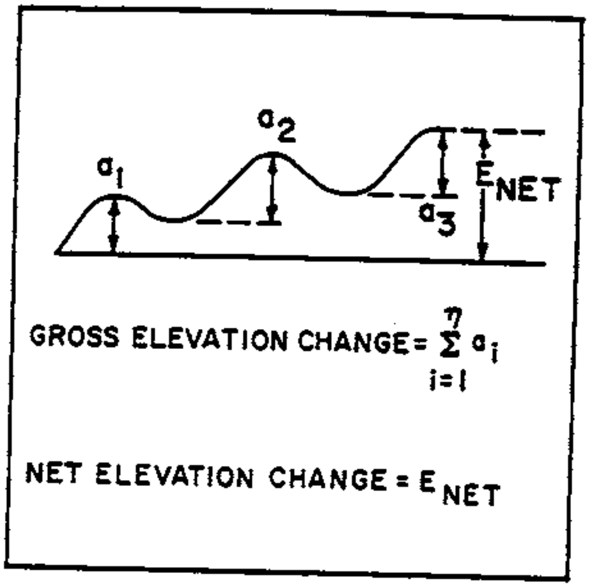


Figure E-2. Definition of gross and net elevation changetrains

Fuel Consumption per Horsepower-To-Weight Ratio

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

Direct Fuel Consumption of Passenger Trains

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

Direct Fuel Consumption of Freight Trains

Average Distribution of Gross Train Weight

Values presented are based on 1974 statistics of 10 major U.S. railroads.

Fuel Consumed in Normal Use - Diesel

Values presented are based on 1974 statistics of 10 major U.S. railroads.

Direct Fuel Consumption of Rail Mass Transit

General Comments:

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

Fuel Consumed in Normal Use

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

Fuel Consumed in Normal Use

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

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

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

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

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

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

Skybus: Rubber-tired on concrete track, DC traction motor, 100 HP. Passenger transportation at Tampa and Seattle-Tacoma Airports.

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

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

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

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

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

APPENDIX F

ENERGY FACTORS FOR AIRCRAFTS, SHIPS AND PIPELINES

APPENDIX F

ENERGY FACTORS FOR AIRCRAFT, SHIPS, PIPELINES

Table of Contents

F-1 DIRECT FUEL CONSUMPTION OF PASSENGER AIRCRAFT AT NORMAL OPERATING MODES

Estimated Fuel Consumption For Typical Operations - Jet Aircraft Fuel

Aircraft Type	FUEL CONSUMPTION RATE, Gal/Hr					TIME IN MODE, Hr					REFERENCE
	Taxi-Idle	Take-off	Climb-out	Cruise	Approach Land	Taxi - Dep.	Idle Arr.	Take-off	Climb-out	Approach Land	
Jumbo Jet*	1053	10335	8677	3576	3154	.32	.12	.012	.04	.07	FR1,FR2,FR3
Long-Range Jet	528	6567	5428	1879	2508	.32	.12	.012	.04	.07	"
Medium Range Jet	436	3980	3335	1136	1550	.32	.12	.012	.04	.07	"
Air Carrier Turboprop	299	1450	1326	582	695	.32	.12	.01	.04	.08	"
STOL Commercial	45	182	152	85	76	.32	.12	.01	.04	.08	"
Gen Aviation Turboprop	44	111	103	61	62	.32	.12	.01	.04	.08	"
Gen Aviation Piston**	1.2	7.3	7.3	7.1	3.2	.20	.07	.005	.08	.10	"

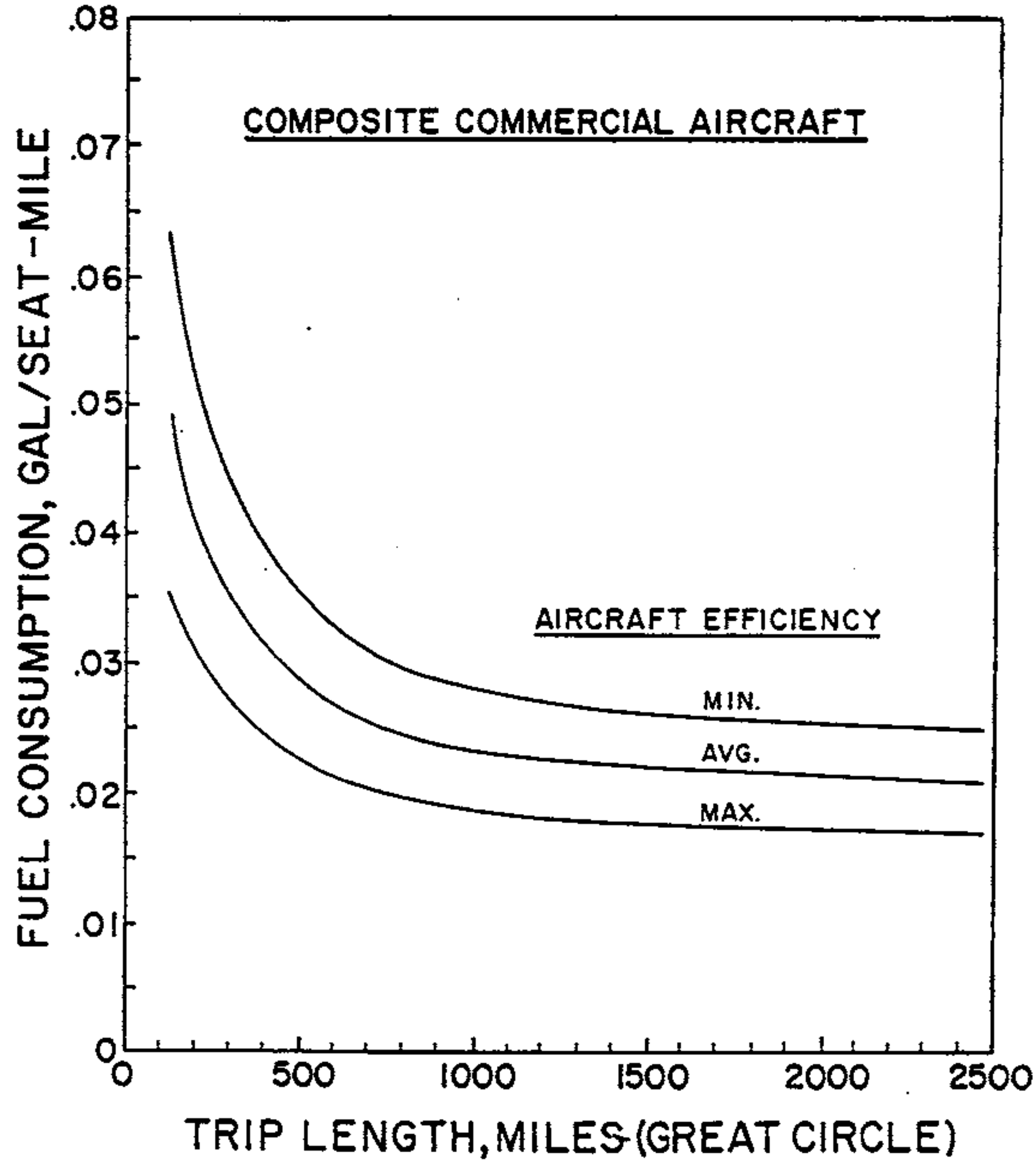
*Jumbo Jets generally carry more than 250 seats and weigh over 200,000 lbs.
**Aviation Gasoline Fuel

F2 FUEL CONSUMED ASSUMING BEST CRUISING SPEED - Jet Aircraft Fuel

Aircraft Type	Approximate Seats	Best Cruise Speed MPH	Fuel Consumption: Cruise Gal/Seat-Mile*	Fuel Consumption: Non-Cruise** (per trip) Gal/Seat	References
Jumbo Jet	378	575	.020	7.2	FR1,FR2,FR3
Long-Range Jet	140	565	.027	10.1	"
Medium Range Jet	133	565	.027	10.1	"
Air Carrier Turboprop	85	360	.019	3.0	"
STOL Commercial	19	190	.028	1.8	"
Gen Aviation Turboprop	10	300	.020	3.0	"
Gen Aviation Piston	5	105	.023	0.3	"
Commuter Aircraft			.019		FR4
Newest Short Range Jet 205			.016		FR5
Newest Medium Range Jet 240			.018		FR5

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

F-3 FUEL CONSUMED IN NORMAL OPERATIONS - Jet Aircraft Fuel



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

F-4 DIRECT FUEL CONSUMPTION OF FREIGHT (CARGO ONLY) AIRCRAFT

DOMESTIC

Type of Aircraft	Capacity (Tons)	Load Factor (Percent)	Trip Length (Miles)	Average Airborne Speed	Ton-Miles Per Gallon	Btu Per Ton-Mile	References
DC-8-50F	38.1	49.4	1,337	478	4.41	33,000	FR7
DC-8-63F	43.9	56.9	1,297	479	5.70	25,500	FR7
B-707-300C	41.8	46.5	1,066	473	4.38	33,200	FR7
B-727-100C/AC	19.2	62.8	816	467	3.62	40,000	FR7

INTERNATIONAL

Type of Aircraft	Load Factor (Percent)	Trip Length (Miles)	Average Airborne Speed	Ton-Miles Per Gallon	Btu Per Ton-Mile	References
DC-8-50F	65.5	1,899	487	5.17	28,100	FR7
DC-8-63F	68.6	1,624	492	6.53	22,300	FR7
B-707-300C	51.8	1,468	491	4.80	30,300	FR7
B-727-100C/AC	62.1	836	459	6.56	22,200	FR7

Average Efficiency 29,000 Btu/Ton-Mile

F5 DIRECT FUEL CONSUMPTION OF PASSENGER CARGO AIRCRAFT (LOWER HOLD)

	Reference
3,300 Btu/Ton-Mile	FR8

F6 INDIRECT MANUFACTURING ENERGY FOR AIRCRAFT

Aircraft		References
Boeing 707-320B	170,161 x 10^6 Btu/Airplane	FR20
Boeing 707-320C	162,396 x 10^6 Btu/Airplane	FR20
Boeing 707 Passenger	20,130 x 10^6 Btu/Airplane	FR20
Cargo Plane	150 Btu/Ton-Mile	FR20
Lower Hold (Cargo)	20 Btu/Seat-Mile	FR20
Commercial Jet	78,170 Btu/Seat-Mile	FR9
Gen Aviation Piston	70,600 Btu/Seat-Mile	FR10

F7 INDIRECT MAINTENANCE ENERGY FOR AIRCRAFT

		References
Boeing 707	13,300 Btu/Plane-Mile	FR20
Cargo Airplane	750 Btu/Ton-Mile	
Lower Hold (Cargo)	100 Btu/Ton-Mile	

F8 INDIRECT AIRPORT CONSTRUCTION ENERGY

		References
Runway	$6,312 \times 10^9$ Btu	FR20
Cargo Terminal	78×10^9 Btu	FR20
Cargo Airplane	100 Btu/Ton-Mile	FR20
Lower Hold (Cargo)	25 Btu/Ton-Mile	FR20

F9 INDIRECT AIRPORT MAINTENANCE ENERGY

		References
Runway System	$53,000 \times 10^6$ Btu/year	FR20
Cargo Terminal	$17,500 \times 10^6$ Btu/year	FR20

F10 PASSENGER RELATED LOAD FACTORS FOR AIRCRAFT

		References
Long Trip	43-58%*	FR6,11,12,13
Short Trip	25-46%	FR6,11,12,13
Overall	48-55%	FR6,11,12,13

*58% refers to international trips

F11 CARGO RELATED LOAD FACTORS FOR AIR TRANSPORT

		Reference
Cargo Only Aircraft	47%	FR12
Passenger Cargo (lower hold)	41%	FR12

F12 DIRECT FUEL CONSUMPTION OF SELECTED FERRYBOATS

System	Vessels in Service	Knots	Passengers [Cars]	Fuel Consumption, Diesel Gal/Rated Pass.-Mile**	References
Delaware-New Jersey; Cape May-Lewes Ferry	3 vessels, (identical, built 1974)	14	700 [100]	.022	FR14
Washington State Ferry Fleet	6 large vessels, (built 1967-72)	18	2000-2500 [N.A.]	.006	FR15
	+ 19 older vessels	Vary	Vary	N.A.	
San Francisco Bay-Golden Gate Ferries	1 vessel	14	575	.005	FR16
	+2 identical vessels, 1976	22	700	.011	

*Knot: 1 nautical mile per hour = 1.151 statute miles per hour

**Statute miles

F13 DIRECT FUEL CONSUMPTION OF INLAND AND COASTAL VESSELS (NORMAL PASSENGER SERVICE)

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

F14 DIRECT ENERGY CONSUMPTION OF INLAND AND COASTAL VESSELS (NORMAL FREIGHT SERVICE)

Fuel consumption: 508 Btu/T-mile
(3.03×10^5 joules/metric T-km)

F15 DIRECT FUEL CONSUMPTION OF MERCHANT SHIPS (CHARACTERISTICS OF U.S. FLAG MERCHANT SHIPS)

Ship Type (No. of Ships)	Engine Type	Avg. Deadweight Long Tons	Avg. Speed Knots	Avg. Fuel Consumption Gal/Dwt. T-mile (naut.)	References
Barge Carrier (6)	ST	43537	22.0	.00209	FR18
Bulk Carrier (1)	ST	13790	11.5	.00120	"
Bulk Carrier (1)	MS	13700	11.5	.00085	"
Chemical Tanker (1)	ST	35949	16.5	.00159	"
Combination (2)	ST	18049	17.0	.00201	"
Container (80)	ST	16627	20.2	.00381	"
Container (1)	MS	2294	16.0	.00427	"
Convertible (17)	ST	19705	22.2	.00382	"
Dry Bulk Carrier (9)	ST	22291	14.4	.00150	"
Dry Bulk Carrier (2)	MS	26724	15.0	.00101	"
General Cargo (157)	ST	13335	19.1	.00379	"
General Cargo (1)	MS	10206	15.5	.00135	"
L.A.S.H. (16)	ST	33407	21.9	.00283	"
Ore/Bulk/Oil (2)	ST	82160	16.5	.00111	"

F15 DIRECT FUEL CONSUMPTION OF MERCHANT SHIPS (CHARACTERISTICS OF U.S. FLAG MERCHANT SHIPS) (Cont'd)

Ship Type (No. of Ships)	Engine Type	Avg. Deadweight Long Tons	Avg. Speed Knots	Avg. Fuel Consumption Gal/Dwt. T-mile (naut.)	References
Partial Container (1)	ST	14361	20.0	.00382	FR18
Passenger Vessel (6)	ST	8434	19.6	.00675	"
Petroleum Tanker (1)	ST	18635	15.0	.00172	"
Special Purpose Cargo (1)	ST	10380	15.0	.00266	"
Tanker (212)	ST	41659	16.1	.00156	"
Tanker (13)	MS	30860	16.2	.00108	"
Vehicle Carrier (8)	ST	14076	24.1	.00510	"
Fleet Average (538)		27000	18.1	.00274	"

ST = Steam Turbine, using Bunker C Fuel Oil

MS = Motor Ship, using Diesel Fuel

Long Ton = 2240 lb

Knot = 1 nautical mile per hour = 1.151 statute miles per hour

F16 FUEL CONSUMPTION IN-BERTH

		References
Steam Turbine - Bunker C Fuel	1900 Gal/day	FR2
Motor Ship - Diesel Fuel	660 Gal/day	FR2

F17 NORMAL OPERATING TIMETABLE

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

		References
At sea:	280 days	FR18
In port:	60 days	FR18
Scheduled Maintenance:	25 days	FR18

F18 INDIRECT MANUFACTURING ENERGY FOR SHIPS

	References
40 Btu/Ton-mile	FR20

F19 INDIRECT MAINTENANCE ENERGY FOR SHIPS

	References
30 Btu/Ton-mile	FR20

F20 INDIRECT FACILITY CONSTRUCTION FOR SHIPS

		References
Dock	797×10^9 Btu/mile	FR20
Canal	100×10^9 Btu/mile	FR20
	50 Btu/Ton-mile	FR20

LOAD FACTORS FOR SHIPS

Ferryboats (Passenger)	26%	FR21

F21 DIRECT ENERGY CONSUMED BY PIPELINES

		References
Coal Slurry	1000 Btu/Ton-mile	FR20
Natural Gas	2000 Btu/Ton-mile	FR20
Oil	325 Btu/Ton-mile	FR20

F22 INDIRECT CONSTRUCTION ENERGY FOR PIPELINES

		References
Oil Pipeline	25 Btu/Ton-mile	FR20
Coal Slurry Pipeline	50 Btu/Ton-mile	FR20

F23 INDIRECT MAINTENANCE ENERGY FOR PIPELINES

		References
Oil Pipeline	100 Btu/Ton-mile	FR20
Coal Slurry Pipeline	100 Btu/Ton-mile	FR20
Coal Slurry Line and Terminal	960×10^9 Btu/mile/year	FR20

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Commentary for Appendix F

F1 DIRECT FUEL CONSUMPTION OF PASSENGER AIRCRAFT

General Comments:

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

Examples of Aircraft Type and Characteristics

Jumbo Jet
- Boeing 747 — 344,300 lb , 305-460 passengers
- Lockheed L-1011 — 237,500 lb, 268 passengers
- McDonnell-Douglas DC-10 — 299,810 lb, 255-270 passengers

Long Range Jet
- Boeing 707 — 141,400 lb, 155 passengers
- McDonnell-Douglas DC-8 — 150,600 lb, 152-206 passengers

Medium Range Jet
- Boeing 727 — 103,720 lb, 103-158 passengers
- Boeing 737 — 60,430 lb, 95-109 passengers
- McDonnell-Douglas DC-9 — 59,115 lb, 80-114 passengers

Air Carrier Turboprop
- Convair 580
- Electra L-188
- Fairchild-Hiller FH 227

STOL (Short takeoff and landing)
- DeHavilland Heron
- DeHavilland Twin Otter

General Aviation Turboprop
- Boeing Super King Air 200
- Piper Cheyenne

General Aviation Piston
- Cessna Cardinal
- Cessna 120 Skywagon
- Cessna Skymaster
- Piper Warrior

F1 <u>FUEL CONSUMED AT NORMAL OPERATING MODES</u> (FCANO)

Activities included in each mode are as follows:

Mode	Engine Operating Times Included in Mode
Taxi	Transit times between ramp and apron; apron and runway and alignment between taxiway and runway.
Idle	Push back from gate; waiting for signal to begin taxiing; waiting at taxiway intersections; runway queuing; gate queuing.
Landing	Touchdown to beginning of taxi on taxiway.
Takeoff	After alignment with runway to liftoff.
Approach	3000 ft altitude to touchdown.
Climbout	Liftoff to 3000 ft altitude.

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

F2 FUEL CONSUMED ASSUMING BEST CRUISING SPEED

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

F3 FUEL CONSUMED IN NORMAL OPERATIONS

Figure F3 is based on 1972 data and reflects actual use of available in-service aircraft. Aircraft types tend to be more fuel efficient in some operations than others, but airline schedules and availability often require that aircraft are not matched to routes in the most fuel efficient way.

Airline statistics usually give credit for great circle miles, regardless of the actual distance of the flight path.

Figure F3.2 shows the deviation between actual fuel consumption and that calculated from theoretically derived "ideal" conditions (no wind, no queue, circuity = 1.00). The average shortfall is 30.2%.

F4 DIRECT FUEL CONSUMPTION OF FREIGHT AIRCRAFT

General Comments:

Air cargo is carried in the lower hold of passenger/cargo aircraft (this is known as "lower hold cargo"), in cargo-only aircraft, and in convertible aircraft that may be used for passenger/cargo or cargo-only service. Typical cargo densities vary from 5 to 14 pcf, the average being 10.7 pcf.

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

Data from four differing sources varied significantly. Reported values ranged from .07 to .59 gallon of fuel per ton-mile depending on the source of information. The values shown assume the aircraft is carrying the average load factors shown in Tables F4 and F11. Aircraft fuel refining energy has been included in the reported energy intensities.

F12 DIRECT FUEL CONSUMPTION OF SELECTED FERRYBOATS

Data presented under Section F10 have been obtained from statistics supplied by the operating agencies of ferry systems.

F13 DIRECT FUEL CONSUMPTION OF INLAND AND COASTAL VESSELS

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

F14 Freight service data are based on 1972 U.S. statistics. Breakdown of the total ton-miles shipped was as follows:

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

F15 CHARACTERISTICS OF U.S. FLAG MERCHANT SHIPS

Data presented under Section F13 have been extracted from computerized files of the U.S. Department of Commerce, Maritime Administration, and include all self-propelled U.S. flag vessels active as of December 1976, and exceeding 4000 long tons deadweight.

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

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

Fuel consumption data are for ships at cruise speed.

F16 FUEL CONSUMPTION IN BERTH

Fuel consumption data are averages for ships in-berth.

APPENDIX G

ENERGY FACTORS FOR VARIOUS MATERIALS

APPENDIX G

This appendix contains the energy factors for a rather diverse collection of materials. Contained herein are the refining, calorific and combined total energies for some commonly used transportation fuels. Also shown are the calorific energy values for some less common fuels as well as energy consumption factors for both residential and nonresidential structures. The energy required to produce some selected materials such as cement, copper and glass; and the energy produced by some natural systems such as woodlands or swamps are also presented.

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LIST OF TABLES

G1 TOTAL ENERGY OF SOME PETROLEUM PRODUCTS COMMONLY USED IN TRANSPORTATION

Petroleum Product	Calorific Energy	Refining Energy	Total Energy	Reference
Gasoline	125,000 Btu/gal	18,700	143,700	GR20,21,8,1,*
Jet Fuel (Military)	127,500 "	10,500	138,000	"
Kerosene (same as commercial jet fuel)	135,000	10,500	145,500	"
Diesel	138,700	8,820	147,600	"
Resid. Oil	149,700	8,980	158,700	"
Coke	143,400	15,700	159,100	"
LPG	95,500	12,700	108,200	"
<u>Lubricating Oils</u>				
General	144,000	62,400	206,800	GR22,1,*
10-40 Oil	144,000	76,000	220,000	"
Synthetic	144,000	148,000	292,000	GR23,1,*

*Indicates work done by authors to derive the factors

G2 PROPERTIES OF SELECTED FUELS

Fuel	Density	Gross Heat Content	References
Butane (Liquid)	5.25 lb/gal	9.34×10^4 Btu/gal	GR1,25
Coal (Composite, all grades)			
Anthracite	93 lb/ft^3	2.54×10^7 Btu/ton	GR1
Bituminous	84 lb/ft^3	2.62×10^7 Btu/ton	"
Lignite	78 lb/ft^3	1.24×10^7 Btu/ton	"
Subbituminous	N.A.	1.7×10^7 Btu/ton	"
Ethane	0.01 lb/gal	6.6×10^4 Btu/gal	GR33
Ethanol (Ethyl Alcohol)	8.02 lb/gal	8.46×10^4 Btu/gal	GR1
Gas, Natural	0.038 lb/ft^3		
Wet	"	1.091×10^3 Btu/ft^3	"
Dry	"	1.02×10^3 Btu/ft^3	"
Liquid	"	9.82×10^4 Btu/ft^3	"
Gasoline, Automotive	6.1 lb/gal	1.25×10^5 Btu/gal	"
Gasoline, Aviation	6.1 lb/gal	1.21×10^5 Btu/gal	"
Gasohol	6.05 lb/gal	1.21×10^5 Btu/gal	"
Hydrogen (Liquid)	1.67 lb/gal	3.21×10^4 Btu/gal	GR19
Hydrogen+Oxygen (Liquid)	4.32 lb/gal	2.19×10^4 Btu/gal	"
Jet Aircraft Fuel	6.6 lb/gal		
Kerosene (commercial)		1.35×10^5 Btu/gal	GR1
Naptha (military)		1.27×10^5 Btu/gal	"
Kerosene	6.71 lb/gal	1.35×10^5 Btu/gal	"
Lubricants	7.61 lb/gal	1.44×10^5 Btu/gal	"
Magnesium Hydride	7.20 lb/gal	5.12×10^5 Btu/gal	GR19
Methane (Liquid)	5.61 lb/gal	7.81×10^4 Btu/gal	"
Methanol (Methyl Alcohol)	5.57 lb/gal	6.46×10^4 Btu/gal	"

G2 PROPERTIES OF SELECTED FUELS (Continued)

Fuel	Density	Gross Heat Content	References
Oils, Fuel Oil			
No. 1 (API 42 deg)	6.790 lb/gal	1.35×10^5 Btu/gal	GR1,3
No. 2 Diesel (API 35 deg)	7.076 lb/gal	1.39×10^5 Btu/gal	"
No. 3 (API 28 deg)	7.387 lb/gal	1.43×10^5 Btu/gal	"
No. 4 (API 20 deg)	7.778 lb/gal	1.48×10^5 Btu/gal	"
No. 5 (API 14 deg)	8.099 lb/gal	1.52×10^5 Btu/gal	"
No. 6 Bunker (resid. F.O.)	8.328 lb/gal	1.50×10^5 Btu/gal	"
Petroleum Cokes	11.6 lb/gal	1.24×10^4 Btu/lb	GR10
Petroleum Crudes			
California sources	7.88 lb/gal	1.38×10^5 Btu/gal	GR30
Other USA sources	7.03 lb/gal	1.38×10^5 Btu/gal	"
Outside USA sources	7.50 lb/gal	1.38×10^5 Btu/gal	"
Propane (Liquid)	31 lb/ft^3	8.53×10^4 Btu/gal	GR1
Sulfur	124 lb/ft^3	8.0×10^6 Btu/ton	GR4
Wood			
Hardwoods	46.2 lb/ft^3	1.013×10^4 Btu/lb	GR4,13
Softwoods	36 lb/ft^3	1.065×10^4 Btu/lb	"
Resin	67 lb/ft^3	3.48×10^6 Btu/ton	GR4

G3 PROPERTIES OF SELECTED MATERIALS

Material	Density	Energy to Produce	References
Aluminum			
Raw ingot	165 lb/ft^3	2.34x10^8 Btu/ton	GR5,6,8,*
Casting	165 lb/ft^3	2.46x10^8 Btu/ton	"
Forged	165 lb/ft^3	2.51x10^8 Btu/ton	"
Wire	165 lb/ft^3	2.48x10^8 Btu/ton	"
Extruded	165 lb/ft^3	2.44x10^8 Btu/ton	"
Stamp	165 lb/ft^3	2.41x10^8 Btu/ton	"
Aggregates			
Crushed gravels	100 lb/ft^3	4.8x10^4 Btu/ton	GR3
Crushed stone	95 lb/ft^3	6.0x10^4 Btu/ton	"
Uncrushed sands & gravels	100 lb/ft^3	1.6x10^4 Btu/ton	"
Asphalts			
Air-refined asphalts	8.2 lb/gal	134,000 Btu/gal*	GR20,7,8,*
Emulsified (60% asphalt)	8.3 lb/gal	81,000 Btu/gal	GR3,7,8,20,*
Cement, Portland	94 lb/ft^3	6.88x10^6 Btu/ton	GR18
Copper			
Casting	556 lb/ft^3	1.25x10^8 Btu/ton	GR5,8,9,*
Rolled	556 lb/ft^3	1.38x10^8 Btu/ton	"
Wire	556 lb/ft^3	1.39x10^8 Btu/ton	"
Glass	165 lb/ft^3	2.09x10^7 Btu/ton	GR5,8,*
Iron, Cast	450 lb/ft^3	21.74x10^6 Btu/ton	GR6,8,9,11,*
Iron, Pig	450 lb/ft^3	10.57x10^6 Btu/ton	GR8,9,11,*
Lime	137 lb/ft^3	7.5x10^6 Btu/ton	GR3

*Indicates work done by authors to derive the factors

G3 PROPERTIES OF SELECTED MATERIALS (Continued)

Material	Density	Energy to Produce	References
Lead	708 lb/ft^3	6.95x10^7 Btu/ton	GR8,9,*
Magnesium, Alloys	112 lb/ft^3	N.A.	
Plastics	59-128 lb/ft^3		
Polyethylene, high density	59-61 lb/ft^3	10.93x10^7 Btu/ton	GR5,8,27,31,*
Polyethylene, low density	56-58 lb/ft^3	11.62x10^7 Btu/ton	"
Polystyrene	50 lb/ft^3	15.34x10^7 Btu/ton	" 32,*
Polyvinyl chloride		10.51x10^7 Btu/ton	"
Rubber			
Rubber goods (general)	94 lb/ft^3	14.73x10^7 Btu/ton	"
Passenger Tires, new	29 lb each	3.10x10^6 Btu/each	GR5,8,27,28,29,*
Passenger Tires, recap	8 lb (add'l rub)	9.39x10^5 Btu/each	"
Med. Trk. Tires, new	45 lb each	4.58x10^6 Btu/each	"
Med. Trk. Tires, recap	12 lb(add'l rub)	1.44x10^6 Btu/each	"
Hvy. Trk. Tires, new	125 lb each	1.27x10^7 Btu/each	"
Hvy. Trk. Tires, recap	22 lb(add'l rub)	3.02x10^6 Btu/each	"
Steel, Alloy		4.66x10^7 Btu/ton	GR6,8,9,11,*
Cold rolled	490 lb/ft^3	5.17x10^7 Btu/ton	"
Pressed	490 lb/ft^3	5.47x10^7 Btu/ton	"
Painted	490 lb/ft^3	6.06x10^7 Btu/ton	"
Stamped	490 lb/ft^3	5.23x10^7 Btu/ton	"
Painted	490 lb/ft^3	5.82x10^7 Btu/ton	"
Drawn	490 lb/ft^3	5.93x10^7 Btu/ton	"
Extruded	490 lb/ft^3	5.18x10^7 Btu/ton	"
Forged	490 lb/ft^3	6.19x10^7 Btu/ton	"
Annealed	490 lb/ft^3	6.45x10^7 Btu/ton	"
Carburized	490 lb/ft^3	6.55x10^7 Btu/ton	"
Induction hardened	490 lb/ft^3	6.24x10^7 Btu/ton	"
Quenched & tempered	490 lb/ft^3	6.46x10^7 Btu/ton	"

*Indicates work done by authors to derive the factors

G3 PROPERTIES OF SELECTED MATERIALS (Continued)

Material	Density	Energy to Produce	References
Steel, Alloy, Construction Items			
Prestressing tendon		5.93×10^7 Btu/ton	GR6,8,9,11,*
Steel, Carbon	490 lb/ft^3	3.98×10^7 Btu/ton	"
Cold Rolled	490 lb/ft^3	4.49×10^7 Btu/ton	"
Pressed	490 lb/ft^3	4.79×10^7 Btu/ton	"
Electroplated	490 lb/ft^3	5.16×10^7 Btu/ton	"
Painted	490 lb/ft^3	5.38×10^7 Btu/ton	"
Stamped	490 lb/ft^3	4.55×10^7 Btu/ton	"
Electroplated	490 lb/ft^3	4.93×10^7 Btu/ton	"
Painted	490 lb/ft^3	5.14×10^7 Btu/ton	"
Drawn	490 lb/ft^3	5.25×10^7 Btu/ton	"
Extruded	490 lb/ft^3	4.49×10^7 Btu/ton	"
Forged	490 lb/ft^3	5.51×10^7 Btu/ton	"
Annealed	490 lb/ft^3	5.77×10^7 Btu/ton	"
Carburized	490 lb/ft^3	5.87×10^7 Btu/ton	"
Induction hardened	490 lb/ft^3	5.56×10^7 Btu/ton	"
Quenched & tempered	490 lb/ft^3	5.78×10^7 Btu/ton	"
Steel, Carbon, Construction Items			
Guardrailing	490 lb/ft^3	5.18×10^7 Btu/ton	GR6,8,9,11,34,*
Pipe	490 lb/ft^3	4.49×10^7 Btu/ton	GR6,8,9,11,35,*
Reinforcing gears	490 lb/ft^3	4.49×10^7 Btu/ton	"
Signs		5.38×10^7 Btu/ton	"
Structures		3.98×10^7 Btu/ton	"
Trackage, mainline railroad	38 lb/lf	3.98×10^7 Btu/ton	"
Trackage, light rail transit	33 lb/lf	3.98×10^7 Btu/ton	"

*Indicates work done by authors to derive the factors

G3 PROPERTIES OF SELECTED MATERIALS (Continued)

Material	Density	Energy to Produce	References
Steel, Stainless	490 lb/ft^3	6.16x107 Btu/ton	GR6,8,9,11,*
Cold Rolled	490 lb/ft^3	6.67×10^7 Btu/ton	"
Pressed	490 lb/ft^3	6.97×10^7 Btu/ton	"
Stamped	490 lb/ft^3	6.73×10^7 Btu/ton	"
Drawn	490 lb/ft^3	7.43×10^7 Btu/ton	"
Extruded	490 lb/ft^3	6.67×10^7 Btu/ton	"
Steel, Stainless Construction Items			
Pipe	490 lb/ft^3	6.67×10^7 Btu/ton	" 35,*
Wire	490 lb/ft^3	7.43×10^7 Btu/ton	"
Wood			
Hardwood	46 lb/ft^3	2.02×10^7 Btu/ton	GR4,13
Softwood	36 lb/ft^3	2.13×10^7 Btu/ton	"
Zinc	440 lb/ft^3	69.5×10^6 Btu/ton	GR6,8,9,*
Forged	440 lb/ft^3	84.86×10^6 Btu/ton	"
Rolled	440 lb/ft^3	74.66×10^6 Btu/ton	"

*Indicates work done by authors to derive the factors

G4 ENERGY PRODUCTION OF SELECTED NATURAL SYSTEMS

NET QUANTITY & ENERGY PRODUCTION

Ecosystem Type	Dry Quantity $lb/ft^2/yr$	Energy Production $Btu/ft^2/yr$	References
Tropical forest	.410	$3.13x10^3$	GR14
Temperate forest	.256	$1.96x10^3$	"
Boreal forest	.164	$1.25x10^3$	"
Woodland and shrubland	.143	$1.10x10^3$	"
Savanna	.184	$1.41x10^3$	"
Temperate grassland	.123	$9.39x10^2$	"
Tundra and alpine	.029	$2.19x10^2$	"
Desert and semidesert	.008	$6.26x10^1$	"
Cultivated land	.133	$1.02x10^3$	"
Swamp and marsh	.410	$3.13x10^3$	"
Lake and stream	.051	$4.14x10^2$	"
Total continental	.158	$1.21x10^3$	"
Algal beds, reefs, estuaries	.369	$2.98x10^3$	"
Open ocean	.026	$2.26x10^2$	"
Total marine	.031	$2.74x10^2$	"
World total	.068	$5.40x10^2$	"

GROSS QUANTITY PRODUCTION

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

ENERGY CONTENT OF LIVING TISSUE

Type	Energy per Dry Weight Btu/lb	
Land plants	$7.64x10^3$	"
Large aquatic plants	$8.09x10^3$	"
Plankton	$8.81x10^3$	"
Animal tissue	$8.99x10^3$	"

G5 ENERGY CONSUMED BY STRUCTURES

ELECTRICITY CONSUMPTION

Type of Structure	Annual Energy Consumed Per Area of Floor Space		
	Energy Delivered kwh/ft^2	Energy Consumed at powerplant Btu/ft^2	Ref.
Residential			
All-electric, single-family residence	10.3	1.219×10^5	GR15
Single-family residence w/electric kitchen	5.4	6.392×10^4	"
Single-family residence w/gas appliances	4.8	5.681×10^4	"
All-electric apartment	7.0	8.285×10^4	"
Apartment w/electric kitchen	4.4	5.208×10^4	"
Apartment w/gas appliances	4.0	4.734×10^4	"
Non-Residential - General Categories			
Office and professional buildings	34.2	4.048×10^5	"
Warehouses	14.4	1.704×10^5	"
Retail outlets	47.8	5.658×10^5	"
Restaurants and cocktail lounges	76.9	9.102×10^5	"
Hotel and motels	26.0	3.077×10^5	"
Service establishments	95.2	11.268×10^5	"
Elementary schools	23.1	2.734×10^5	"
High schools and colleges	38.8	4.592×10^5	"
Hospital and convalescent facilities	100.7	1.191×10^6	"
Churches	6.0	7.102×10^4	"
Theaters and recreation	32.5	3.847×10^5	"
Manufacturing/industrial	50.1	5.93×10^5	"

G5 ENERGY CONSUMED BY STRUCTURES (Continued)

NATURAL GAS CONSUMPTION

Type of Structure	Annual Energy Consumed per Dwelling Unit Btu/unit	Ref.
Residential		
Single-family residences	1.10×10^8	GR15
Multi-family, 4 or fewer units	6.40×10^7	"
Multi-family, 5 or more units	5.80×10^7	"
	Annual Energy Consumed per Area of Floor Space Btu/ft^2	
Non-Residential - General Categories		
Office	4.20×10^4	"
Shopping center	2.40×10^5	"
Hotel	6.00×10^5	"
Industrial	3.96×10^4	"

G6 ENERGY LEVELS BY LAND USE

Land Use	Annual Consumption(Btu/acre)	References
Agricultural	NA	
Industrial		
Chemical	1.37×10^{10}	GR16,17,*
Commercial	1.20×10^{9}	"
Light	3.40×10^{9}	"
Medium	8.70×10^{9}	"
Mining, processing	9.4×10^{9}	"
Paper	1.37×10^{10}	"
Residential		
High density	5.00×10^{8}	"
Planned mixed housing	6.0×10^{8}	"
Urban sprawls	8.0×10^{8}	"

*Indicates work done by authors to derive the factors

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G8 COMMENTARY

G1. TOTAL ENERGY OF SOME PETROLEUM PRODUCTS COMMONLY USED IN TRANSPORTATION

Approximately 10% of the oil consumed in the United States is expended to refine petroleum products used in transportation systems. This table lists estimates of the total energy equivalent for some of the more common transportation related petroleum products. It is the result of an extensive engineering analysis based on information from References 20, 21, 22 and 23 and updated to 1980 conditions using References 1 and 8.

The calorific energy is the heat energy which would be obtained if the fuel were directly burned. The refining energy is the energy necessary to make it available for use. The total energy is the equivalent amount of energy that must be expended for every unit of fuel consumed. The total energy value is the number that should be used when translating between fuel energy and "equivalent barrels of oil".

G2. PROPERTIES OF SELECTED FUELS

General Comments:

Data presented are estimates of the potential thermal energy available in each fuel if it were consumed with 100% efficiency. Some reported values of fuel energy vary by more than 15% between references. Refined fuels (gasoline, diesel) tend to have a more consistent energy value than unrefined fuels (coal, residual oil).

Wood

Potential thermal energy of wood as a fuel varies with species and moisture content. Values vary by more than 20% between references. The values reported in Table G-1 include the average calorific (thermal) energy and the production energy (harvesting, transport) of 1450 Btu/lb for softwood and 1530 Btu/lb of hardwood from Reference 13.

Table G-1. Properties of Selected Wood, Air Dry

Species	Density pcf	Density (kg/m^3)	Thermal Energy Btu/lb	Thermal Energy (joules/kg)
Birch	41	(657)	7500	(1.74×10^7)
Cherry	35	(561)	7900	(1.94×10^7)
Fir, douglas	32	(513)	N.A.	
Hickory	51	(817)	7600	(1.77×10^7)
Oak	46	(737)	7800	(1.81×10^7)
Pine	31	(497)	8100	(1.88×10^7)
Poplar	28	(449)	7700	(1.79×10^7)

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

Hardwoods are defined as broad-leafed species (without reference to the actual strength of the wood itself). Softwoods are defined as species having needle-like leaves. Resin Values are based on samples from pine trees.

G3. PROPERTIES OF SELECTED MATERIALS

General Comments:

A special effort was made to obtain accurate values for the energy equivalent of materials used in vehicle manufacture and in roadway construction. Many of these energy factors have been updated to 1980 conditions and therefore, are new numbers that have never been published. Also, an attempt has been made to determine what percentages of the manufacturing energy of each material was derived from premium fuels — petroleum and natural gas — since these energy sources are the ones in most critical demand (see DOT EIR requirements, Federal Register, December 1980). Both the energy equivalent and the percentage of that energy which is premium fuel derived are given in Table G-2 for materials for which the information was available. These values were used to develop some of the enerby values for vehicle manufacturing and construction items listed in Appendices C, E and F.

The energy necessary to manufacture an item can be broken down into three basic categories: 1) raw materials production from basic ores, 2) fabrication of the raw material into individual parts or components, and 3) assembly of the parts into the final product. In Section G3, the raw material and fabrication energies have been added for some of the more commonly used finished products.

Where these materials must be transported over very long distances after manufacture, the energy consumed in transportation of the manufactured products should be added to the base values.

Aggregates

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

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

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

Asphalts

There are two common methods used to determine the energy equivalent of asphalt. One is to assume that it is a construction material which is a by-product of the refining process, and as such should be given no energy value outside of the energy it takes to heat and distribute it (Reference 3). A second is to assume that it is a fuel and as such its full calorific (heating value) energy equivalent should be used. Unfortunately, asphalt contains such large amounts of sulfur and other mineral contaminates that its use as a fuel (as Residual or Bunker C fuel oil) is extremely limited.

The approach adopted in this report was to determine the next best use of the asphalt if it were not used as a construction material. Residual oil markets are already near saturation and have little capacity to absorb additional supply. Asphalt can be transformed into useful fuel products through the additional refinery operations of coking, cracking and desulfurization. This route has not been commonly used in the past due to the additional expenditure of time, money and energy, but it is quite possible with modern refineries.

For the purpose of this analysis, we took the base value of the calorific energy inherent in asphalt, subtracted out the material and energy losses of the above processing steps, and called the remainder the "equivalent asphalt energy". This is the net amount of energy produced if asphalt were refined into useful fuel products.

Cement-Portland

The energy value given was reported by the Portland Cement Association with updated energy efficiencies provided by U.S. Department of Energy. As an aid, the following table is presented:

Table G-2. Frequently Used Units of Cement

Ton	2000 lb	(907 kg)	= 6.88×10^6 Btu
Barrel	376 lb	(171 kg)	= 1.29×10^6 Btu
Sack	94 lb	(43 kg)	= 3.23×10^5 Btu

Iron

See comments for steel

Plastics

All plastics assume injection molding is used for primary fabrication.

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

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

Rubber

The values reported here are for the synthetic rubber, SBR (Styrene Butaline Rubber). The new tires are for a large passenger car with 2 lb of steel belts and 27 lb SBR. The recaps have 6 lb SBR added after buffing.

Steel

Reported values for the energy equivalent of steel range from 20,000,000 Btu/ton to over 100,000,000 Btu/ton. For the purpose of this report, we reanalyzed the steel industry using the methodology of Reference 9 upgraded to 1980 conditions using data from References 8 and 11. The methodology of Reference 9 was used because it presents the most detailed disaggregate process analysis where all assumptions and data sources are shown explicitly. Fabrication energies were taken from Appendix D of Reference 6, again updated to 1980 energy efficiencies using Reference 8.

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

Table G-3. Properties of Prestressing Steel

Type	Diameter in	(mm)	Weight lb/ft	(kg/m)
Strand	1/4	(6.4)	.122	(.182)
"	3/8	(9.5)	.274	(.408)
"	1/2	(12.7)	.494	(.735)
Bar	3/4	(19.1)	1.50	(2.23)
"	1	(25.4)	2.67	(3.97)
	1-1/4	(31.8)	4.17	(6.20)

G4. ENERGY PRODUCTION OF SELECTED NATURAL SYSTEMS

Data under Section G5. represent the mean production of various ecosystems. The range of values vary in general by a factor of ± 2 from the mean.

G5. ENERGY CONSUMED BY DWELLINGS

Data presented under Section G6. are based on a study by the City of Los Angeles, California.

Electricity consumption in kwh is measured at the point of consumption. Energy consumed at the power plant refers to the estimated total energy consumed by the utility system to produce and transmit electricity to the user and assumes 33% efficiency. The values given are in units of energy per surface area of the consumer structure.

Natural gas consumption is based on statistical quantities of cubic feet consumed and converted to thermal energy at the rate of 1000 Btu/cf.

G6. LAND USE ENERGY LEVELS

Data presented under Section G6. are estimates of the annual energy consumption of populated areas.

Industrial data are based on dollar costs of feedstock, plus all additional dollar costs to the industry for processing, plant operations, etc., to provide the final product.

Residential data are based on fuel and electricity consumed for utilities, HVAC, and transportation. Utility and HVAC values reflect the quantity of energy at the point of use, and not the primary energy input at the power plants. Transportation values provide only the direct (fuel) energy consumption by the region.

APPENDIX H

LIFE CYCLE COSTING

LIST OF FIGURES

LIST OF TABLES

Life Cycle Costing

Life cycle costing is an economic evaluation tool which enables the engineer to estimate the long run cost consequences of his design. It takes into account the most important costs and puts them on a common time basis by a technique called "discounting". By discounting costs over the useful life of a project into today's dollars, life cycle costing can be used to determine which energy conservation investments will be the most economic. Life cycle costing is particularly suited for the comparison of alternative projects, and for the selection of those projects that will provide the highest overall net return.

Economic analysis is an art rather than an exact science. Economic analyses are only as good as their underlying assumptions about future conditions. There are important factors which must be considered in any analysis. These include choosing a study period, estimating the life of assets, and dealing with the real worth of energy.

The Btu content of a barrel of oil is constant with respect to time. It will have the same number 20 years from now as it does today. But, as petroleum becomes more scarce, its value to society will certainly change. This change in value will be reflected in its price. Oil embargo or glut, these considerations for future predictions will have to be made by the engineer at the time of analysis for each individual project.

Considering the present value of the cash flow is the basis of life cycle costing. This procedure is often termed "engineering economics", "analysis of capital investment" or simply "time value of money". Whatever the name, life cycle costing analysis must include an interest cost of capital to reflect the worth of money over time. For cases of unequal or irregular cash flow, a change in the rate can materially affect the calculated difference between alternatives. The preferred practice in all analyses is to make the particular economic analysis with two or more rates.

The discount technique is generally used to express all costs in either of two ways. As "present value" as though they were all incurred today, or as "annual values" as though they were even annual payments spread out over the life of the project.

By either method, this time adjustment accounts for the real earning potential of capital and may also be used for inflation. Discounting is essential for making any realistic economic assessment when cash flows are spread over time.

A simplified example will be worked to show the basic economic concept. This example shows only the cost analysis for the energy related items. An in-depth analysis should show labor construction costs as well.

<u>Example</u>

Two alternatives are being considered for the construction of a one mile section of rural highway. The proposed project is a straight section of two-lane road on level land. The project is being evaluated between an AC and a PCC pavement. The project is being considered over a 40-year life.

Alternative 1

It is proposed to construct the road using an asphalt concrete pavement. The structural requirements are:

.45 ft asphalt concrete (AC)
.80 ft Class A cement treated base (CTB)
1.20 ft Class 2 aggregate subbase (AS)

Placement of the AC and AS consists of spreading and compacting. The placement of CTB consists of blade mixing, spreading and compacting.

It is assumed that the AC pavement will require periodic rejuvenation and overlays throughout its effective life. For this project, it is assumed that the AC will need rejuvenating (a seal coat) after the first 8 years and an AC overlay after the first 16 years. This maintenance schedule is assumed to be cyclic over the 40-year analysis period. In other words, a rejuvenating agent is expected to be applied in the 8th, 24th and 40th years, and a 0.4 foot thick AC overlay is called for in the 16th and 32nd years.

Alternative 2

It is proposed to construct the road using portland cement concrete. The structural requirements of the pavement are:

.75 ft portland cement concrete (PCC)
.45 ft Class A cement treated base (CTB)
.50 ft Class 2 aggregate subbase (AS)

The procedure for placing the AS and CTB is the same as that required for the AC pavement. Placement of PCC requires not only spreading, but joint sawing.

It is assumed that the PCC pavement will require grinding and grooving every 15 years. Five percent of the surface will require grinding and grooving the first time and 15 percent the second time.

An energy analysis was performed for both alternatives and the results are shown in Tables H-1 and H-2.

The total energy expended is 12.767×10^9 Btu per lane mile for the AC pavement and 7.591×10^9 Btu per lane mile for the PCC. In this particular case, the PCC pavement is less energy intensive than the AC pavement by 5.176×10^9 Btu or the equivalent of 892 barrels of oil over the 40-year analysis period. There is a temptation for many engineers to stop at this point in the selection process and if we were looking for just the energy consumption, it would be correct. But the cost-effectiveness of the two alternatives have not been examined. The dollar costs which will be incurred during the life of the project have yet to be considered.

The following is a simple illustration of how the cash flow from an energy conservation investment can be adjusted by the discounting technique to provide present value amounts. To perform the analysis, the discount and compounding factors listed in Table H-3 were used. Tables of factors for other rates are available in most engineering economic textbooks.

TABLE H-1

ENERGY CONSUMPTION OF AC PAVEMENT

	ENERGY, BTU/LANE-MILE			
	Production	Calorific	Placement	Total
Construction				
Subbase	$9.504x10^7$	0	$6.843x10^7$	$1.635x10^8$
Base	$115.317x10^7$	0	$6.387x10^7$	$12.170x10^8$
Asphalt Seal	$0.396x10^7$	$11.067.10^7$	$0.022x10^7$	$1.148x10^8$
AC	$71.717x10^7$	$318.336x10^7$	$3.673x10^7$	$39.373x10^8$
	$196.934x10^7$	$329.403x10^7$	$16.925x10^7$	$54.326x10^8$
Maintenance				
Rejuvenate	$1.188x10^7$	$33.201x10^7$	$0.066x10^7$	$3.445x10^8$
Overlay	$127.497x10^7$	$565.931x10^7$	$6.530x10^7$	$69.996x10^8$
	$128.685x10^7$	$599.132x10^7$	$6.596x10^7$	$73.441x10^8$
Total	$325.619x10^7$	$928.535x10^7$	$23.521x10^7$	$127.767x10^8$

TABLE H-2

ENERGY CONSUMPTION OF PCC PAVEMENT

	ENERGY, BTU/LANE-MILE			
	Production	Calorific	Placement	Total
Construction				
Subbase	$3.960x10^7$	0	$2.851x10^7$	$0.681x10^8$
Base	$64.866x10^7$	0	$3.593x10^7$	$6.846x10^8$
Asphalt Seal	$0.396x10^7$	$11.067.10^7$	$0.022x10^7$	$1.148x10^8$
PCC	$566.890x10^7$	0	$0.986x10^7$	$56.788x10^8$
Sawing Joint			$.150x10^7$	$0.015x10^8$
	$636.112x10^7$	$11.067x10^7$	$7.602x10^7$	$65.478x10^8$
Maintenance				
Grinding	$62.819x10^7$		$0.997x10^7$	$6.382x10^8$
Grooving	$39.262x10^7$		$1.246x10^7$	$4.051x10^8$
	$102.081x10^7$		$2.243x10^7$	$10.433x10^8$
Total	$738.193x10^7$	$11.067x10^7$	$9.845x10^7$	$75.911x10^8$

TABLE H-3

Interest Factors For One Dollar

Year	8% Compound Amount (Inflation)	10% Present Worth (Discount)
8	1.8509	.46651
15	3.1722	.23939
16	3.4259	.21763
24	6.3412	.10153
30	10.063	.05731
32	11.737	.04736
40	21.725	.02210

A time-line diagram for the cash flow of the project for both pavement alternatives is shown in Figure H-1.

For this example, it is assumed that energy prices will rise 3 percent faster than prices in general. Assuming a 5 percent inflation rate over the 40-year analysis period, the overall rate of price escalation for energy would be approximately 8 percent. A 10 percent discount rate for the value of capital overtime was arbitrarily selected, and the current price of a barrel of crude oil was placed at $30.

To obtain the dollar value for the energy consumed in the initial placement of the AC pavement, its energy value of 54.326×10^8 Btu was first divided by 5.8×10^6 Btu/barrel to obtain the number of barrels of oil required, and then multiplied by $30 per barrel.

$$\frac{54.326 \times 10^8 \text{ Btu}}{5.8 \times 10^6 \text{ Btu/barrel}} \times \$30/\text{barrel} = \$28{,}100$$

A similar procedure is followed for events in subsequent years except that the rate of inflation must be applied to the price of oil and the dollar value then converted to their present worth. To find the dollar value for the AC seal coat application in the eighth year, the energy value is converted to barrels of oil and the inflation and discount factor from Table H-3 applied.

TIME-LINE DIAGRAM

AC Pavement

	Initial Paving	Seal Coat	AC Overlay	Seal Coat	AC Overlay	Seal Coat
Years	0	8	16	24	32	40
Btu Expended	$54.326x10^8$	$1.148x10^8$	$34.998x10^8$	$1.148x10^8$	$34.998x10^8$	$1.148x10^8$
Present Worth	$28,100	$513	$13,497	$382	$10,062	$285
Total	$52,839					

PCC Pavement

	Initial Paving	Grind & Groove 15%	Grind & Groove 15%	
Years	0	15	30	40
Btu Expended	$65.478x10^8$	$2.608x10^8$	$7.824x10^8$	
Present Worth	$33,868	$1,024	$2,334	
Total	$37,226			

Figure H-1

$$\frac{1.148 \times 10^8 \text{ BTU}}{5.8 \times 10^6 \text{ BTU/barrel}} \times \$30\ (1.8509) \times (.46651) = \$513$$

The summation of all such events at their present worth yields the total life cycle cost of the project. In this case, the PCC pavement is shown to be the most cost-effective pavement by $15,613.

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APPENDIX I

TRANSPORTATION SYSTEM MANAGEMENT

LIST OF FIGURES

APPENDIX I

TRANSPORTATION SYSTEM MANAGEMENT

Transportation System Management (TSM) actions are strategies which generally encourage mode shifts, reduce travel demand or improve vehicular flow. These may involve items such as traffic operations, signal systems, ramp metering, one-way street, ridesharing, high occupancy vehicles, parking management, flexible work hours, park and ride, pricing actions and shuttle buses. This appendix provides an example analysis and references for assessing energy savings for TSM projects.

Recent energy shortfalls and increased cost of fuel has resulted in regulations placing greater emphasis on analysis of energy usage in the transportation planning process. Many TSM projects have the potential to save energy with low implementation costs.

The report titled "Energy Impacts of Transportation Systems Management Actions", (DOT-1-82-4), Final Report, October 1981, provides for easy to apply manual methods for estimating energy savings for various TSM strategies. These methods usually estimate only the direct energy. Fuel consumption factors and adjustments in this publication (Appendix C) are more recent than those shown in the DOT report.

The following example is based on DOT-1-82-4, but has been updated with Appendix C factors.

I-1 Freeway Ramp Metering

In cases where freeway segments experience severe peak hour congestion, metering of vehicles entering at ramp junctions has proven to be an effective strategy to improve average travel speeds (IR1). A review of the relationships between speed and volume shows that as the demand volume on a freeway segment increases, speed decreases (Figure I-1).

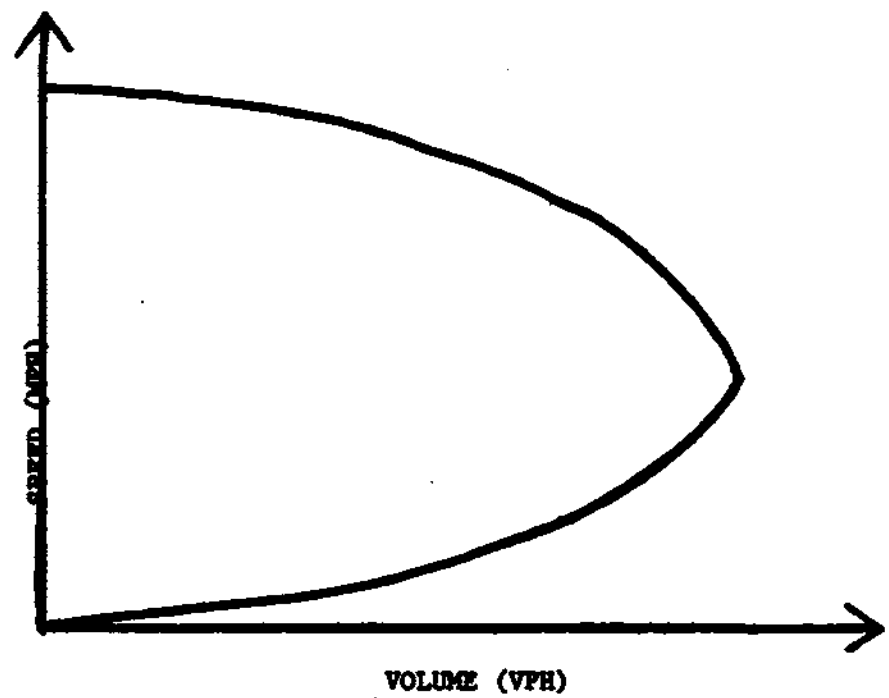

Figure I-1

Speed - Flow Relationship

Ramp metering attempts to control the volume on a segment so that an acceptable speed can be maintained.

Consider a two-lane freeway segment with a peak hour capacity of 4,000 vehicles per hour (one direction) and a single lane entrance ramp with a peak hour demand of 400 vehicles per hour. The peak hour demand upstream from the ramp is 3,600 vehicle per hour (Figure I-2). As a result, the volume-to-capacity ratio downstream from the ramp approaches 1.0 during peak hours.

Under such conditions, "Metering" of the entering ramp vehicles can reduce the volume to capacity ratio and improve the quality of flow along the segment.

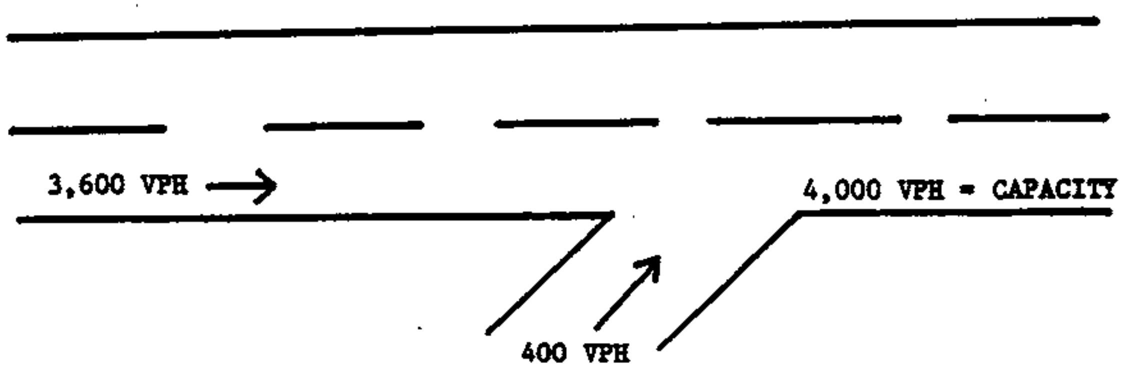

Figure I-2

Volume Determination of Freeway Ramp

Direct energy consumed by the traffic stream is a function of the volume, traffic mix, and vehicle speed. Normally, optimum fuel consumption occurs at a speed of 30-40 miles per hour for free flow conditions. However, typical freeway congestion involves numerous accelerations and decelerations which increases fuel consumption above free flow. The optimum fuel consumption for congested conditions occurs at approximately 50 miles per hour where traffic is moving at a steady pace but less than the speed limit.

Wagner (IR2) has summarized the results of ramp metering projects in several urban areas. Improvement in average travel speed during peak hours in the range of 14% to 27% has been observed when ramp metering is combined with computerized freeway surveillance (IR3).

Analysis of energy savings resulting from speed increases due to ramp metering can become very complex.

Generally, such projects are implemented in very heavily congested travel corridors which include a number of ramp junctions. Computer programs such as FREQ6PE have been developed to aid in such analysis (IR4).

Ramp metering is usually a part of a comprehensive freeway surveillance and control system designed to meet the local needs of a specific corridor. Therefore, manual analysis methods may not be appropriate because of the complexity of such a system. A simplified method for analysis of a single ramp has been developed to demonstrate the principles of such analysis. An example is included to illustrate the application of the energy factors contained in this handbook. It does not include the energy effect of queuing on the ramps or congestion on paralleling city streets and therefore would not be applicable for a comprehensive analysis.

ENERGY ANALYSIS WORKSHEET

RAMP METERING

****

BASE DATA

	DEMAND AM + PM PEAK		SEGMENT LENGTH(MI)		EFFECTED VMT
AUTO	6600	X	6	=	39600
M.TRUCK	600	X	6	=	3600
H.TRUCK	200	X	6	=	1200

	SPEED(MPH)
BASE	35
REVISED	45

FUEL CONSUMPTION SAVED

	CHANGE IN FCR (TABLE C:4)		FUEL ADJ. FACTOR (TABLES C:5'S)		EFFECTED VMT		ENERGY SAVINGS (IN GALLONS)
AUTO	3.8/1000	X	0.960	X	39600	=	144
M.TRUCK	15.6/1000	X	0.970	X	3600	=	54
H.TRUCK	13.3/1000	X	0.987	X	1200	=	16

DAILY ENERGY SAVING	214

	WORKING DAYS PER YEAR				GALLONS
YEARLY ENERGY SAVING	250	X	214	=	53500

Instructions for Worksheet

Step 1: Identify the analysis period which will be impacted by the project. Normally a.m. peak and p.m. peak hour traffic will be included.

Step 2: Identify the length of the segment in miles.

Step 3: Identify the total peak-hour demand for the analysis period for autos, medium trucks and heavy trucks.

Step 4: Identify base average speed for the analysis period.

Step 5: Estimate the improvement in average speed that results from ramp metering; literature indicates that this improvement may range for 10% to 30% (2).

Step 6: With the base average speed and the revised speed enter Table C:4 (page C-23) to find corresponding fuel consumption rates in gallons per mile. Subtract the revised rate from the base to find the difference. This value is the number of gallons conserved per thousand miles.

Step 7: Multiply Step 2 x Step 3 x the number of analysis periods, i.e., peak hours per day, x Step 6 to find the unadjusted daily fuel consumption, in gallons.

Step 8: From Table C:5 (pages C-24,25,26), find fuel adjustment factor for analysis year.

Step 9: Multiply Step 7 x Step 8 x 250 to find yearly energy savings in gallons for each vehicle class.

Step 10: Total yearly energy saving obtained by adding all energies saved by all vehicle classes.

Example

Given: A two-lane urban freeway 6 miles long, two peak hour periods with speed and volume information outlined below:

		Peak Hour Volume (VPH)		Average Peak Hour Speed (MPH)	
Before Ramp Metering		a.m.	p.m.	a.m.	p.m.
	Auto	3300	3300	35	35
	Med Truck	300	300	35	35
	Hvy Truck	100	100	35	35
After Ramp Metering					
	Auto	3300	3300	45	45
	Med Truck	300	300	45	45
	Hvy Truck	100	100	45	45

Find: 1981 Energy savings resulting from ramp metering project which results in an increase of 29% in the average speed.

Results and Limitations

After applying the worksheet, it is found that the ramp metering project results in an annual savings of 53,500 gallons of fuel.

The simplified method outlined below represents only a cursory analysis of energy savings associated with ramp metering. For a more complete discussion of analysis methods, consult the literature (IR1).

References

IR1. Traffic Control Systems Handbook, prepared for FHWA, U.S. Department of Transportation, Washington, D.C., June 1976.

IR2. Wagner, Frederick A., Traffic Control System Improvements - Impacts and Costs, prepared for FHWA, U.S. Department of Transportation, Washington, D.C., March 1980.

IR3. Claffey, Paul, "Running Costs of Motor Vehicles as Affected by Road Design and Traffic," NCHRP Report 111, Highway Research Board, Washington, D.C., 1971.

IR4. Jovanis, Paul P., A.D. May, and Waiki Yip, FREO6PE - A Freeway Priority Entry Control Simulation Model, Research Report No. 78-8, Institute of Transportation Studies, University of California, Berkeley, 1978.

APPENDIX J

HIGHWAY ENERGY ANALYSIS PROGRAM
VERSION 2.1

APPENDIX J

Highway Energy Analysis Program
Version 2.1

The Highway Energy Analysis Program (HEAP) is a computer model that will determine the total energy consumption for different roadway alternates. It calculates the direct and indirect energy due to traffic and the indirect energy associated with roadway maintenance and construction. It is based on the data and methodologies presented in the 1985 version of "Energy and Transportation Systems."

WHAT IT DOES DO

- HEAP will analyze the energy consumed for a project with up to six alternates each with up to 30 roadway segments (links), with each link having up to eight different traffic conditions.

- HEAP will determine the energy consumption for any analysis time span between the years 1980 and 2005.

- HEAP will allow the input of different levels of traffic information - from a very detailed speed tacograph to generalized alternate-wide VMT figures.

- HEAP will allow the input of traffic volumes at both the beginning year and end year of the analysis period. Traffic volumes for other years are interpolated from these values.

- HEAP will determine the direct energy consumption for four different vehicle types: Light Duty Vehicles (LDV), Medium Trucks (MT), Heavy Trucks (HT) and Buses. The first three vehicle types are handled in a similar fashion, having the same options of adjusting fuel consumption due to grade, curvature, stops, slowdowns, idle time, congestion and/or other miscellaneous factors. Buses are handled completely independently due to the different sources of fuel consumption data available to them.

- HEAP will determine the indirect energy due to vehicle depreciation, maintenance and repair, tire wear, and oil consumption for LDVs, MTs and HTs. HEAP will also adjust these indirect energy factors for pavement deterioration or improvement if it is explicitly input. Bus indirect energy is also calculated.

- HEAP determines the indirect energy due to construction based on the dollar cost and the type of construction.

- HEAP determines the indirect roadway maintenance energy based on the total lane miles and type of pavement.

- HEAP has the capability to determine the energy consumption for off-project VMT. This feature may be useful in attempting to equalize the level of service and provide a common basis of comparison for project alternates with different mainline capacities.

- HEAP will allow the input of a fuel correction factor. This can be used to adjust roadway links for circuity or for such things as cold start fuel corrections.

- HEAP can calculate the energy efficiency for TSM options on a Btu per vehicle mile basis, or a Btu per passenger mile basis if load factors are specified.

- HEAP is menu driven to allow ease of operation

- HEAP has provisions for easily performing a sensitivity analysis of vehicle-related parameters.

- HEAP calculates a number of "Measures of Effectiveness" (MOE) for each alternate, which may be used as desision criteria.

- HEAP will output a variety of printouts, depending on user need.

<u>WHAT HEAP DOES NOT DO</u>

- HEAP does not predict traffic patterns, nor analyze them for validity. It will accept virtually any traffic condition no matter how ridiculous (example: it will take a 1,000,000 ADT of Heavy Trucks on a two-lane road in the peak hour period).

- HEAP does not determine the additional pavement maintenance energy as it deteriorates with time. If a pavement must be resurfaced, this should be input as a separate construction cost.

APPENDIX K

UPDATED TABLES

Fuel Correction Factors

(Tables C:5:1-3, Energy and Transportation Systems)

Year	Light Duty Vehicles	Medium Trucks	Heavy Trucks
1980	1	1	1
1981	.960	.970	.987
1982	.920	.937	.974
1983	.874	.901	.956
1984	.825	.864	.935
1985	.779	.829	.913
1986	.791	.734	.834
1987	.761	.721	.808
1988	.742	.715	.795
1989	.727	.703	.783
1990	.712	.691	.772
1991	.701	.679	.760
1992	.691	.663	.749
1993	.685	.658	.739
1994	.685	.663	.728
1995	.675	.647	.718
1996	.669	.632	.718
1997	.659	..623	.708
1998	.653	.613	.699
1999	.647	.604	.689
2000	.641	.596	.689
2001	.639	.587	.680
2002	.633	.583	.671
2003	.630	.579	.671
2004	.627	.575	.671
2005	.627	.571	.663
2006	.625	.571	.663
2007	.622	.567	.633
2008	.622	.567	.633
2009	.619	.563	.633
2010	.619	.563	.633
2011	.616	.559	.654
2012	.616	.559	.654
2013	.614	.555	.654
2014	.614	.555	.654
2015	.611	.552	.654

Correction factors are determined from the on road fleet mpg as predicted by The Motor Fuel Consumption Model (Fourteenth Periodical Report, Dec. 12, 1988), prepared by Energy and Environmental Analysis, Inc. for the U.S. Department of Energy.

Highway Construction Price Index

(Tables C:21, Energy and Transportation Systems)

Year	Index
1973	0.56
1974	0.83
1975	0.99
1976	0.86
1977	1.00
1978	1.14
1979	1.46
1980	1.54
1981	1.76
1982	1.55
1983	1.59
1984	1.84
1985	1.83
1986	1.85
1987	1.92
1988	1.96
1989	2.08

Data obtained from *Summary: Price Index For Selected Highway Construction Items*, 1st Quarter 1990, California Department of Transportation, Office of Office Engineers, Sacramento, CA.