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U.S. Energy Conversion and -Use Characteristics

C. H. Imhoff
A. Liberman
W. B. Ashton

February 1982

Prepared for the U.S. Department of Energy
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Pacific Northwest Laboratory
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Pacific Northwest Laboratory
Richland, Washington 99352

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PREFACE

A current and reliable source of information on energy consumption patterns and characteristics is a fundamental requirement for effective R&D planning in advanced energy technology programs. This document is the initial version of a program planning handbook that summarizes certain key data regarding U.S. energy conversion and use. It is intended as just such a source document. The most current data regarding energy conversion processes (consumption, losses, efficiencies, capital stocks) have been assembled here to make diverse and sometimes inaccessible information more readily available to energy conversion and use R&D managers and planners.

Current plans call for the document to be updated and revised from time to time as new and better data become available. Accordingly, users of the handbook are encouraged to submit requests, information, or comments to the Pacific Northwest Laboratory to enhance the usefulness of future editions.

This study was completed for the Division of Energy Conversion and Utilization Technologies (ECUT) in the Department of Energy (DOE). The division's mission is to identify and research long-range technology concepts that are attractive for more efficient energy use. To meet its goals, the ECUT staff has established a planning and systems analysis project that was responsible for conducting this study.

This report is one of a series of studies in support of the ECUT research planning effort. Other documents in the series contain assessments of energy conservation technology areas, methods to appraise research projects for support, and data reference sources. Publications from this project include:

Hopp, W. et al. 1981. An Overview of Energy Conservation Research Opportunities. PNL-3944, Pacific Northwest Laboratory, Richland, Washington.

Hopp, W. et al. 1981. Identification of Energy Conservation Research Opportunities: A Review and Synthesis of the Literature. PNL-3966, Pacific Northwest Laboratory, Richland, Washington.

Hopp, W. et al. 1981. Identification of Energy Conservation Research Opportunities - Executive Summary. PNL-3966Ex. Sum., Pacific Northwest Laboratory, Richland, Washington.

Imhoff, C. H. et al. 1982. U.S. Energy Conversion and Use Characteristics.
PNL-4075, Pacific Northwest Laboratory, Richland, Washington.

U.S. Department of Energy. 1981. The 1981 Work Element Appraisal.
DOE/CE-0024, U.S. Department of Energy, Washington, D.C.

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SECTION 1.0

INTRODUCTION

SECTION 1.0

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1.0 INTRODUCTION

The long-range goal of the Energy Conversion and Utilization Technology (ECUT) Program is to enhance energy productivity in all energy-use sectors by supporting research on improved efficiency and fuel switching capability in the conversion and utilization of energy. This program charter is quite timely; it has been introduced when public interest in the potential of improved energy productivity is growing rapidly. A key issue of improved energy productivity analysis is the need to achieve a clear understanding of both past and present energy use. Lucid descriptions of U.S. energy consumption, inventories, and replacement rates of important energy-using devices and processes are vital to effective energy research decision making. Unfortunately, energy-use information is often of uncertain quality; some data are relatively accurate, whereas other data are, at best, a good guess (Hirst 1980).

Regardless of the deficiencies of current information, a summary of the best available energy-use information is needed now to support current ECUT program planning. This document is the initial draft of this type of summary and serves as a data book that will present current and periodically updated descriptions of the following aspects of energy use:

- gross U.S. energy consumption in each major energy-use sector
- energy consumption by fuel type in each sector
- energy efficiency of major equipment/processes
- inventories, replacement rates, and use patterns for major energy-using capital stocks.

These data will help the ECUT program staff perform two vital planning functions:

- determine areas in which research to improve energy productivity might provide significant energy savings or fuel switching
- estimate the actual effect that specific research projects may have on energy productivity and conservation.

These functions are important because the ECUT program is responsible for establishing the general directions of a major, long-term research program and for initiating specific research projects that will eventually fulfill the program goals.

The first function essentially identifies significant areas of energy demand where more detailed investigation might be warranted. Such target areas characteristically consume either significant quantities of energy or large proportions of specific strategic fuels, such as oil. Therefore, recent, accurate information describing consumption in each sector by quantity and fuel type must be compiled to help identify target areas. Figure 1.1 is a sample of the required information. The figure displays oil use in the manufacturing, transportation, and residential/commercial sectors and highlights, for example, autos and trucks as major targets for improving current energy use because they account for both a large share of the total U.S. consumption (about 20%) and more oil consumption than any other end uses. Identifying these key target areas for energy conservation provides the foundation to further ECUT planning and leads to the second task of evaluating how energy productivity in these various target areas may be improved.

The second function deals with the need to establish an annual research activity budget. Clearly, estimates of the possible fuel savings and the potential for fuel switching will be important criteria in defining an ECUT research and development budget based on project benefits. Accurate, consistent estimates of current and future energy use for each ECUT research project will be needed to use these criteria to establish program funding priorities. Fuel consumption data alone are incapable of completely quantifying these measures. Additional data that are useful for estimating the future market penetration of the improved technology will be needed to predict how each project will affect future energy demand. These estimates require a knowledge of present equipment inventories, sales, scrappage rates, and use pattern descriptions. Because current and newly proposed projects will be evaluated each year and both energy supply and demand in the U.S are changing rapidly, the descriptions of energy use must be updated each year. However, the necessary information is currently published in numerous, disparate sources, none

FIGURE 1.1. Estimated End-Use Consumption of Oil, 1978

of which are compiled to allow examination of the specific areas of the ECUT program. Because of these problems, the ECUT staff has difficulty obtaining a clear understanding of current energy use.

In summary, this book is a compilation of the major types of information that are essential to the yearly ECUT planning and evaluation activities. The goal is to provide within a single document the best available energy-use information that is relevant to the ECUT Program. A simple, consistent format is used to insure easy reference by the ECUT program staff.

1.1 STATUS OF CURRENT ENERGY-USE EVALUATION

During the last eight years, U.S. energy consumption has ranged from 74.6 quads to slightly under 79.0 quads. Repeatedly, policy makers have asked how much of the nation's energy consumption is essential and how much is waste. The response has varied considerably among the various studies and reports that have estimated the potential for conservation. This variance stems from the lack of a universally accepted measure of the potential for improving energy productivity and the difficulty of quantifying the conservation potential accurately to enable valid comparisons of alternate policy and/or research options.

The major obstacle to measuring the potential for improved energy productivity is the lack of accurate, detailed energy-use information. To effectively evaluate conservation potential, decision makers need information that clearly describes U.S. energy consumption and accurately highlights uses that offer significant potential for improved energy productivity. Eric Hirst (1980) has classified the major issues of energy productivity and conservation analysis that require accurate energy use data:

- current status of energy use in the major economic sectors (industry, transportation, and residential/commercial), including statistics on energy-using capital stocks (equipment, appliances, processes, etc.)
- expected changes over time in energy use and capital stocks

- determinants of changes in energy use, such as fuel prices, GNP, government and utility conservation programs, fuel availability, etc.

Data describing the first issue, the current status of energy use, are currently easier to obtain than data forecasting expected changes in energy use. Data for the third issue, determinants of energy use, are the most difficult to obtain because they depend upon accurate descriptions of both current energy use and expected changes. Most current energy-use information describes present trends because it is the easiest type to collect and because most productivity and conservation analyses examine current use first. However, the analyses encounter serious problems even in this first step.

First, accurate evaluation of current energy use requires access to very disaggregated information describing energy use by fuel type, end use, process, etc. Unfortunately, accurate, recent information in such detail is rarely available. Table 1.1 is an example of the best information presently available in the residential/commercial sector. Although it appears to be fairly comprehensive, much of the data are based on analyses of anecdotal information and reconciliations of estimates of energy-use totals.

A second problem with assessing current energy use is that inconsistent formats and definitions of end uses in various data bases also add to the uncertainty of using current energy-use information. Oil consumption in the residential/commercial sector is a typical example; the U.S. Bureau of Mines estimates of oil consumption for 1950-1976 include the use of asphalt for the residential/commercial sector, yet present analyses include it elsewhere. Industrial information is another example; some data bases add agricultural consumption to industrial consumption, whereas others do not. These problems cause serious inconsistencies in aggregate energy analyses and exemplify the barriers to assessing even current energy-use patterns.

Investigations of trends and determinants of energy use have been directly affected by this uncertain quality and general lack of detailed, disaggregated data, forcing analyses of these topics to focus primarily on the aggregated

TABLE 1.1. Residential/Commercial Energy Consumption by Sector, Fuel Type, and End Use, 1977 (10¹⁵ Btus)

	<u>Electricity^(a)</u>	<u>Gas</u>	<u>Oil</u>	<u>Other</u>	<u>Total</u>
<u>Residential</u>					
Space heaters	1.25	3.64	2.26	0.54	7.69
Water heaters	1.17	0.87	0.14	0.08	2.26
Refrigerators	1.49				1.49
Freezers	0.64				0.65
Ranges/ovens	0.52	0.31			0.83
Air conditioners	1.10				1.10
Lights	0.96				0.96
Other	0.68	0.48			1.15
TOTAL	7.81	5.30	2.40	0.62	16.12
<u>Commercial</u>					
Space heaters	0.37	1.94	1.90	0.35	4.56
Air conditioners	2.03	0.16			2.19
Water heaters	0.04	0.09	0.10		0.23
Lights	2.23				2.33
Other	40.85	0.20			1.05
TOTAL	5.62	2.39	2.00	0.35	10.36

(a) Electricity is reported as primary energy (11,500 Btu/kWh).

Source: Oak Ridge National Laboratory 1979.

aspects of energy use. This problem appears to have influenced major conservation analyses. Typically, these reports have examined only several general energy issues, have evaluated a single major end-use area at an aggregate level, or have examined a well-defined process that performs a very specific function. The best contemporary studies of general energy productivity and conservation potential have concentrated primarily on space conditioning in buildings, passenger automobile efficiency, industrial cogeneration, and various integrated community energy systems. Numerous analyses of conservation

potential in particular technologies, such as petroleum refining and industrial boilers, have also been performed. However, combining the conclusions of these studies to obtain a general overview of the potential for productivity improvement and conservation is virtually impossible due to the disparate nature of both the criteria used to define and the data used to measure conservation potential. These problems hinder the identification of particular segments of the economy that show the greatest promise for improved energy productivity and conservation.

These deficiencies in energy-use information are being addressed, and more accurate data will be available in the future. However, to support present ECUT activities, the best current information must be identified and compiled in a consistent, easy-to-use summary.

1.2 ECUT PLANNING INFORMATION REQUIREMENTS

The ECUT program has two main objectives:

- improve the technology base used by industry to develop high-efficiency energy conversion and utilization equipment
- evaluate new or innovative concepts for improved efficiency or alternate fuel use in energy conversion and utilization equipment.

Three of the current ECUT planning activities designed to meet these objectives have a clear need for a common information base that describes current energy use. First, the ECUT program staff must monitor current trends in consumption, process efficiencies, sales demand for new technologies, and many other aspects of general energy use. This information is found in many disparate publications, printed by various sources. Thus, a summary reference document, routinely updated and compiled in a simple format, would simplify the task of obtaining current information that relates to ECUT programs.

The yearly appraisal of proposed research is the second activity that requires a common base of energy-use information. Questions of potential fuel savings, fuel switching capability, and market penetration require accurate, disaggregated data on gross consumption, fuel type used, average efficiency of equipment, as well as number of units currently being used and replaced.

The third major activity is the assessment of research needs in areas excluded from current research programs. Again, accurate energy-use data are essential to identifying end uses that offer the greatest potential for improved energy productivity and conservation. Technical experts can then concentrate on these areas and recommend specific research activities for further funding.

Descriptions of the data sources and examples of the uses of the different types of data are provided in Section 2. The energy-use information is presented in the last four sections; Section 3 contains general, national consumption data; and Sections 4 through 6 contain residential/ commercial, industrial, and transportation consumption data, respectively. In each section the information describes the following:

- gross fuel consumption
- consumption of specific fuel types
- efficiency of energy-using processes and equipment
- capital stock characteristics, including inventories, replacement rates, and use patterns.

SECTION 2.0

METHODOLOGY FOR USING THE DATA BOOK

SECTION 2.0

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2.0 METHODOLOGY FOR USING THE DATA BOOK

In this data book assessments of the potential for improving energy productivity and conservation will take place at two general levels of ECUT activities. First, general U.S. energy consumption will be examined to identify significant areas of energy use where technology research may be warranted. The second level of analysis will examine these target areas more closely to identify and choose specific research programs. At this more detailed level the benefits of the proposed energy productivity improvement and conservation research will be estimated to facilitate the project ranking, thus insuring that the research activities are in accord with the ECUT program objectives. In this chapter the energy-use information within this document is described and ways in which this information can support these different ECUT program activities is explained, both in identifying target research areas and in choosing and evaluating specific research programs.

2.1 QUANTIFYING CONSERVATION POTENTIAL

In spite of the deficiencies of present energy-use information and the problems of quantifying conservation potential, the potential benefits of the proposed research projects must be estimated to justify the overall program. These judgments are based on many criteria, although two are most prominent in energy conservation analysis and warrant a brief discussion.

The terms "energy conservation" and "energy-productivity improvement" are closely related. Improving energy productivity means obtaining more service from a given amount of energy, and thus requiring an improvement in the effectiveness with which the energy is used. This improved effectiveness implies that energy will be conserved, assuming that the consumer demand for that service increases more slowly than the rate of efficiency improvement. This impact of consumer demand and technology on energy demand can be viewed according to the following definition of energy use, called the "principle of factorization."

$$\text{energy use} = (\text{energy intensity}) \times (\text{level of activity}).$$

For example,

$$\text{litres used} = (\text{litres/km})(\text{km traveled})$$

This concept separates the problem of energy productivity and conservation into two areas:

- the need to improve the technologies used to convert and use energy or fuels (reduce energy intensity)
- the importance of understanding and/or changing the demand for specific activities that use energy (reduce level of activity).

Successful research and development in these areas are normally measured by two major criteria:

- actual energy savings
- savings of a critical fuel (such as oil).

The near-term ECUT program goals emphasize decreasing the energy intensity of U.S. energy use. The following discussion explains how the ECUT staff, using the criteria of fuel savings and fuel switching, may use this data book to estimate the current, potential program benefits. First, however, a brief introduction to current analysis of energy efficiency is presented to define the types of data typically used in these analyses.

Measuring Energy Efficiency

The energy intensity of a task or service is the amount of energy required to perform a unit amount of that task. For example, the energy intensity of personal transport would be measured in gallons per mile traveled (the more familiar quantity of energy efficiency, miles per gallon, is simply the inverse of energy intensity). Traditionally, equipment or process efficiency has been measured as the ratio of:

$$\frac{\text{the energy transferred as the function of the system}}{\text{the total energy required by the system,}}$$

or more simply

$$\frac{\text{energy out of the device}}{\text{energy into the device.}}$$

This measure, called the "first-law efficiency," is based upon the first law of thermodynamics, which assumes that energy is neither created nor destroyed. The utility of the first-law efficiency is limited to comparing systems that provide the same useful function. However, it fails to describe some important aspects of energy use. For example, warm air furnaces are typically rated at about 60% efficiency, meaning that 60% of the energy consumed will be delivered as heat to the rooms. However, this efficiency measure implies that 100% efficiency is the best possible performance; this is misleading. Heat pumps also provide space heat, yet they achieve efficiencies much higher than 100% because they move heat from the outside into the home rather than producing it by combustion.^(a)

Unfortunately, the first-law efficiency also fails to indicate the potential for improved energy productivity. It fails to provide insight to two important factors:

- What is the theoretical limit to improving the effectiveness with which a system uses energy to perform a function?
- Is the quality of the energy well matched to the quality required to perform the task?

These factors have a significant influence upon fuel savings both by reducing the quantity of energy used and by insuring that high-quality energy is not used when low-quality heat is sufficient.^(b) Because generating a unit of low-quality energy requires less energy than generating a unit of high-quality heat, achieving a better match between the quality of energy and the task could produce significant fuel savings. The general conclusion is that energy quality is an integral part of energy-use analysis because the U.S. energy

(a) Heat pumps are rated by a COP, defined as the ratio of the amount of heat delivered to the energy used to effect that delivery. This ratio is typically between 1.5 and 2.5.

(b) The quality of a unit of energy is high when a large fraction of that energy can be transformed into useful work. For example, one Btu of natural gas is capable of performing one-fourth the useful work of one Btu of electricity, thus it is a lower quality energy source. Another example is thermal energy; one Btu at the heat of combustion is capable of performing more useful work than a Btu at room temperature.

economy flagrantly misuses high-quality energy sources (such as electricity and high-temperature thermal energy) to perform low-temperature applications.

The second law of thermodynamics is now being applied in conservation assessments because it addresses the concept of energy quality. The following measure, called the second-law efficiency, has been proposed because it accounts for both the quantity and quality of energy, in addition to describing the theoretical limit to improving the efficiency of the activity:

$$\frac{\text{theoretical minimum fuel required to perform a task}}{\text{actual fuel used to perform a task}}$$

The differences between first- and second-law analysis are summarized in Table 2.1.

Understanding the effectiveness with which equipment and/or processes use energy is clearly vital to understanding and evaluating the potential for energy productivity improvement and conservation. Current energy consumption, appropriateness of the fuel quality, and the theoretical potential for efficiency improvement all provide information that is important to the ECUT program and all help to define both the extreme limits and the practical levels of potential future technology improvement. First-law efficiencies will also continue to be important because the concept is useful for comparing similar technologies and is well understood by the general public. Therefore, when available, first and/or second-law efficiencies are listed in the data book for different processes and types of equipment in each end-use sector.

2.2 DATA DESCRIPTION

The information compiled in this document was chosen to meet the information requirements of the major ECUT Program activities:

- monitor current energy use
- appraise proposed ECUT research projects
- assess research and development needs.

TABLE 2.1. Typical Indicators of Second-Law Performance in Thermodynamic Processes

Characteristics	1st Law Efficiency	2nd Law Efficiency
	$\frac{\text{Useful Output}}{\text{Useful Input}}$	$\frac{\text{Availability Required}}{\text{Availability Used}}$
1. Accounts for energy use	Yes	Yes
2. Measures energy quality	No	Yes
3. Identifies thermodynamic limit of energy efficiency	No	Yes
4. Is useful for evaluating a variety of energy systems	Yes, but is misleading when efficiencies are greater than 1	Yes, efficiency is always less than 1.
5. Is commonly used and easily understood	Yes	No

Source: Hevert et al. 1980.

The requirements of each activity will be summarized and the related data will be described. Finally, a generic summary of the data will be presented, highlighting both the quality of the included data and the important gaps in the data.

Monitoring Energy-Use Changes

Understanding current U.S. energy use is a formidable task. Because contemporary energy-use patterns are complex and present energy-use data are uncertain and disparate, the ECUT program staff has difficulty keeping abreast of current energy-use trends. This document can assist staff activities in the following ways:

- inform staff of current trends in energy use
- highlight target areas of important energy use
- track the current status of available energy-use information
- identify gaps in energy-use information.

Current energy-use data are presented in different levels of detail. Aggregate national consumption by fuel type in the residential/commercial, industrial, and transportation sectors is presented in graphic form in the General Energy Consumption section (see Figure 2.1) to highlight general energy flows. This information is followed by figures that display energy use in important end-use areas (see Figure 2.2). These figures clearly reveal both significant areas of energy consumption and end uses that use a large share of a specific fuel type. For example, Figure 2.2 clearly displays the significance of residential/commercial space heating compared to all other major end uses. Figures displaying the consumption of specific fuels in the major end-uses are also included. For example, Figure 2.3 displays natural gas consumption and highlights the major role of natural gas in space heating.

If more detailed information is desired, the user may turn to the chapter dedicated to the sector being evaluated and find the following information:

- general consumption by fuel type
- details of significant energy-using equipment and processes
- general characteristics of typical energy losses
- efficiencies of major equipment
- inventories and profiles of use for major capital stocks.

This simple access to energy-use information at different levels of detail allows a user to first identify general areas of interest and then to examine in more detail any or all of the desired types of information mentioned above.

Project Appraisal

The project appraisal process requires consistent data to quantify the criteria being used to judge research programs. Fuel switching and the potential for energy savings will obviously be important criteria; both also are inextricably related to estimates of market penetration potential.

Estimating the potential fuel savings of a project can be done in several ways. If the current efficiency and gross consumption data of a specific function are obtained from this book and the improvement will affect a known proportion of that total consumption, then the expected efficiency improvement

CONSUMPTION BY END-USE SECTOR

CONSUMPTION BY FUEL TYPE

FIGURE 2.1. 1979 U.S. Energy Consumption (DOE 1980a)
10¹⁵ Btus and Percent of Total

is sufficient for estimating the fuel savings. For example, if an automotive improvement is being evaluated, the user could obtain the following from the transportation section:

- vehicle miles traveled (VMT) yearly
- total consumption of gasoline by that type of vehicle.

FIGURE 2.2. Estimated National End-Use Energy Consumption, 1978

The estimated current average vehicle efficiency would be:

$$\frac{\text{yearly vehicle miles traveled}}{\text{total annual gasoline consumption}}$$

Estimated fuel savings would be:

$$\text{Current Consumption} - \left(\frac{1}{\left(\frac{\text{Current efficiency}}{\text{1 + expected \% improvement}} \right)} \times \text{Yearly VMT} \right)$$

FIGURE 2.3. Estimated End-Use Consumption of Natural Gas, 1978

The other methods of estimating potential fuel savings of a project depend upon the market penetration potential. Unfortunately, market penetration potential is difficult to estimate. However, data describing auto sales, vehicle scrappage rates, and characteristics of vehicle use and ownership are included because they improve the users' ability to estimate these figures. For example, the vehicle sales figures and the fleet fuel efficiency estimates found in the transportation section could then be used to estimate fuel savings. Thus, if an improvement would need to be installed when the automobile was built, sales figures would define the upper limit of the market penetration potential.

Estimates of fuel switching potential require information that describes the consumption of a specific fuel by a process and estimates the fraction of that process or service that will be satisfied by the new, substitute fuel. Data on the age of current stock, scrappage rates, and sales of new stock, taken from the appropriate section, can be combined with the description of current consumption by fuel type to provide an estimate of current fuel switching potential.

Because the ECUT program is pursuing mid- and long-term energy research, most projects will not produce measurable benefits for many years. Therefore, program justification requires that future benefits also be estimated, which requires information that describes future energy use. This document contains no such estimates yet; hopefully they can be included in forthcoming updates.

Identifying New Research and Development Opportunities

Assessing research and development needs is the final activity that requires energy-use information. This assessment requires an understanding of energy use and identification of target research areas. The next stage involves a more thorough examination of each target. At that stage the current state of the technology must be fully understood so that the potential for improvement can be evaluated. The energy efficiency data in this book support this task by describing both the current efficiency and, where the second-law efficiencies have been estimated, the limits to improvements of efficiency. Both indicate whether significant improvements are feasible. Also, the information describing energy losses in the target area can reveal

generic problems that require further research or can indicate certain aspects of a service that might be provided by a different technology or a fuel of more appropriate quality.

2.3 ASSESSING DATA QUALITY

A final and important part of this effort is the evaluation of the quality of the current data needed by the ECUT program. Figures 2.4, 2.5, 2.6, and 2.7 are schematic representations of the data that were included in this edition. In each figure the age of the data is indicated and the apparent quality of the data is classified. The quality estimates were based on a broad survey of available energy information.

Each element of information in the diagrams is preceded by numbers in the following form:

data quality code, date

For example, the notation "1, 1978" implies that the information is recent and generally accepted and represents consumption in 1978.

Six data quality codes are used:

- 1 = Information is recent and probably representative of present trends.
- 2 = Information is not very recent yet is the best available and/or is sufficiently representative of present trends.
- 3 = Information may be dated and/or of questionable quality: timely improvement is conceivable and is being pursued.
- 4 = Information may be dated and/or of questionable quality; improvement is presently infeasible.
- 5 = Information is absent from the report; availability is being examined.
- 6 = Information is absent from the report; probably unavailable for now.

FIGURE 2.4. National Energy-Use Data Quality

General Consumption	Building Heat Loss and Gain	Efficiencies of Household Energy Systems	Equipment Stocks	Building Stocks
1,1979 gross consumption by: • fuel type • end-use	1,1977 air infiltration 3,1978 solar gain	1,1977 gas & oil furnace performance	1,1978 primary heating equipment	1,1978 residential housing inventory by: • type • size • year of construction
2,1976 significant uses: • space heat • water heat 3,1975 • appliances	5 occupancy heat utilization: • grey water heat recovery 3,1978 • appliance heat utilization	2,1977 gas & oil water heater performance 2,1977 heat pump characteristics • efficiency • capacity • power use	1,1977 household appliances 4,1975 commercial appliances	4,1976 commercial building inventory by: • type of heat • energy source supplied • year of construction • type of air conditioning • % of glass surface area
	3,1974 thermal losses • walls • ceilings • windows	2,1978 FEA improvements 2,1978 household appliances		

KEY:

- Data Quality Code:
1. Information is recent and representative of current trends.
 2. Information is dated yet is best available and/or representative of current trends.
 3. Information is of questionable quality; better data will be available.
 4. Information is of questionable quality; better data are unavailable.
 5. Information is absent from this report; data are being sought.
 6. Information is absent from this report; data are currently unavailable.

FIGURE 2.5. Residential/Commercial Energy-Use Data Quality

General Energy Consumption		Efficiencies and Energy Losses		Stock Characteristics	
1,1979	general consumption by fuel type	3,1973	heat rejection in 6 industries	1,1980	boiler & process heater stocks-quantities and useful-life
1,1979	industry sub-groups' consumption by fuel type	2,1974	heat loss from steam leaks	1,1980	projected boiler requirements
2,1974	end-use consumption by industry sub-groups	2,1975	efficiencies of 7 industries	3	electric motor stocks
2,1974	energy consumption patterns of key industries (Btu consumption for specific processes)	3,1974	theoretical minimum fuel consumption for 8 industries	5	other boiler stock data
1,1979	consumption by 16 largest energy users	3,1972	conservation potential of selected industries	1,1980	industrial equipment inventories (in dollars)
1,1979	industry energy cost by fuel type	3,1975	efficiency of electric motors	5	industrial equipment inventories by industry and/or equipment type
		2,1977	second law efficiencies of select industries		

KEY:		1,1979	Date Quality Code:	1. Information is recent and representative of current trends.
Data Quality Code	Date			2. Information is dated yet is best available and/or representative of current trends.
				3. Information is of questionable quality; better data will be available.
				4. Information is of questionable quality; better data are unavailable.
				5. Information is absent from this report; data are being sought.
				6. Information is absent from this report; data are currently unavailable.

FIGURE 2.6. Industrial Energy-Use Data Quality

General Energy Consumption		Vehicle Efficiencies and Energy Losses		Vehicle Use, Ownership, and Stocks	
1,1978	general consumption by mode	2,1974	power train losses	1,1978	vehicle stock by model
1,1978	fuel type by mode	2,1974	effects of drag, weight, and rolling resistance	1,1978	scrappage rates: • automobiles • small trucks • large trucks
	significant consumption by:	4,1976	effect of typical accessories	1,1979	new automobile registrations by fuel type
2,1976	• passenger travel energy intensity		expected impact of sample technology improvements	1,1978	ownership profiles
2,1976	• freight energy intensity	1,1979	• automobiles	1,1977	trip profiles
1,1978	• automobile fleet energy consumption	2,1976	• freight trucks	1,1978	auto and truck sales
		1,1980	efficiencies of new automobiles by EPA class	1,1979	installed energy-related equipment

KEY:		Date Quality Code:	
Data Quality Code	1,1979	1.	Information is recent and representative of current trends.
	Date	2.	Information is dated yet is best available and/or representative of current trends.
		3.	Information is of questionable quality; better data will be available.
		4.	Information is of questionable quality; better data are unavailable.
		5.	Information is absent from this report; data are being sought.
		6.	Information is absent from this report; data are currently unavailable.

FIGURE 2.7. Transportation Energy-Use Data Quality

This classification method describes the current status of the energy-use information in this document and highlights those data that must be used with caution or must be obtained when they become available in the future.

In summary, the goal of this effort was to compile the best available information for each sector to describe the following:

1. general energy consumption by quantity and fuel type
2. specific consumption of significant energy-using activities or processes
3. energy losses of equipment
4. efficiencies of current equipment
5. inventories and use profiles of capital stocks.

The energy-use information is separated into four chapters: general U.S. consumption, residential/commercial consumption, industrial consumption, and transportation consumption.

Each chapter contains a table of contents to insure easy reference and a data quality figure that displays the age, source, and probable quality of the data. Each is followed by an introduction to the current trends in consumption within the sector. The overall consumption patterns for the sector are described in terms of gross consumption and consumptions by fuel type. Subsequent data are preceded by discussions that describe the data and explain how the data can be used with other data to estimate various aspects of energy conservation potential.

SECTION 3.0

GENERAL CONSUMPTION

SECTION 3.0

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AGGREGATE NATIONAL DATA QUALITY

Per Major Sector	Per Major Fuel Type
1,1973+ gross consumption	3,1974+ per major end use 1977 1978
1,1973+ fuel type	1,1979+ per sector
	5 + historical trends

KEY:

- Data Quality Code:
1. Information is recent and representative of current trends.
 2. Information is dated yet is best available and/or representative of current trends.
 3. Information is of questionable quality; better data will be available.
 4. Information is of questionable quality; better data are unavailable.
 5. Information is absent from this report; data are being sought.
 6. Information is absent from this report; data are currently unavailable.

3.0 GENERAL CONSUMPTION

3.1 NATIONAL ENERGY CONSUMPTION

A brief overview of the general consumption data for the entire U.S. economy, revealing the relative consumption of the residential/commercial, transportation, and industrial sectors, is presented in Figure 3.1. The overview displays the gross consumption (quadrillion Btus or quads) in each sector in 1979, as well as the distribution of the primary fuels used to meet the

FIGURE 3.1. 1979 U.S. Energy Consumption (DOE 1980a)
10¹⁵ Btus and Percent of Total

national demand. Note that in energy consumption literature, manufacturing, mining, agriculture, and construction are typically included in the industrial sector. Important aspects of these subsectors are disaggregated later in the Industrial Energy Consumption section.

These aggregated national consumption data are more recent than some of the disaggregated data presented for each sector. Most of the transportation and residential/commercial sector information presented in later sections represents 1977 through 1979 consumption, while the industrial data represent 1974 through 1977 consumption levels. The age differences should be considered when comparing this with later sections.

3.2 GENERAL ALLOCATION OF MAJOR ENERGY TYPES

The importance of switching from imported or scarce energy sources to abundant domestic sources is a major topic in the energy conservation debate. Programs in which conversion of major oil burners to coal burners is encouraged have already started. Also, recent decreases of electrical power generation capacity surpluses have stimulated interest in trends of the mix of energy supplied to consumers. These are a few examples of reasons why knowing the distribution of each fuel in the major sectors is important. Clearly, understanding the current demand for fuels is essential to planning for the technologic improvements that will affect energy use in the U.S. Figure 3.2 presents the allocation of major energy sources, natural gas, coal, oil, and electricity in the U.S. in 1979.

3.3 ENERGY CONSUMPTION IN MAJOR END-USE AREAS

Disaggregating energy-use data beyond general sector consumption to reveal energy-use characteristic in end uses such as household heating, private automobile transportation, direct heating in manufacturing, etc. enhances an analyst's ability to identify how energy can be used more efficiently. This disaggregation allows the end uses of multiple sectors to be ranked according to the magnitude of energy use, thus identifying end uses where research and development might achieve fuel savings. Figure 3.3 displays the most recent information on the relative consumption in the

NATURAL GAS CONSUMPTION

COAL CONSUMPTION

OIL CONSUMPTION

ELECTRICITY CONSUMPTION
(11,500 Btu/kWhr)

FIGURE 3.2. Energy Consumption by Fuel Type (DOE 1980a)
10¹⁵ Btus and Percent of Total

FIGURE 3.3. Estimated National End-Use Consumption, 1978

transportation, residential/commercial, and manufacturing sectors and the consumption by the major end uses in these sectors. Because construction and agriculture end uses were very numerous and relatively insignificant compared to manufacturing end uses, only the manufacturing areas were included. Agricultural and construction energy use is described in Section 5. The primary purpose of Figure 3.3 is to provide a simple and concise comparison of end-use consumption across the three major sectors. Once an area of interest is identified, the reader can find more detailed and current information on that area in the appropriate sections that follow. The information in the figure is approximate because it was obtained by integrating data from various data bases, yet it is sufficiently accurate to clearly display the important relationships of end-use energy consumption.

Another important aspect of end-use energy consumption is the consumption of specific types of fuels. Certain strategic energy sources such as oil and gas are used predominately in certain end uses; thus, research to increase the effectiveness of the use of certain fuels must address those end uses. Figures 3.4 through 3.7 display the approximate consumption of oil, natural gas, coal, and electricity in the major sectors and in important end uses within those sectors. In summary, these figures were developed to reveal the relative significance of energy consumption in major end uses. The information is approximate because it was extracted from several sources; more detailed and accurate information follows in subsequent sections.

FIGURE 3.4. Natural Gas Consumption in the United States, 1978

FIGURE 3.5. Oil Consumption in the United States, 1978

FIGURE 3.6. Electricity Consumption in the United States, 1978

FIGURE 3.7. Coal Consumption in the United States, 1978

SECTION 4.0

RESIDENTIAL/COMMERCIAL ENERGY CONSUMPTION

SECTION 4.0

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4.29	Direct-Fired Oil Water Heater Shipments	4.42
4.30	Electric Water Heater Shipments	4.43
4.31	Gas Water Heater Shipments	4.44
4.32	Attic Insulation in Occupied Single-Family and Mobile Homes, 1976	4.45
4.33	Storm Windows in Single-Family and Mobile Homes, 1976	4.46

RESIDENTIAL/COMMERCIAL DATA QUALITY

General Consumption	Building Heat Loss and Gain	Efficiencies of Household Energy Systems	Equipment Stocks	Building Stocks
1,1979 - gross consumption by: • fuel type • end-use - significant uses: 2,1976 • space heat 5 • water heat 3,1975 • appliances	1,1977 - air infiltration 3,1978 - solar gain - occupancy heat utilization: 5 • grey water heat recovery 3,1978 • appliance heat utilization 3,1974 - thermal losses • walls • ceilings • windows	1,1977 - gas & oil furnace performance 2,1977 - gas & oil water heater performance 2,1977 - heat pump characteristics • efficiency • capacity • power use 2,1978 - FEA improvements 2,1978 - household appliances	1,1978 - primary heating equipment 1,1977 - household appliances 4,1975 - commercial appliances	1,1978 - residential housing inventory by: • type • size • year of construction 4,1976 - commercial building inventory by: • type of heat • energy source supplied • year of construction • type of air conditioning • % of glass surface area

KEY:

- Data Quality Code:
1. Information is recent and representative of current trends.
 2. Information is dated yet is best available and/or representative of current trends.
 3. Information is of questionable quality; better data will be available.
 4. Information is of questionable quality; better data are unavailable.
 5. Information is absent from this report; data are being sought.
 6. Information is absent from this report; data are currently unavailable.

4.0 RESIDENTIAL/COMMERCIAL ENERGY CONSUMPTION

4.1 GENERAL CONSUMPTION

Energy consumption in the residential/commercial sector accounted for 37% of the total U.S. energy used in 1979. Six major areas, space heating, water heating, air conditioning, refrigeration, lighting, and cooking, accounted for over 90% of this consumption; space heating alone accounted for over 50%. Residential and commercial consumption is usually combined because the end uses are similar, although the relative magnitude of the consumption in both areas do differ (see Figures 4.1 and 4.2).

Oil and natural gas, two critically important energy sources, provide more than half of the total energy used in the residential/commercial sector. This energy usage accounts for 38% of the U.S. natural gas consumption and 19% of the U.S. oil consumption, often in performance of tasks that could be met with energy of much lower quality and less strategic importance. This sector also accounted for 59% of U.S. electrical demand in 1979. Figures 4.1 and 4.2 display the relative consumption, by fuel type, in the major end-use applications in 1979 for both residential and commercial buildings. This information is tabulated in Table 4.1. Table 4.2 represents residential energy consumption data for the year from April 1979 through March 1980. These data are more recent than the ORNL data in Table 4.1, yet they were tabulated according to the house characteristics instead of specific energy end uses. Based upon this EIA information, energy consumption per household for the year ending March 1980 dropped nearly 9% (+6) from the consumption levels of the previous years. However, the number of households increased by about 900,000 units or about 1%; thus, the decrease in overall residential energy consumption was statistically insignificant.

According to the EIA data, fuel oil use (1.71 quads) decreased 22% (+21) from the 2.19 quads (+0.33) purchased during the previous 12 months. The decrease is attributed to fuel switching by 8% (+3) of the households that use fuel oil and a 12% (+7) reduction in the average household consumption of fuel oil. Milder weather and other conservation measures also contributed to this decline. A similar survey for the commercial sector should be available in 1982.

FIGURE 4.1. 1977 Residential Energy (Oak Ridge National Laboratory 1979)
10¹⁵ Btus and Percent of Total

FIGURE 4.2. 1977 Commercial Energy Use (Oak Ridge National Laboratory 1979)
10¹⁵ Btus and Percent of Total

TABLE 4.1. Residential/Commercial End-Use Energy Consumption
by Fuel Type, 1977 (10¹⁵ Btu)

	(a) <u>Electricity</u>	<u>Gas</u>	<u>Oil</u>	<u>Other</u>	<u>Total</u>
<u>Residential</u>					
Space Heaters	1.25	3.64	2.26	0.54	7.69
Water heaters	1.17	0.87	0.14	0.08	2.26
Refrigerators	1.49				1.49
Freezers	0.64				0.64
Ranges/ovens	0.52	0.31			0.83
Air conditioners	1.10				1.10
Lights	0.96				0.96
Other	0.68	0.48			1.15
Total	7.81	5.30	2.40	0.62	16.12
<u>Commercial</u>					
Space heaters	0.37	1.94	1.90	0.35	4.56
Air conditioners	2.03	0.16			2.19
Water heaters	0.04	0.09	0.10		0.23
Lights	2.23				2.33
Other	0.85	0.20			1.05
Total	5.62	2.39	2.00	0.35	10.36

(a) Electricity is reported as primary energy (11,500 Btu/kWh).

Source: Oak Ridge National Laboratory 1979.

TABLE 4.2. Residential Energy Consumption by Household Characteristics, April 1979 Through March 1980(a)

Household Characteristics	Total Households (mil'n)	Total Amount Consumed (quad'n Btu)	Average Amount Consumed Per Household (mil'n Btu)	Natural Gas Total Amount Consumed (quad'n Btu)	Electricity Total Amount Consumed (quad'n Btu)	Fuel Oil and Kerosene Total Amount Consumed (quad'n Btu)	Liquid Petroleum Gas Total Amount Consumed (quad'n Btu)
TOTAL HOUSEHOLD	77.5	15.39	197.4	5.31	8.07	1.71	0.307
CENSUS REGION							
Northeast	17.2	3.41	198.3	1.05	1.30	1.03	0.029
North Central	20.7	4.86	234.8	2.48	1.97	0.31	0.098
South	24.9	4.56	183.0	0.91	3.23	0.28	0.143
West	14.7	2.57	174.8	0.88	1.57	0.09	0.037
YEAR HOUSE BUILT							
1939 or Earlier	25.5	5.14	201.6	2.12	1.97	0.96	0.092
1940 to 1949	6.9	1.27	184.1	0.50	0.60	0.14	0.029
1950 to 1959	14.7	2.90	197.3	1.11	1.47	0.28	0.035
1960 to 1964	7.5	1.48	197.3	0.48	0.80	0.17	0.026
1965 to 1969	7.8	1.46	187.2	0.41	0.97	0.06	0.033
1970 to 1974	8.1	1.66	204.9	0.41	1.13	0.06	0.058
1975 to 1979	7.1	1.48	208.5	0.28	1.13	0.04	0.034
TYPE OF STRUCTURE							
Single Family							
Detached							
Total	50.1	11.12	222.0	3.74	6.00	1.17	0.216
Owners	43.1	9.76	226.5	3.20	5.33	1.05	0.171
Renters	7.0	1.36	194.3	0.53	0.67	0.12	0.044
Single Family Attached							
Total	3.3	0.66	200.0	0.30	0.30	0.05	0.003
Owners	2.0	0.44	220.0	0.21	0.20	0.03	0.003
Renters	1.3	0.24	184.6	0.09	0.13	0.02	--
2-4 Unit Building							
Total	9.3	1.60	172.0	0.80	0.57	0.21	0.16
Owners	2.3	0.54	234.8	0.27	0.20	0.08	0.001
Renters	7.0	1.05	150.0	0.53	0.37	0.14	0.016
5+ Unit Building							
Total	10.6	1.31	123.6	0.38	0.70	0.22	0.007
Owners	1.4	0.19	135.7	0.05	0.13	--	--
Renters	9.2	1.12	121.7	0.33	0.57	0.22	0.007
Mobile Home	4.1	0.35	85.4	0.01	--	0.01	--
Other	0.1	0.02	200.0	0.01	--	0.01	--

(a) Electricity is reported as primary energy (11,500 Btu/kWh).

Source: DOE 1981c.

4.2 AREAS OF SIGNIFICANT CONSUMPTION

Characteristics of Space Heat Equipment and Fuels

Conservation research has focused on space heating because it accounts for about 50% of the energy used in the residential/commercial sector. The fuel oil and natural gas shortages in the mid 1970s also created significant changes in consumer energy-use patterns and selection of heating systems. In 1978, 55% of residential buildings used natural gas for space heat. Fuel oil was used in 22% of the homes, and electricity was used in 16% of the homes. However, price rises and supply instability encouraged 2.7% of all households to switch from one main heating fuel to another. The main shift involved houses that previously used fuel oil; 8.2% of these homes switched during the year ending March 1980. Approximately 54% of these switched to wood systems and 38% switched to natural gas. Wood systems also account for approximately 47% of all secondary heating systems.

Figure 4.3 reveals the distribution of the major types of residential heating equipment used in 1978. Table 4.3 presents, according to the type of building and the year of construction, the type of primary heating equipment used in residential buildings in 1978. The disaggregation by year of construction structure type will lend insight to trends in equipment popularity and the market potential for new technologies that improve or supplement existing equipment. Relative proportions of fuel types used in space heating are listed in Table 4.4 to aid assessments of conservation potential for technology developments that apply to systems using specific types of fuel.

FIGURE 4.3. 1976 Distribution of Residential Heating Equipment, Percent of Total (Oak Ridge National Laboratory 1979)

TABLE 4.3. Primary Heating Equipment by Type of Housing Structure and Year of Construction, 1978
(thousand Housing Units)

	Total Housing Units	Single Family Detached					Single Family Attached	Building with 2-4 Units	Building with 5 or More Units	Mobile Home	Other
		Total	1 - 4 Rooms	5 Rooms	6 Rooms	7 or More Rooms					
TOTAL HOUSING UNITS	76,608	48,547	8,768	12,696	11,850	15,233	3,128	10,749	9,151	4,805	228
PRIMARY HEATING EQUIPMENT											
Warm Air Furnace with Ducts	38,394	25,246	3,148	6,691	6,262	9,146	1,845	4,964	2,897	3,329	113
Electric Heat Pump	1,154	923	116	181	143	484	83	28	69	50	--
Steam or Hot Water System	12,365	5,956	382	1,065	1,708	2,800	602	2,659	3,112	37	--
Hot Water Pipes (Radiant Heat)	1,122	604	118	212	130	143	15	39	444	--	20
Floor, Wall, or Pipeless Furnace	5,999	4,207	1,160	1,320	1,108	619	11	568	625	487	--
Built-In Electric Units	5,608	3,016	790	6571	705	850	283	895	1,191	209	14
Room Heaters with Flue	4,736	3,031	1,164	926	583	358	68	915	490	168	62
Room Heaters without Flue	2,736	2,071	778	602	441	250	85	384	52	194	--
Fireplace, or Stove	2,242	1,893	640	524	385	343	17	65	16	232	19
Portable Space Heaters	1,786	1,414	399	471	368	176	-0-	180	42	149	--
Other	107	51	18	33	--	--	--	18	39	--	--
None	359	134	53	--	17	63	19	34	173	--	--
	Total Housing Units	1975 or Later	1970 to 1974	1965 to 1969	1960 to 1964	1950 to 1959	1940 to 1949	1939 or Earlier			
TOTAL HOUSING UNITS	76,608	5,245	8,768	8,201	7,926	13,761	7,548	25,159			
PRIMARY HEATING EQUIPMENT											
Warm-Air Furnace with Ducts	38,394	3,343	5,897	4,799	4,119	7,727	3,512	8,998			
Electric-Heat Pump	1,154	478	209	124	163	115	27	37			
Steam- or Hot-Water System	12,365	54	229	934	1,157	1,602	1,275	7,116			
Hot-Water Pipes (Radiant Heat)	1,122	97	58	127	101	191	14	533			
Floor, Wall, or Pipeless Furnace	5,999	98	585	394	597	1,161	1,109	2,056			
Built-In Electric Units	5,608	920	1,213	1,018	788	537	239	892			
Room Heaters with Flue	4,736	35	141	255	345	1,018	596	2,345			
Room Heaters without Flue	2,736	--	172	213	229	519	289	1,314			
Fireplace, or Stove	2,242	204	172	152	258	261	240	954			
Portable Space Heaters	1,786	15	93	187	168	387	227	708			
Other	107	--	--	--	--	55	--	52			
None	359	--	--	--	--	187	19	153			

Note: Data may not sum to totals due to rounding. Dashes "--" represent or round to zero.

Source: DOE 1980b.

TABLE 4.4. Type of Residential Main Heating Fuel, 1979 (million households)

Household Characteristics	Total Households	Natural Gas	Fuel Oil and Kerosene	Electricity	Liquid Petroleum Gas	Wood	Coal	Other and None
TOTAL HOUSEHOLDS	77.5	42.4	14.6	12.8	3.71	3.41	0.23	0.31
WATER HEATING FUEL								
Natural Gas	42.6	38.9	1.8	1.5	0.05	0.17	0.02	0.11
Electricity	25.9	3.3	7.3	11.1	1.57	2.51	0.07	0.10
Fuel Oil and Kerosene	5.6	0.1	5.2	--	--	0.25	0.05	--
Liquid Petroleum Gas	3.0	--	0.3	0.2	2.05	0.33	0.02	0.06
Other	0.2	--	--	--	0.02	0.11	0.04	0.01
None	0.3	0.1	--	--	0.03	0.04	0.03	0.02
TYPE OF STRUCTURE								
Single Family Detached								
Total	50.1	27.5	9.9	7.1	2.37	3.03	0.19	0.12
Owners	43.1	23.2	8.7	6.5	1.82	2.65	0.18	0.10
Renters	7.0	4.3	1.2	0.6	0.56	0.38	0.02	0.02
Single Family Attached								
Total	3.3	2.4	0.5	0.3	0.08	0.02	0.02	--
Owners	2.0	1.6	0.3	--	0.08	0.02	0.02	--
Renters	1.3	0.9	0.2	0.3	--	--	--	--
2-4 Unit Building								
Total	9.3	6.5	1.3	1.1	0.19	0.04	--	0.07
Owners	2.3	1.6	0.4	0.3	--	--	--	0.02
Renters	7.0	5.0	0.9	0.8	0.19	0.04	--	0.05
5 or More Unit Building								
Total	10.6	4.8	2.1	3.3	0.07	0.22	--	0.12
Owners	1.4	0.6	--	0.6	--	0.22	--	--
Renters	9.2	4.2	2.0	2.7	0.07	--	--	0.12
Mobile Home	4.1	1.1	0.8	1.0	1.00	0.11	0.02	--
Other	0.1	0.1	--	--	--	--	--	--
YEAR HOUSE BUILT								
1939 or Earlier	25.5	15.2	7.1	0.9	0.90	1.21	0.12	0.13
1940 to 1949	6.9	4.4	1.3	0.5	0.32	0.29	0.02	0.09
1950 to 1959	14.7	9.1	2.7	1.6	0.55	0.66	0.02	0.02
1960 to 1964	7.5	4.0	1.5	1.5	0.25	0.16	0.03	--
1965 to 1969	7.8	3.7	0.8	2.6	0.46	0.18	--	--
1970 to 1974	8.1	3.6	0.8	2.6	0.80	0.29	--	0.03
1975 to 1979	7.1	2.4	0.4	3.2	0.42	0.63	0.03	0.04

Note: Data may not sum to totals due to rounding.

Source: DOE 1981c.

Energy Consumption of General Appliances

More than half of the U.S. electricity consumption occurs in the residential/commercial sector. Roughly 16% of this electricity is used for space heat. The remaining demand is from minor household appliances and lighting. Because appliances consume a significant portion of electrical energy, this section presents estimates of the average consumption of various household and commercial electrical appliances.

Table 4.5 presents household appliance consumption data, and Table 4.6 presents similar information for commercial appliances. These tables display the relative significance of the consumption of appliances and can be used in conjunction with the appliance inventory information (Section 4.5) to approximate the appliance's total consumption.

TABLE 4.5. Average Electrical Consumption of Selected Minor Household Appliances (annual kWh/household)(a)

Appliance	Pacific Gas & Electric	Baltimore Gas & Electric	Carolina Power & Light	Library of Congress
Air cleaner	216	156-612	547	216
Blanket	147	200		147
Blender	1			15
Broiler	85			100
Carving knife	8			8
Clock	17	18	18	
Coffee maker	140			106
Deep fryer	83			83
Dehumidifier	377			377
Egg cooker	14			14
Fan (attic)	291			291
(circulating)	43			43
(furnace)	650		1152	
(rollaway)	138			138
(window)	170			170
Floor polisher	15			
Food waste disposer	7	36	30	30
Frying pan	100			186
Germicidal lamp	141			
Grill (sandwich)	33			33
Hair dryer (600 W)	25			
Heat lamp (infrared)	13			
Heating pad	10			10
Hot plate	90			
Humidifier	163		252	136
Iron	60			144
Mixer (food)	2			13
Radio (solid-state)	18			
Roaster	60			205
Sewing machine	11			
Shaver	0.5	2		
Slow cooker				
Toaster	39			39
Toaster oven		168		
Trash compactor	4		36	50
Vacuum cleaner	46		67	
Vibrator	2			
Waffle iron	20		14	22
Waterbed heater	1460			

(a) Reported as purchased electricity (3412 Btus/kWh).

Sources: Oak Ridge National Laboratory 1979.

TABLE 4.6. Consumption of Selected Commercial Appliances

Appliance Type	Fuel Type (a)	1975 Energy Consumption (10 ¹² Btu)	
		End use	Prime
Space heating			
Cast-iron boilers (hot water & steam)	G	507.2	507.2
Unit heaters	G	251.3	251.3
Duct furnaces	G	147.5	147.5
Warm-air furnaces	G	102.5	102.5
Steel boilers (hot water & steam)	G	94.6	94.6
Cast-iron boilers (hot water & steam)	O	504.8	504.8
Warm-air furnaces	O	474.9	474.9
Steel boilers (hot water & steam)	O	324	324
Unit heaters	O	22.3	22.3
Baseboard heaters	E	1.9	6.4
Heat pumps (single & split)	E	5.65	19.2
Unit heaters	E	28.8	97.8
Air conditioning			
Direct absorption (unitary)	G	29	29
Direct absorption (built up)	G	2.3	2.3
Indirect-fired absorption	G	38.7	38.7
Air conditioner, year-round unit	E	38.2	129.8
Air conditioner, condenser only	E	86.1	292.5
Horizontal	E	51.1	173.6
Heat pump (single and split)	E	4.8	16.3
Centrifugal liquid chiller	E	34.3	116.5
Reciprocating liquid chiller		15.9	54
Water heating			
Water heater	G	536.4	536.4
Water heater	O	136.1	136.1
Water heater	E	68.5	232
Refrigeration			
Central warehouse storage	E	114.8	398.9
Supermarket display	E	96.9	329.1
Restaurant storage	E	44.5	151.2
Cooking			
Coffee makers & urns	G	3.7	202.0
Kettle, cooker, and pressure cooker	G	21.5	167.2
Boilers	G	11.9	129.6
Fryers	G	42.5	420.8
Griddles and grills	G	32.7	356.3
Deck and convection ovens	G	35.3	429.7
Ranges and braising pans	G	50.5	392.6
Coffeemakers and urns	E	10.9	360.0
Kettle, cooker, and pressure cooker	E	16.0	75.8
Broilers	E	4.8	32.4
Fryers	E	17.3	105.2
Griddles and grills	E	17.7	118.7
Deck and convection ovens	E	19.0	142.6
Ranges and braising pans	E	13.6	65.4
Lighting			
Incandescent	E	579.8	670,000
Fluorescent	E	1350.0	585,000
High-intensity discharge	E	375.0	20,000
Metal halide	E	41.8	

(a) Fuel type: G--natural gas, E--electricity, O--oil.

Source: Oak Ridge National Laboratory 1979.

4.3 HEAT LOSS AND GAIN IN BUILDINGS

Air Infiltration

Heat loss and gain greatly affect the efficiency of space heating and cooling. Air infiltration can account for up to 40% of the heat loss in a typical house. Thus, reducing the leakiness of structures while insuring healthy air exchange levels is an important research area. Figure 4.4 displays the relative significance of heat loss by various physical systems in a typical house.

FIGURE 4.4. Air Leakage Test Results: Average Texas Home of 1780 ft² (Oak Ridge National Laboratory 1979)

Proportion of Heat Loss to Heat Gain

Research on passive technologies such as wall insulation and window glazing can complement active conditioning system research. Significant market penetration of advanced building envelope materials, waste heat utilization systems, and design for improved net solar gain would reduce the energy consumption of future active space conditioning systems. Homes constructed with innovative techniques and reasonable south-facing windows have required as little as one sixth as much space heating fuel as conventional homes.

Table 4.7 outlines the differences between a new home built to FHA standards and a new home built to more efficient specifications as defined by Ross and Williams (1981). Figure 4.5 compares the expected performance of the two-house types. For the standard and target houses under different weather conditions Table 4.8 presents the American Institute of Physics' (1975) breakdown of heat losses and gains.

TABLE 4.7. FHA and Model House Characteristics

	<u>FHA Standard</u>	<u>Model House</u>
Ceiling	7 inches insulation	same
Walls	3 inches insulation	5 inches insulation
Doors	ordinary	ordinary and storm
Basement	basement-wall insulation 1 inch thick 18 inches high	basement-wall insulation 4 inches thick 48 inches high
Window placement	45 ft ² per side	100 ft ² on south 40 ft ² on west 40 ft ² on east none on north
Window structure	single glazing poorly fitted storm	single glazing tight-fitted storm indoor shutters at night
Air infiltration	1.0 exchange/hour	0.5 exchanges/hour

Source: Ross and Williams 1981.

FIGURE 4.5. Heat Losses and Gains for Alternate House Designs (Ross and Williams 1981)

TABLE 4.8. Heat Loss and Gain Energy Balance: Standard and Target House Power in Btu/hr (with kWh in parentheses)

	Standard house	
	Cold, Partly Cloudy Day (T = 70°F = 39°C)	Mild, Clear Day (T = 30°F = 17°C)
Energy losses(a)		
walls and roof	7,200 (2.1)	16,800 (4.9)
floor	1,100 (0.3)	1,100 (0.3)
windows	6,600 (1.9)	15,400 (4.5)
incoming air (heating)	8,000 (2.3)	18,700 (5.5)
incoming air (humidification)	<u>3,800 (1.1)</u>	<u>3,800 (1.1)</u>
Total	26,700 (7.8)	55,800 (16.3)
Energy gains		
solar through windows	5,200 (1.5)	2,600 (0.8)
3 people	1,000 (0.3)	1,000 (0.3)
electric load	5,700 (1.7)	5,700 (1.7)
gas furnace load to balance(b)	14,800 (4.3)	46,500 (13.6)
solar collector load to balance		
Total	26,700 (7.8)	55,800 (16.3)
	Target house	
	Cold, Partly Cloudy Day (T = 70°F = 39°C)	Mild, Clear Day (T = 30°F = 17°C)
Energy losses(a)		
walls and roof	2,800 (0.8)	6,500 (1.9)
floor	400 (0.1)	400 (0.1)
windows	1,800 (0.5)	4,200 (1.2)
incoming air (heating)	1,600 (0.5)	3,700 (1.1)
incoming air (humidification)	<u>800 (0.2)</u>	<u>800 (0.2)</u>
Total	7,400 (2.2)	15,600 (4.6)
Energy gains		
solar through windows	8,300 (2.4)	4,200 (1.2)
3 people	1,000 (0.3)	1,000 (0.3)
electric load	2,400 (0.7)	2,400 (0.7)
gas furnace load to balance(b)		
solar collector load to balance	<u>-4,300 (-1.3)(c)</u>	<u>8,000 (2.3)</u>
Total	7,400 (2.2)	15,600 (4.6)

(a) The losses in the first and third columns are also found in Table 3.1.

(b) The actual fuel input is larger; the value here does not include flue losses and duct distribution losses.

(c) Presumably, the windows would be shaded to reduce the solar input! The heat collected by the roof-top collector would be transferred to some suitable user of low-temperature heat.

Source: American Institute of Physics 1975.

4.4 EFFICIENCIES OF SELECTED EQUIPMENT

Water Heaters and Hot Air Furnaces

The efficiencies of many products have been improved since 1973 when the energy shortage first gained national attention. Conservation potential studies have attempted to document the changes in the first- and second-law efficiencies of major appliances, yet the information is incomplete. However, the following tables present the estimated efficiencies of some major end-use areas such as space heating, cooking, and water heating.

Tables 4.9 and 4.10 present estimates of average first- and second-law efficiencies for these main residential/commercial applications. Tables 4.11 and 4.12 display the simulated performance characteristics of typical gas- and oil-fired furnaces. Table 4.13 presents specific statistics on water heating units, including estimates of jacket and pilot light losses.

TABLE 4.9. Efficiencies of Household Energy Systems

Household Task	Ambient Temperature T_0 F (C)	Task Temperature T_2 F (C)	First-Law Efficiency %	Second-Law Efficiency %
Hot-water heating				
Electric	55 (13)	120 (49)	0.75 ^(a)	0.015
Gas	55 (13)	120 (49)	0.50	0.029
Space heating				
at the room	40 (4)	70 (21)	0.60	0.028
at the register	40 (4)	110 (43)	0.60	0.074
at the furnace plenum	40 (4)	160 (71)	0.75	0.145
Air conditioning	90 (32)	55 (13)	2.0 (COP) ^(a)	0.045

(a) The first-law efficiency is a factor of 3 smaller if one refers back to the fuel at the electric power plant (to compute the second-law efficiency, one must refer back to the power plant fuel).

Source: American Institute of Physics 1975.

TABLE 4.10. Estimated Second-Law Efficiencies of Household Energy Use

Use	Estimated Overall Second-Law Efficiency %
Space Heating	0.06
Water Heating	0.03
Cooking	--
Air Conditioning	0.05
Refrigeration	0.04

Source: American Institute of Physics 1975.

TABLE 4.11. Efficiency and Operating Cost of Gas-Fired, Residential Furnaces^(a)

System Parameters	Actual Load (10 ⁶ Btu/yr)	Gas Usage (10 ⁶ Btu/yr)	Electric Usage (10 ⁶ Btu/yr)	Utilization Efficiency (%)	Operating Cost ^(b) (\$/yr)
No combustion air loss	68.9	87.5	1.0	77.9	
Standard furnace	73.0	10.0	1.2	68.1	210.47
Cycling pilot	72.6	94.5	1.2	72.1	199.34
Cycling pilot with vent damper	71.2	86.3	1.0	78.9	181.98
Cycling pilot with power draft	69.6	82.2	1.3	82.6	175.81
Cycling pilot with direct vent	67.9	93.0	1.1	73.2	196.14
75% static efficiency	73.0	102.3	1.1	66.7	215.09
81% static efficiency	73.2	95.9	1.0	71.0	201.69
84% static efficiency	73.2	93.0	1.0	73.3	195.47
80,000-Btu/hr furnace	72.5	98.4	1.1	69.2	206.88
125,000-Btu/hr furnace	73.5	102.1	1.1	66.7	214.82
40-sec fan-on delay	72.4	97.7	1.3	69.5	207.47
160-sec fan-on delay	74.6	107.3	0.8	63.7	222.08
40-sec fan-off delay	74.4	104.8	0.94	65.1	218.39
160-sec fan-off delay	41.2	95.2	1.5	71.3	203.75
40 sec on; 160 sec off	70.9	93.6	1.7	72.2	202.63
3 cycles/hr at 50% load	73.8	100.6	1.1	67.7	211.61
5°F night setback	67.5	92.7	1.0	73.5	194.82
Cycling pilot, vent damper, 84% eff., 40-sec fan-on; 160-sec fan-off	68.2	77.1	1.5	87.5	168.15
Cycling pilot, power draft, 84% eff., 40-sec fan-on; 160-sec fan-off	67.4	75.4	1.5	89.5	164.65

(a) Two-story, three-bedroom residence with basement; attached unheated garage; aluminum siding; 0.1076-m (3-in.) insulation in walls; 0.15-m (6-in.) insulation in ceiling; the thermopane windows; 137.8 m² (1484 ft²) of floor area.

Location--Syracuse, NY.

Weather--Syracuse over 10 years, 1965-1974.

Season--September-May.

(b) Calculated on basis of gas cost of \$2.00 for 10⁶ Btu and electricity cost of \$0.03/kWh.

Source: Oak Ridge National Laboratory 1979.

TABLE 4.12. Efficiency of Oil-Fired Residential Boilers

Boiler No.	Boiler Type	Steady- State Efficiency	Seasonal ^(a) Fuel-Use Efficiency	Annual ^(a) Fuel Use (gal)
1	Dry-base, single-pass vertical fire tube, steel nonretention head	69.2	56.7	1440
2	Dry-base, cast iron, retention head	74.8	64.7	1260
3	Wet-base, two-pass horizontal fire-tube steel, induced draft	81.2	75.5	1090
4	Wet-base, cast iron, retention head	81.0	75.2	1084

(a) Installation parameters: design load, 50,000 Btu; design temperature, 68°F; domestic water use, 40 gpd; outlet water temperature, 180°F; 100% oversized.

Source: Oak Ridge National Laboratory 1980.

TABLE 4.13. Comparison of Energy Consumption and Efficiencies: Typical Electric and Gas Water Heaters

Water Heater Type and Source	Total Energy Input (10 ⁴ Btu/day)	Useful Energy Out (10 ⁴ Btu/day)	Jacket Losses (% of total input)	Flue Losses		Efficiency	
				Main Burner Pilot	(% of total input)	Unit Prime Source Energy ^(a)	(%)
Electric							
Mutch ^(b)	4.1	3.2	21.2			78.8	24
Spann and Slaughter ^(c)	7.5	5.9	20.9			79.1	24
Hoskins ^(d)	6.2	5.0	19.0			81	24
Lee ^(e)	6.2	5.1	17.0			83	25
Gas							
Mutch ^(f)	7.1	3.2	35.0	12.0	7.5	45.5	45.5
Spann and Slaughter ^(g)	11.6	5.9	15.7	19.3	13.9	51.4	51.4
Hoskins ^(h)	9.8	5.4	12.3	21.4	14.3	52.0	52.0
Lee	10.2	5.1	12.8	22.5	14.7	50.0	50.0

(a) Including a 30% electric generation and distribution efficiency.

(b) Hot water consumption, 50 gpd; temperature rise, 85°F; ambient temperature, 70°F; insulation thickness, 2 in.; tank size, 66 gal.

(c) Hot water consumption, 75 gpd; temperature rise, 85°F; ambient temperature, 70°F; insulation thickness, 2 in.; tank size, 66 gal.

(d) Hot water consumption, 72 gpd; temperature rise, 85°F; ambient temperature, 70°F; insulation thickness, 2 in.; tank size, 50 gal (jacket loss includes distribution piping loss).

(e) Hot water consumption, 71.4 gpd; temperature rise, 85°F; ambient temperature, 70°F; insulation thickness, 1-3/4 in.; tank size, 50 gal.

(f) Hot water consumption, 50 gpd; temperature rise, 85°F; ambient temperature, 70°F; insulation thickness, 1 in.; tank size, 40 gal; main burner rate, 7490 Btu/hr-ft³; pilot rate, 750 Btu/hr.

(g) Hot water consumption, 75 gpd; temperature rise, 85°F; ambient temperature, 70°F; insulation thickness, 1 in.; tank size, 40 gal; main burner rate, 7520 Btu/hr-ft³; pilot rate, 750 Btu/hr.

(h) Hot water consumption, 72 gpd; temperature rise, 85°F; ambient temperature, 70°F; insulation thickness, 1 in.; main burner rate, 7490 Btu/hr-ft³; (jacket loss includes distribution piping loss).

(i) Hot water consumption, 71.4 gpd; temperature rise, 85°F; ambient temperature, 70°F; insulation thickness, 3/4 in.; main burner rate, 8430 Btu/hr-ft³; pilot rate, 700 Btu/hr (jacket loss includes floor loss).

Source: Oak Ridge National Laboratory 1979.

Heat Pump Performance

Rising consumer demand for heat pumps, stimulated by the potential for energy savings and fuel switching, has dramatically stimulated the interest in heat pump research, development, and commercialization. Tables 4.14 through 4.16 display the performance of standard air- and water-cooled heat pumps built in 1976. These standards can be used as an approximate baseline for current heat pump performance when estimating the effect of heat pump research. This information was obtained primarily from trade associations. Updates will be included when newer information becomes available.

The energy conservation potential of heat pumps is very dependent upon design parameters, especially the expected ambient air temperatures. Table 4.17 lists the COP of a standard heat pump operating in different temperature ranges. The results support the hypothesis that heat pumps may be more marketable in regions with moderate climates because the pumps can operate at higher efficiencies, thus offering consumers greater fuel cost savings.

TABLE 4.14. Single-Package Water-Cooled Heat-Pump Characteristics, 1976

Rated ^(a) Cooling Capacity Category (10 ³ Btu hr)	Cooling ^(b)			High-temperature Heating		
	Capacity Range (Btu hr)	EER ^(d) Range (Btu Whr)	Range of Power Use (W)	Capacity Range (Btu/hr)	COP ^(c) Range	Range of Power Use (W)
Under 16.5	9,000-14,000	7.04-9.00	1,000-1,700	8,500-16,000	1.99-3.06	1,150-1,600
16.5-21.9	18,000-21,500	7.50-9.00	2,250-2,500	17,000-25,500	2.08-3.25	2,150-2,400
22.0-26.9	22,000-25,500	6.38-8.89	2,700-3,450	24,000-27,500	2.34-2.93	2,600-3,100
27.0-32.9	27,000-32,500	8.23-9.29	3,150-3,950	31,000-40,000	2.61-3.66	2,750-3,600
33.0-33.9	33,000-33,000	8.05-9.57	3,450-4,100	34,000-35,500	2.85-3.15	3,300-3,500
39.0-43.9	39,000-43,000	8.08-9.07	4,300-5,200	38,000-55,000	2.37-3.56	4,100-4,700
44.0-53.9	50,000-53,000	7.81-8.55	6,200-6,500	50,000-63,000	2.66-3.08	5,500-6,000
54.0-64.9	61,000-64,000	7.44-8.89	7,200-8,600	61,000-85,000	2.45-3.37	6,100-7,400
65.0-95.9	96,000-96,000	8.65-8.70	9,990-11,100	92,000-92,000	2.70-3.17	8,500-10,000
97.0-134.9	128,000	7.39	17,300	122,000	2.17	16,500

(a) Heat pumps are generally sized for application by their cooling capacity.

(b) Cooling from 95°F outdoor to 80°F indoor coil air temperatures (dry bulb).

(c) Heating from 47°F outdoor to 70°F indoor coil air temperatures (dry bulb).

(d) EER (energy efficiency ratio) is the ratio of cooling capacity to the power input.

(e) COP (coefficient of performance) is the ratio of the total heat output, excluding supplementary heating coils, to the total electrical input.

Source: Oak Ridge National Laboratory.

TABLE 4.15. Single-Package Air-Cooled Heat-Pump Characteristics, 1976

Rated ^(a) Cooling Capacity Category (10 ³ Btu/hr)	Cooling ^(b)			High-Temperature Heating ^(c)			Low-Temperature Heating ^(d)		
	Capacity Range (Etu/hr)	EER ^(e) Range (Btu/Whr)	Range of Power Use (W)	Capacity Range (Btu/hr)	COP ^(f) Range	Range of Power Use (W)	Capacity Range (Btu/hr)	COP ^(f) Range	Range of Power Use (W)
Under 16.5	17,000-21,000	5.71-6.21	2,800-3,500	17,000-22,000	1.92-2.08	2,400-3,200	8,500-13,000	1.21-1.49	2050-2,650
22.0-26.9	22,000-26,000	5.18-7.32	3,200-4,300	21,000-28,000	1.74-2.47	2,700-3,850	10,500-15,500	1.15-1.64	2300-3,300
27.0-32.9	27,000-32,000	5.51-7.32	4,100-5,100	27,000-36,000	1.88-2.57	3,400-4,300	14,000-23,000	1.27-1.77	2900-3,300
33.0-38.9	33,000-37,000	5.24-7.05	5,000-6,300	34,000-40,000	1.92-2.64	4,000-5,400	16,500-26,000	1.15-2.05	3000-4,800
39.0-43.9	39,000-42,000	6.50-7.37	5,700-6,800	40,000-45,000	2.30-2.57	4,900-5,700	12,000-29,000	1.31-1.89	3900-5,000
44.0-53.9	46,000-50,000	5.11-7.66	6,400-9,400	47,000-62,000	2.22-2.56	5,600-7,200	23,000-34,000	1.41-2.00	3600-6,200
54.0-64.9	54,000-60,000	5.49-8.31	7,100-10,200	56,000-63,000	2.09-2.69	6,200-8,400	28,000-37,000	1.37-2.52	3900-6,400
65.0-96.9	83,000-95,000	7.04-9.06	9,600-13,500	87,000-100,000	2.44-3.11	8,200-12,000	44,000-58,000	1.54-2.22	5800-11,000
97.0-134.9	106,000-122,000	6.93-8.03	13,200-17,600	115,000-122,000	2.40-2.86	11,900-14,900	60,000-79,000	1.60-2.11	9200-12,500

(a) Heat pumps are generally sized for application by their cooling capacity.

(b) Cooling from 95°F outdoor to 80°F indoor coil air temperatures (dry bulbs).

(c) Heating from 47°F outdoor to 70°F indoor coil air temperatures (dry bulbs).

(d) Heating from 17°F outdoor to 70°F indoor coil air temperatures (dry bulbs).

(e) EER (energy efficiency ratio) is the ratio of cooling capacity to the power input.

(f) COP (coefficient of performance) is the ratio of the total heat output, excluding supplementary heating coils, to the total electrical input.

Source: Oak Ridge National Laboratory 1979.

TABLE 4.16. Single-Package Heat Pump, Aggregate Performance Characteristics, 1976

Heat Pump Type	Cooling Mode			High-Temperature Heating Mode			Low-Temperature Heating Mode		
	Weighted Mean Capacity (Btu/hr)	Weighted Mean COP	Maximum Error in Energy Use (%)	Weighted Mean Capacity (Btu/hr)	Weighted Mean COP	Maximum Error in Energy Use (%)	Weighted Mean Capacity (Btu/hr)	Weighted Mean COP	Maximum Error in Energy Use (%)
Air-cooled									
Single package	39,014	1.92	13.9	41,405	2.43	13.8	23,202	1.72	20.9
Split system	35,137	1.96	13.3	37,000	2.36	11.9	21,880	1.73	15.9
Water-cooled									
Single package	31,674	2.47	9.2	34,545	7.4				

(a) Weighted by unit shipment of heat pumps.

Source: Oak Ridge National Laboratory 1979.

TABLE 4.17. Measured COP Versus Temperature: Typical 3-Ton Heat-Pump

<u>Outdoor Temperature Range (°F)</u>			<u>Maximum Heating Output Excluding Auxiliary Resistance Heat (Btu/hr)</u>	<u>Coefficient of Performance</u>
-10	-	-6	10,500	1.07
-5	-	-1	13,000	1.18
0	-	4	15,200	1.32
5	-	9	17,600	1.47
10	-	14	20,000	1.61
15	-	19	22,000	1.73
20	-	24	24,500	1.84
25	-	29	27,000	2.02
30	-	34	29,300	2.13
35	-	39	31,700	2.23
40	-	44	34,000	2.33
45	-	49	36,100	2.44
50	-	54	38,600	2.54
55	-	59	40,600	2.63
60	-	64	43,000	2.72

Source: Oak Ridge National Laboratory 1979.

FEA Efficiency Improvement Potential

Obtaining a second-law efficiency of 100% is physically impossible. Even approaching such an efficiency becomes increasingly expensive. Thus, the improvement of a device or process has a breakeven point at which further efficiency improvements become increasingly uneconomical. The Federal Energy Administration (FEA) (a predecessor of the Department of Energy) estimated possible appliance efficiency improvements and the respective costs for common appliances. Tables 4.18 and 4.19 display these FEA estimates of possible efficiency improvements and cost increases. These figures are targets only.

TABLE 4.18. Estimated Efficiency Improvements and Cost Increases for Selected Commercial Appliance Improvements and Design Changes

Improvement(a)	Application(a)	Energy Type(b)	Cost Increase (%)	Efficiency Improvement(c)	
				Steady State (%)	Operating(d) (%)
Compact boilers	SH, WH	G, O	0-25	5-15	10-25
Pulse combustion	SH, WH	G	25-80	10-15	15-25
Heat-pipe heat exchanger	SH, WH	G, O	20-25	5-10	5-20
Heat-pipe furnace	SH	G	5-15	10	20
Heat pump--gas	SH	G	100	100	100
Flue-gas heat recovery	SH, WH	G, O	10-50	5-15	5-15
Increased air flow	SH	G, O	0-5	1-2	1
Heat pump--electric	SH, WH	E	50-150	10-100	10-100
Emulsified fuel	SH, WH	O	15-20	5-10	7
Flue dampers	SH, WH	G	5-15	0	5-15
Electric ignition	SH, WH, C	G	5-15	0	1-10
Optimum sizing	SH	G, O	30	0	5-10
Power combustion	SH, WH, C	15	15	10	20
Improved evaporator-condenser surface	AC, R	E, G	0-15	5-15	5-15
Improved evaporator-condenser capacity	AC, R	E, G	0-20	5-15	5-15
Reduced storage temperature	WH	E, G, O	20-100	0-2	5-10
Heat-pipe water heater	WH	G	20	10	10-20
Improved insulation	SH, WH, R	E, G, O	1-10	0.2-10	0.1-10
Hot gas-line heat recovery	WH, R	E			
Outside combustion air	SH, WH	G, O	5-10	0	0.5-8
Heat traps	WH	E	5-10	0	0-2
Burner modulation	SH, WH	G, O	10-80	0-10	10-20
Thermal storage	SH, WH, AC	E, G	10-1000		
Wet condenser	AC, R	E	25	20-40	30-50
High-efficiency compressors	AC, R	E	0-5	2-7	2-7
Evaporative coolers	AC, R	E			
Improved refrigerant	AC, R	E, G			
Improved temperature requirement	R	E, G	0	5-40	5-40
Improved coatings--fluorescent lamps	L	E	40-50		7-12
Heat-pipe oven	C	G	25	15	15
Screw-in fluorescent lamps	L	E	200		150
Heat-pipe griddle	C	G	25	100	150
Improved coatings--incandescent	L	E			50
Heat-pipe fryer	C	G	25	50	50

(a) SH--Space heating, WH--water heating, AC--air conditioning, R--refrigeration, C--cooking, L--lighting.

(b) G--gas, O--oil, E--electricity.

(c) Improvements in efficiency are defined as the change in efficiency divided by the original efficiency.

(d) Operating efficiency is defined as the useful energy output divided by the energy input.

Source: Oak Ridge National Laboratory 1979.

TABLE 4.19. FEA Target Efficiency Improvement, Energy Savings, and Price Increase Estimates for FEA Accepted Appliance Design Improvements

<u>Appliance</u>	<u>Efficiency Improvement (%)</u>	<u>Energy Savings (%)</u>	<u>Price Increase^(a) (\$/unit)</u>
Refrigerators and Refrigerator-Freezers	39(b)	28(b)	28.40
Dishwashers	25(b)	20(b)	15.30
Clothes dryers			
gas		15(b)	3.35
combined	8(b)	7(b)	
electric		4(b)	3.28
Room air conditioners	28(b)	22(b)	56.19
Water heaters			
gas	20(b)		12.38
oil	19(b)		27.68
electric	15(b)		11.65
Ranges and ovens			
gas	104(b)	51(b)	25.49
electric	3(b)	3(b)	4.37
Clothes washers	47(b)	32(b)	0.73

(a) Figures derived from data reported in July 15, 1977, Federal Register.

(b) Figures derived from data reported in April 11, 1978, Federal Register.

Source: Oak Ridge National Laboratory 1979.

4.5 CHARACTERISTICS OF BUILDING STOCK

Building structure characteristics and inventories are essential to evaluating research programs for different energy conservation technologies. This section contains housing, building, and appliance stock information that can serve as a guide to defining the market penetration potential of various technology improvements.

Housing stock and appliance inventory information was typically obtained by combining the results of Bureau of Census surveys with the surveys and forecasts of appliance manufacturing trade associations. Unfortunately, sampling techniques and category definitions were inconsistent, which significantly reduced the accuracy of past aggregate data. An additional area of concern was the lack of sufficient historical data that are essential to estimating replacement rates of building stock and appliances. Recently, the U.S. Energy Information Administration (EIA) published the results of annual surveys of residential and nonresidential building stocks. These surveys categorize important building characteristics such as age, size, window area, type, etc. according to primary heating fuel, heating and cooling equipment, etc. The residential survey also identifies the number of households that have certain appliances and lists specific appliance features that are important to energy consumption analyses. The following sections on building characteristics and energy conversion and conservation systems used this recent EIA data when possible because they are consistent and more recent than other sources currently available. Certain appliance information from trade associations and Bureau of Census publications was also used.

Building Characteristics

The majority of the residential buildings are owner-owned, detached, single-family homes. One third of the homes were built before 1940. Over 70% of the units had only one floor and the median number of rooms was five. More than 40% of the homes had no air conditioning, whereas a majority of the homes that were air conditioned used window rather than central systems. Table 4.20 summarizes residential housing stock by the type of housing structure. Year of construction, size, number of windows per room, and air-conditioning

equipment are the characteristics. Heating equipment was discussed earlier (Section 4.2.1) because of its significant role in overall residential/commercial energy consumption.

Tables 4.21 through 4.25 present characteristics of commercial buildings according to year of construction, supplied energy sources, heating system characteristics, air-conditioning equipment, and glass (as a percent of exterior surface). The survey revealed that the majority of commercial buildings are fairly small; 57% have an enclosed floor-space area of less than 5000 feet.

Virtually all commercial buildings used electricity; natural gas was used in only 57% of these buildings; and fuel oil (and kerosene) was used in only 21% of the building stock.

The presence of air-conditioning equipment varied substantially by type of buildings. Approximately 64% of nonresidential buildings were air conditioned, yet insignificant differences existed among the number of buildings that are cooled by window units, package units, or central systems. The building population was evenly divided between use of self-contained heating units and central heating units.

TABLE 4.20. Characteristics of the Housing Stock by Type of Housing Structure, 1978
(thousand housing units)

	Total Housing Units	Single Family Detached		Single Family Attached		Building With 2-4 Units		Building With 5 or More Units		Mobile Home		Other
		Own	Rent	Own	Rent	Own	Rent	Own	Rent	Own	Rent	
TOTAL HOUSING UNITS	76,608	42,074	5,711	2,233	878	2,337	8,268	551	8,361	3,773	949	1,433
YEAR HOUSE BUILT												
1939 or Earlier	25,159	12,570	2,598	787	221	1,499	3,737	116	2,800	48	--	782
140 to 1949	7,548	5,168	999	243	59	63	620	--	159	37	--	195
1950 to 1959	13,761	9,760	1,077	363	90	88	507	36	1,225	436	41	142
1960 to 1964	7,926	4,951	480	179	00	13	448	156	1,241	321	125	14
1965 to 1969	8,201	3,568	251	250	124	75	1,309	25	1,604	540	304	152
1970 to 1974	8,768	3,462	179	354	365	260	807	209	1,007	1,623	396	106
1975 or Later	5,245	2,594	127	55	20	339	839	51	325	768	83	41
ESTIMATED SIZE OF RESIDENCE (IN SQ FT)												
Less than 500	4,234	444	333	136	13	74	1,096	25	1,520	261	147	167
500 to 999	14,413	56,252	1,200	266	194	430	2,259	99	1,392	2,306	612	361
1,000 to 1,499	14,665	10,033	718	363	95	880	939	143	659	573	72	171
1,500 to 1,999	8,449	6,782	438	279	75	117	315	100	180	119	0-0	44
2,000 to 2,999	5,712	5,018	166	183	--	99	14	27	64	32	--	109
3,000 or More	2,210	1,953	47	14	14	23	123	--	36	--	--	--
Not Reported	26,924	12,592	2,809	953	487	714	3,522	197	4,509	482	118	541
NUMBER OF WINDOWS PER ROOM												
One or Less	26,370	11,679	1,506	1,003	578	1,001	4,028	378	5,279	524	79	513
Two	33,180	19,615	2,887	1,034	242	924	3,035	160	2,423	1,574	525	751
Three	11,329	6,978	992	212	37	225	1,036	35	432	1,056	157	169
Four or More	5,729	3,802	326	14	21	186	169	17	227	619	188	161
AIR CONDITIONING												
Central Air Conditioning Only	17,401	10,408	441	722	305	230	1,672	75	2,278	995	139	135
INDIVIDUAL Room Units Only	25,135	14,272	1,856	735	62	833	2,351	266	2,497	1,190	522	561
Central A/C and Room Units	235	235	--	--	--	--	--	--	--	--	--	--
No Air Conditioning	33,837	17,158	3,414	806	511	1,273	4,245	250	3,586	1,588	288	715

Source: DOE 1980b.

TABLE 4.21. Commercial Buildings: Type by Year Constructed, 1979
(estimated numbers in thousands)

<u>Building Characteristics</u>	<u>Total</u>	<u>1900 or Before</u>	<u>1901 to 1920</u>	<u>1921 to 1945</u>	<u>1946 to 1960</u>	<u>1961 to 1970</u>	<u>1971 to 1973</u>	<u>1974 to Present</u>
Commercial Buildings	3,995	321	408	783	1,008	744	205	525
Building Type								
Assembly	448	53	61	84	101	80	17	51
Automotive Sales and Service	401	13	25	74	127	97	23	42
Education	161	2	12	23	53	47	6	18
Food Sales	366	20	38	64	95	69	17	63
Health Care	44	3	2	4	11	11	3	11
Lodging	101	3	5	13	33	28	12	6
Office	600	46	53	117	118	121	41	104
Residential	347	68	72	97	63	30	7	10
Retail/Services	714	68	63	129	219	105	28	103
Warehouse and Storage	430	21	42	96	99	77	25	70
Other	237	15	22	45	50	48	18	39
Vacant	146	10	13	38	40	31	6	8

Notes: Data may not sum to totals due to rounding. A dash "-" represents or rounds to zero.
Source: DOE 1981c.

TABLE 4.22. Commercial Buildings: Type by Energy Sources Supplied to the Building, 1979 (estimated numbers in thousands)

<u>Building Characteristics</u>	<u>Total</u>	<u>Elec- tricity</u>	<u>Natural Gas</u>	<u>Fuel Oil/ Kerosene</u>	<u>Liquid Petroleum Gas</u>	<u>Wood</u>	<u>Coal</u>	<u>Steam</u>	<u>Other</u>
Commercial Buildings	3,995	3,867	2,248	813	294	114	55	38	16
Building Type									
Assembly	448	443	270	129	41	10	9	4	1
Automotive Sales and Service	401	395	203	132	32	18	6	1	2
Education	161	161	92	47	12	--	6	4	1
Food Sales	366	365	214	50	56	14	9	1	2
Health Care	44	44	28	10	2	--	--	2	1
Lodging	101	101	53	18	10	1	1	6	1
Office	600	599	356	94	25	8	5	9	5
Residential	347	345	260	107	22	26	6	1	--
Retail/Services	714	712	450	113	51	17	1	1	2
Warehouse and Storage	430	366	154	60	16	7	4	1	1
Other	237	230	110	42	25	11	8	4	1
Vacant	146	105	59	10	2	2	1	3	--

Notes: Rows do not sum to total because of multiple energy sources. Data may not sum to totals due to rounding. A dash "-" represents or rounds to zero.

Source: DOE 1981c.

TABLE 4.23. Commercial Buildings: Type by Heating System Characteristics, 1979
(estimated numbers in thousands)

Building Characteristics	Total	Heating System Characteristics								
		Self-Contained Units				Central System				
		Forced Air	Radiant			Forced Air	Radiant	Other	Other	None
			Electric Base-Boards	Radiators	Other					
Commercial Buildings	3,995	1,122	67	49	393	1,013	489	323	113	427
Building Type										
Assembly	448	88	6	3	37	169	66	59	7	15
Automotive Sales and Service	401	155	--	2	64	99	14	20	24	24
Education	161	37	1	2	9	38	45	26	2	2
Food Sales	366	143	3	1	44	93	27	19	14	23
Health Care	44	8	--	1	--	21	7	6	--	--
Lodging	101	22	4	--	19	17	23	10	3	2
Office	600	199	20	9	28	183	92	43	15	12
Residential	347	38	5	18	35	75	118	48	11	--
Retail/Services	714	253	18	11	78	185	47	54	14	55
Warehouse and Storage	430	108	4	3	30	58	20	16	6	184
Other	237	52	5	--	43	51	23	18	14	32
Vacant	146	21	--	--	6	25	7	4	4	77

Notes: Data may not sum to totals due to rounding. A dash "--" represents or rounds to zero.
Source: DOE 1981c.

TABLE 4.24. Commercial Buildings: Type by Air Conditioning Equipment, 1979
(estimated numbers in thousands)

<u>Building Characteristics</u>	<u>Total</u>	<u>Window Units</u>	<u>Package Units</u>	<u>Central System</u>	<u>Combination/ Other</u>	<u>No Air Conditioning</u>
Commercial Buildings	3,995	814	746	709	278	1,449
Building Type						
Assembly	448	47	85	95	46	175
Automotive Sales and Service	401	70	25	28	16	252
Education	161	37	28	31	13	53
Food Sales	366	95	106	77	25	64
Health Care	44	9	7	15	7	5
Lodging	101	30	10	16	10	35
Office	600	108	188	186	61	59
Residential	347	137	33	36	22	118
Retail/Services	714	169	163	130	35	216
Warehouse and Storage	430	47	40	54	17	272
Other	237	54	50	23	20	90
Vacant	146	10	12	18	6	100

Notes: Data may not sum to totals due to rounding. A dash "-" represents or rounds to zero.

Source: DOE 1981c.

TABLE 4.25. Commercial Buildings: Type by Glass as Percentage of Exterior Surface, 1979
(estimated numbers in thousands)

<u>Building Characteristics</u>	<u>Total</u>	<u>75% or More</u>	<u>At Least 50% But Less Than 75%</u>	<u>At Least 25% But Less Than 50%</u>	<u>Less Than 25%</u>
Commercial Buildings	3,995	55	247	1,000	2,693
Building Type					
Assembly	448	6	23	120	299
Automotive Sales and Service	401	3	37	135	226
Education	161	6	32	53	71
Food Sales	366	4	27	100	235
Health Care	44	1	3	14	26
Lodging	101	3	11	32	55
Office	600	10	42	170	379
Residential	347	3	18	102	224
Retail/Services	714	11	24	142	537
Warehouse and Storage	430	7	8	50	364
Other	237	1	12	44	180
Vacant	146	--	11	37	98

Notes: Data may not sum to totals due to rounding. A dash "-" represents or rounds to zero.

Source: DOE 1981c.

General Energy Conversion and Conservation System Statistics

Table 4.26 presents the appliance characteristics of residential buildings according to family income. Virtually all homes had at least one refrigerator and one oven. Nearly three fourths had a washing machine and over half had a clothes dryer. More than one third of residential buildings had freezers and dishwashers. The only major change noted in appliance use was an increase in ownership of dishwashers - 35% in 1978 versus 28% in 1974.

The most common refrigerator features were temperature controls (97%), separate freezer door (76%), and frost-free features (53%). Households with microwave ovens typically had convection gas or electric ovens as well. Table 4.27 presents inventories of commercial appliances for 1975; more current information is presently unavailable.

Inventories of water heating units have been limited to estimating the numbers of households that use specific energy sources (Table 4.28) for water heating according to primary heating fuel. To illustrate trends in consumer preference for water-heating devices, Tables 4.29 through 4.31 display manufacturer shipments of oil, gas, and electric water heaters.

To illustrate the market into which new window glazing and home insulation technologies must diffuse, Tables 4.32 and 4.33 were included. They estimate the presence of storm windows and attic insulation in single-family and mobile homes.

TABLE 4.26. Household Appliances by 1977 Family Income (thousand households)

	Total Households	1977 Family Income					
		Less Than \$5,000	\$5,000 to \$9,999	\$10,000 to \$14,999	\$15,000 to \$19,999	\$20,000 to \$24,999	\$25,000 or More
<u>Total Households</u>	76,608	11,030	14,623	14,604	11,635	9,808	14,908
<u>Refrigerator</u>							
One	66,013	10,242	13,272	12,912	10,029	8,255	11,304
Two or More	10,351	657	1,275	1,673	1,589	1,553	3,604
<u>Refrigerator Features</u>							
Temperature Control	74,229	9,939	14,048	14,224	11,405	9,780	14,834
Separate Freezer Door	58,428	6,071	9,836	11,205	9,593	8,169	13,555
Automatic Ice Maker	11,345	468	1,299	1,976	1,874	1,866	3,861
Extra Insulation	10,334	783	1,823	1,919	1,841	1,523	2,445
Energy-Saver Switch	9,812	410	1,020	1,812	1,777	1,352	3,340
Ice Water Maker	1,878	113	303	232	229	143	858
<u>Type of Defrost</u>							
Full Frost Free	40,509	2,985	5,690	7,942	7,158	6,090	10,645
Automatic Defrost	6,008	1,150	1,309	1,139	712	637	1,061
Manual Defrost	29,847	6,764	7,548	5,504	3,749	3,080	3,202
<u>Separate Food Freezer</u>	27,006	2,555	4,280	4,726	4,836	3,670	6,938
<u>Electric Oven</u>							
One	34,860	3,303	5,919	6,780	5,950	4,593	8,316
Two or More	5,117	187	532	793	751	807	2,048
Electric Oven and Microwave	4,411	137	213	587	808	572	2,094
<u>Gas Oven</u>							
One	34,576	6,834	7,825	6,600	4,888	4,288	4,149
Two or More	1,368	79	207	289	135	211	447
Gas Oven and Microwave	1,491	72	110	319	291	219	480
<u>Oven Features</u>							
Electric Oven							
Self Cleaning	9,026	376	785	1,366	1,542	1,467	3,491
Continuous Cleaning	3,385	30	256	598	596	404	1,501
Gas Oven							
Self Cleaning	2,594	392	459	605	438	285	415
Continuous Cleaning	2,424	117	320	581	397	406	604
<u>Microwave Oven</u>	5,970	253	323	906	1,083	790	2,614
<u>Range or Counter Top Burners</u>							
Electric Burners Only	38,992	3,526	5,318	7,431	6,479	5,157	10,081
Gas Burners Only	35,160	6,958	7,903	6,812	4,809	4,252	4,426
Both	1,714	150	334	234	296	325	375
<u>Cooking Fuel Used Most</u>							
Electricity	39,979	3,693	6,467	7,606	6,630	5,292	10,290
Natural Gas	31,204	5,983	6,770	5,946	4,290	3,988	4,227
Liquid Petroleum Gas (LPG)	4,928	1,069	1,334	938	698	513	376
Other	33	33	--	--	--	--	--
Not Applicable	464	251	52	114	17	16	14
<u>Washing Machine</u>							
Automatic	54,049	5,127	8,755	9,702	9,364	8,073	13,028
Wringer	3,422	798	1,358	632	299	180	156
<u>Clothes Dryer</u>							
Electric	34,523	2,245	4,953	6,226	6,288	5,559	9,252
Gas	11,030	524	1,489	1,880	1,959	1,925	3,253
<u>Dishwasher</u>	26,454	815	2,218	4,358	4,173	4,411	10,479

Note: Data may not sum to totals due to rounding.

Source: DOE 1980c.

TABLE 4.27. Estimated Commercial Appliance Inventory

Appliance Type	Fuel Type (a)	Size Range (10 ³ Btu/hr)	Average Size (10 ³ Btu/hr)	1975 Inventory (10 ³)	Replacement Rate (b) (%)
Space heating					
Cast-iron boilers (hot water & steam)	G	200-5500	850	501	42
Unit heaters	G	25-500	165	1343.7	63
Duct furnaces	G	62-500	260	476.7	61
Warm-air furnaces	G	150-480	250	347.2	35
Steel boilers (hot water & steam)	G	500-23,000	5200	11.5	42
Cast-iron boilers (hot water & steam)	O	200-5500	840	466.3	33
Warm-air furnaces	O	230-830	450	823.1	60
Steel boilers (hot water & steam)	O	500-23,000	5000	37.8	49
Unit heaters	O	100-500	250	89.1	54
Baseboard heaters	E	5	5	380.6	33
Heat pumps (single & split)	E	54-250	40	127.6	39
Unit heaters	E	10-200	70	409	29
Air conditioning					
Direct absorption (unitary)	G	125-250	180	161.4	40
Direct absorption (built up)	G	600	600	3.9	38
Indirect-fired absorption	G	1200-18,000	6000	8.6	23
Air conditioner, year-round unit	E	54-640	60	655.6	37
Air conditioner, condenser only	E	54-640	50	1751.6	34
Horizontal	E	54-640	60	878.6	37
Heat pump (single and split)	E	54-250	40	127.6	39
Centrifugal liquid chiller	E	900-12,000	4000	37.5	30.2
Reciprocating liquid chiller	E	78-1500	240	67.4	13.1
Water heating					
Water heater	G	75-1000	250	805.7	67
Water heater	O	200-700	300	155.7	33
Water heater	E	150	150	171	40
Refrigeration					
Central warehouse storage	E				
Supermarket display	E	2-40			
Restaurant storage	E	2-8	5	1984.8	53
Cooking					
Coffee makers & urns	G	15-25	20	65	3.7
Kettle, cooker, and pressure cooker	G	100-180	140	60	21.5
Boilers	G	100-120	110	75	11.9
Fryers	G	100-120	110	71	42.5
Griddles and grills	G	80-120	100	63	32.7
Deck and convection ovens	G	80-140	110	62	35.3
Ranges and braising pans	G	110-170	140	56	50.5
Coffeemakers and urns	E	5-15	10	65	3.2
Kettle, cooker, and pressure cooker	E	50-90	70	60	4.7
Broilers	E	50-60	55	75	1.4
Fryers	E	50-60	55	71	5.1
Griddles and grills	E	40-60	50	63	5.2
Deck and convection ovens	E	40-70	55	62	5.6
Ranges and braising pans	E	55-85	70	56	4.0
Lighting					
Incandescent	E		75(c)	95	170.7
Fluorescent	E		40(c)	90	379.6
High-intensity discharge	E		400(c)	85	110.6
Metal halide	E				12.3

(a) Fuel type: G--natural gas, E--electricity, O--oil.

(b) Percentage of annual sales used to replace worn-out equipment.

(c) Listed in terms of "watts."

Source: Oak Ridge National Laboratory 1979.

TABLE 4.28. Water-Heating Fuel in Residential Buildings, 1978
(thousand housing units)

<u>Water Heating Fuel</u>	
Natural Gas	42,123
Electricity	25,048
Fuel Oil, Kerosene	5,768
LPG	3,102
Wood	259
None	<u>308</u>
Total Housing Units	76,608

Source: DOE 1980c.

TABLE 4.29. Direct-Fired Oil Water Heater Shipments
(number of units)

<u>Year</u>	<u>Current(a) Industrial Reports</u>
1960	21,795
1961	N/A ^(b)
1962	N/A
1963	N/A
1964	N/A
1965	16,448
1966	16,244
1967	13,514
1968	10,389
1969	13,834
1970	13,642
1971	14,650
1972	15,600
1973	30,400
1974	26,700
1975	32,000
1976	38,000
1977	35,600

(a) Data prior to 1972 come from series MA-34N; all other data are from series MA-36F. The Gas Appliance Manufacturers Association, Inc., also publishes these data, which are, however, taken directly from the Current Industrial Reports.

(b) Not available.

Sources: Oak Ridge National Laboratory
1979.

TABLE 4.30. Electric Water Heater Shipments
(number of units)

<u>Year</u>	<u>Merchandising^(a)</u>	<u>Current Industrial Reports^(b)</u>
1960	715,000	679,000
1961	785,000	N/A ^(c)
1962	900,000	N/A
1963	950,000	N/A
1964	1,000,000	N/A
1965	1,095,000	1,095,000
1966	1,035,500	1,036,000
1967	1,261,000	1,398,500
1968	1,480,000	1,925,200
1969	1,549,000	1,924,100
1970	1,684,000	1,995,300
1971	1,922,000	2,210,800
1972	2,265,000	2,534,600
1973	2,591,000	2,806,600
1974	2,487,000	2,569,400
1975	2,183,000	2,246,700
1976	2,616,000	2,574,000
1977		3,079,300

(a) Merchandising data came from GAMA.

(b) Data previous to 1967 in series MA-34N come from the National Electrical Manufacturers Association in which estimates are based on reports from 60 to 70% of total industry shipments. This information is also available by storage size (i.e., gallon capacity).

(c) Not available.

Sources: Oak Ridge National Laboratory 1979.

TABLE 4.31. Gas Water Heater Shipments (number of units)

<u>Year</u>	<u>Merchandising^(a)</u>	<u>Current Industrial Reports^(b)</u>	<u>AGA</u>
1960	2,666,200	2,799,718	2,721,000
1961	2,671,500	N/A ^(c)	2,732,000
1962	2,876,000	N/A	2,876,000
1963	2,403,700	N/A	2,597,000
1964	2,724,100	N/A	2,724,000
1965	2,614,100	2,904,947	2,737,000
1966	2,636,440	2,788,650	2,637,000
1967	2,555,000	2,871,773	2,555,000
1968	2,756,000	2,977,256	2,756,000
1969	2,742,000	2,701,974	2,742,000
1970	2,785,000	2,910,371	2,785,000
1971	3,089,000	3,127,774	3,088,000
1972	3,163,000	3,320,200	3,163,000
1973	3,080,000	3,041,300	3,080,000
1974	2,569,000	2,955,400	2,569,000
1975	2,645,000	3,194,200	2,645,000
1976	3,114,000	3,267,500	3,112,000
1977	N/A	3,460,000	(N/A)

(a) Merchandising data come from GAMA. Data are also available by two fuel subcategories--natural gas and LP gas.

(b) Data earlier than 1971 are from Heating and Cooking Equipment, series MA-34N; all other data are from Major Household Appliances, series MA-36F.

(c) Not available.

Sources: Oak Ridge National Laboratory 1979.

TABLE 4.32. Attic Insulation in Occupied Single-Family and Mobile Homes, 1976
(10³ units)

<u>Region and Structure Type</u>	<u>Attic Insulation</u>			
	<u>Not Present</u>	<u>Present</u>	<u>Not Reported</u>	<u>Unknown</u>
United States				
Mobile homes	225.1	2,925.7	9.1	303.5
Single-family, detached	7457.6	35,139.8	165.5	3163.3
Single-family, attached	532.9	1,453.0	281.7	551.5
Northeast				
Mobile homes	17.0	253.9	1.2	19.7
Single-family, detached	956.6	6,535.5	42.8	288.2
Single-family, attached	282.9	646.5	34.3	235.4
North Central				
Mobile homes	30.5	617.6	0.7	46.0
Single-family, detached	1218.5	11,293.9	49.6	674.9
Single-family, attached	41.0	257.3	73.5	93.8
South				
Mobile homes	122.5	1,233.1	5.7	153.3
Single-family, detached	3671.5	11,352.0	48.9	1285.6
Single-family attached	103.7	367.4	114.1	106.3
West				
Mobile homes	55.1	821.1	1.5	84.5
Single-family, detached	1611.0	5,958.4	24.2	914.6
Single-family, attached	105.3	181.8	59.8	116.0

Source: Oak Ridge National Laboratory 1979.

TABLE 4.33. Storm Windows in Single-Family and Mobile Homes, 1976
(10³ units)

<u>Region and Structure Type</u>	<u>Storm Windows</u>			<u>Not Reported</u>
	<u>None</u>	<u>Some</u>	<u>All</u>	
United States				
Mobile homes	1,820.6	201.8	1,437.3	3.7
Single-family, detached	19,384.5	4937.5	21,464.9	139.3
Single-family, attached	938.0	360.1	1,239.1	281.9
Northeast				
Mobile homes	15.1	17.1	259.6	
Single-family, detached	497.6	1148.1	6,135.9	41.5
Single-family, attached	213.0	227.0	723.0	36.1
North Central				
Mobile homes	51.1	39.2	603.8	0.7
Single-family, detached	879.9	1536.3	10,776.4	44.3
Single-family, attached	65.2	37.2	289.7	73.5
South				
Mobile homes	1,106.1	80.8	324.7	3.0
Single-family, detached	11,146.0	1575.4	3,594.4	42.2
Single-family, attached	296.2	81.7	202.5	111.1
West				
Mobile homes	648.3	64.7	249.2	
Single-family, detached	6,861.0	677.7	958.2	11.3
Single-family, attached	363.6	14.2	23.9	61.1

Source: Oak Ridge National Laboratory 1979.

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SECTION 5.0

INDUSTRIAL ENERGY CONSUMPTION

SECTION 5.0

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INDUSTRIAL DATA QUALITY

<u>General Energy Consumption</u>		<u>Efficiencies and Energy Losses</u>		<u>Stock Characteristics</u>	
1,1979	general consumption by fuel type	3,1973	heat rejection in 6 industries	1,1980	boiler & process heater stocks-quantities and useful-life
1,1979	industry sub-groups' consumption by fuel type	2,1974	heat loss from steam leaks	1,1980	projected boiler requirements
2,1974	end-use consumption by industry sub-groups	2,1975	efficiencies of 7 industries	3	electric motor stocks
2,1974	energy consumption patterns of key industries (Btu consumption for specific processes)	3,1974	theoretical minimum fuel consumption for 8 industries	5	other boiler stock data
1,1979	consumption by 16 largest energy users	3,1972	conservation potential of selected industries	1,1980	industrial equipment inventories (in dollars)
1,1979	industry energy cost by fuel type	3,1975	efficiency of electric motors	5	industrial equipment inventories by industry and/or equipment type
		2,1977	second law efficiencies of select industries

- Date Quality Code:
1. Information is recent and representative of current trends.
 2. Information is dated yet is best available and/or representative of current trends.
 3. Information is of questionable quality; better data will be available.
 4. Information is of questionable quality; better data are unavailable.
 5. Information is absent from this report; data are being sought.
 6. Information is absent from this report; data are currently unavailable.

5.0 INDUSTRIAL ENERGY CONSUMPTION

The Industrial Sector of the U.S. economy accounts for slightly over one quarter (28.8%) of the nation's fuel consumption. Comprised of manufacturing, mining, agriculture, and construction firms and businesses, this sector is characterized by diversity; thousands of different energy-using processes and different kinds of machinery and equipment are commonly used. Although gross consumption is highly concentrated in a few industry groups, no one fuel or end use dominates the sector. Furthermore, an industry group often consumes several different types of fuel to produce a single product type. Complexity is added to the industrial energy picture by some industries' need to internally convert fuel forms (i.e., hydrocarbon fuels to electricity or coal to coke) or to consume captive fuel sources (i.e., coal consumption by mining operations or petroleum consumption by refiners).

Many reports describing the conservation potential in the industrial sector have been published during the last eight years. These reports have characteristically focused on a small group of industries (5 to 10 are usually chosen because they consume relatively large amounts of energy in absolute terms) and contain information on the application of new or previously unused techniques and processes that might conserve energy in a particular industry. Other reports have studied existing energy-use patterns to identify areas of waste and inefficiencies, but these reports also have concentrated mainly on industries that use large amounts of energy. Few studies have tried to detail the effect that previously unused and new technologies could have on energy use across the entire sector, nor have they commented on the research needs arising from bottlenecks or relative inefficiencies that only have an incremental impact on any one industry, but gain significance when all of the potential applications are aggregated.

This report presents a detailed and accurate account of who uses energy in the industrial sector, how they use it, and where trends or patterns extend beyond a specific industry. Consequently, this section contains data that describe fuel consumption, end uses, efficiencies of specific equipment and of whole production systems, stock characteristics, and miscellaneous information gleaned from various attempts to portray industrial energy use and misuse.

The data in this study are intended to be used to ascertain the potential for conservation in the industrial sector. The information can be used to assist in evaluating several key topics in the assessment of conservation potential, including the following:

- the speed with which new technology will enter the capital stock due to turnover
- the potential fuel savings resulting from the new application of a technology
- bottlenecks to greater efficiency, suggesting the need to look into new ways to perform existing functions
- areas of industrial energy use most likely to yield potential fuel savings
- the opportunity for employing fuel-saving techniques in multiple applications and in numerous industries
- areas where fuel switching will be most beneficial.

5.1 GENERAL CONSUMPTION

Despite the drastic changes that have occurred in the energy market during the last decade, present industrial energy patterns are not very different from those existing ten years ago. A fixed equipment stock and a relatively stable technology base have constrained industry to certain production processes. Even when new technologies embodied in new processes and equipment have been available, many industrial decision makers have been reluctant to employ resources to improve energy efficiency because of many uncertainties on the energy-use horizon. Incremental consumption changes have taken place in some areas (even some large changes have surfaced in a select group of industries such as glass-plate making), but they have occurred slowly without changing the overall character of the ways industry uses energy.

The only significant change that has occurred in industrial energy use concerns the mix of fuel types and electricity consumed. Figures 5.1 and 5.2 show average fuel costs (\$/MMBtu) in 1977 and the quantity of six key fuels purchased by manufacturing industries for the same years. While consumption

of most fuel types has gradually increased over the years, total use of every fuel type except natural gas was lower in 1979 than in 1978. Natural gas consumption rose from 5.60 quads in 1978 to 5.86 quads in 1979, an increase of nearly 5%. Fuel switching between natural gas and the other major fuels and electric energy, particularly residual fuel oil, which occurred from 1974 to 1978, reflected relative price changes but was more closely related to decreased availability of natural gas hookups and the instability of existing natural gas sources. Increased natural gas availability in 1979 explains the increase in consumption of this fuel during that year.

Figure 5.3 also depicts price increases among the six key industrial fuels by indicating the cost per Btu (1971 is the base year). Natural gas prices have increased over 500% between 1971 and 1979, whereas the cost of purchased electric energy has increased nearly three-fold during that same time period.

FIGURE 5.1. U.S. Manufacturing Energy Costs, 1967-1979

FIGURE 5.2. U.S. Manufacturing Gross Energy Consumption, 1967-1979

FIGURE 5.3. Cost of Selected Fuels and Purchased Electric Energy Consumed by All Manufacturing Industries, 1967, 1971, and 1974-1979, Per Btu (Department of Commerce 1981a)

Types of Fuel Consumed by Each Industry Group

Table 5.1 presents the gross fuel consumed by each manufacturing category for the years 1977 to 1979 in quadrillion Btu. The categories used in Table 5.1 were selected from a 2-digit Standard Industrial Code (SIC) classification that appears in the left-hand column. This level of aggregation is used to group together industries that produce similar products and can be assumed to use similar production processes. Tables in Section 5.2 break down energy consumption into smaller groupings (down to the 4-digit SIC level) for several industries, if more detail is desired.

The decrease of natural gas consumption relative to other key fuels is most clearly seen in Figure 5.4. Each fuel type, except natural gas, has accounted for a larger portion of total industry consumption during the period from 1971 to 1974. Natural gas use totaled 55% of all industrial consumption in 1971 but dropped to about 45% by 1978.

Table 5.2 is a more disaggregated description of energy use; it uses the same industrial categories, but shows how much of each fuel type (in trillion Btu) was used by each industry group in 1974 and what percentage of total fuel consumption by that industry group was used by that fuel type. For example, in the food processing industries (SIC 20), 75.3 trillion Btu of coal was consumed. This consumption accounted for 0.4% of the total amount of fuel consumed by that industry group. Although the information in Table 5.2 is seven years old, it is the best that is presently available and is compatible with subsequent end-use energy information that is contained in Tables 5.4 and 5.5. If more current data are desired on the amount of each fuel type that industry consumes, the reader can refer to the most recent editions of either the Department of Energy (DOE) Monthly Energy Review or the Department of Commerce Annual Survey of Manufacturers Fuels and Electric Energy Consumed Supplement. Updating this information would be highly beneficial, although the information conveyed by these tables is still useful since energy-use patterns have not changed much since 1974.^(a) Levels of use have changed somewhat since 1974, but the relative use of fuels and performance of end uses appearing in 1974 is still indicative of industry today.

(a) Still unavailable.

TABLE 5.1. Fuel Consumption by Industry Group, U.S., 1977-1979,
Quadrillion Btu

SIC Code	1977	1978	1979
20 Food and Kindred Products	0.9524	0.9802	0.9423
21 Tobacco Products	0.0208	0.0208	0.0212
22 Textile Mill Products	0.3392	0.3265	0.3159
23 Apparel, Other Textile Products	0.0656	0.0692	0.0632
24 Lumber and Wood Products	0.2277	0.2308	0.2247
25 Furniture and Fixtures	0.0527	0.0553	0.0514
26 Paper and Allied Products	1.3084	1.3013	0.13102
27 Printing and Publishing	0.0923	0.0915	0.0896
28 Chemicals, Allied Products	2.9785	2.9001	2.794
29 Petroleum and Coal Products	1.3034	1.2227	1.2413
30 Rubber, Miscellaneous Plastic Products	0.2723	0.2606	0.2489
31 Leather, Leather Products	0.0231	0.0216	0.0199
32 Stone, Clay, Glass Products	1.2518	1.3003	1.2705
33 Primary Metal Industries	2.5394	2.7109	0.7020
34 Fabricated Metal Products	0.03953	0.4002	0.3889
35 Machinery, Except Electric	0.3396	0.3507	0.3546
36 Electric, Electronic Equipment	0.2493	0.2549	0.2511
37 Transportation Equipment	0.3899	0.3977	0.3833
38 Instruments, Related Products	0.0784	0.0790	0.0811
39 Miscellaneous Manufacturing Industries	0.0491	0.0490	0.0476
United States	12.8882	12.9234	12.8015

Source: U.S. Department of Commerce 1980 and 1981b.

FIGURE 5.4. Percent of Manufacturing Energy Consumption by Selected Fuels and Purchased Electric Energy: 1971 and 1974-1978 (Department of Commerce 1981a)

TABLE 5.2. Type of Fuel Consumed by Industry Group., U.S., 1974 in 10¹² Btu and as a Percent of Total Consumed by All Industry

5.2a. MANUFACTURING

SIC Code	Coal-T	Coke	Distillate	Residual	Miscellaneous Petroleum	LPG	Natural Gas	Other Gas	Electricity ^(a)	Other	All
20 Food	75.3 0.4	1.6 0.0	66.8 0.3	65.5 0.3	0.0 0.0	0.0 0.0	475.6 2.4	0.0 0.0	126.7 0.6	123.2 0.6	934.7 0.6
21 Tobacco	5.5 0.0	0.0 0.0	1.1 0.0	4.1 0.0	0.0 0.0	0.0 0.0	4.5 0.0	0.0 0.0	3.5 0.0	0.3 0.0	1.1 0.1
22 Textile	22.0 0.1	0.0 0.0	26.0 0.1	36.7 0.2	0.0 0.0	0.0 0.0	102.1 0.5	0.0 0.0	91.3 0.5	38.1 0.2	316.7 1.6
23 Apparel	1.0 0.0	0.0 0.0	4.3 0.0	1.4 0.0	0.0 0.0	0.0 0.0	15.4 0.1	0.0 0.0	25.0 0.1	17.9 0.1	04.9 0.3
24 Lumber	2.8 0.0	0.0 0.0	34.1 0.2	8.3 0.0	0.0 0.0	0.0 0.0	72.9 0.4	0.0 0.0	30.5 0.3	84.7 0.4	253.3 1.3
25 Furniture	2.8 0.0	0.0 0.0	5.1 0.0	2.5 0.0	0.0 0.0	0.0 0.0	25.3 0.1	0.0 0.0	14.2 0.1	9.1 0.0	59.1 0.3
26 Paper	208.8 1.0	0.0 0.0	25.2 0.1	488.6 2.4	0.0 0.0	62.6 0.3	414.3 2.1	0.0 0.0	132.7 0.7	891.6 4.4	2223.7 11.1
27 Painting	0.4 0.0	0.0 0.0	5.2 0.0	2.0 0.0	0.0 0.0	0.0 0.0	31.4 0.2	0.0 0.0	31.5 0.2	18.2 0.1	68.7 0.4
28 Chemicals	322.2 1.6	2.5 0.0	120.1 0.6	165.1 0.8	725.8 3.6	1074.3 5.3	2092.6 10.4	0.0 0.0	436.9 2.2	271.5 1.4	5211.0 25.9
29 Petroleum and Coal	5.3 0.0	0.0 0.0	50.3 0.3	281.5 1.4	374.0 1.9	39.5 0.2	111.4 5.5	1043.1 ^(b) 5.2	83.7 0.4	83.2 0.4	3071.9 15.3
30 Rubber	29.6 0.1	0.0 0.0	18.3 0.1	25.7 0.1	01.0 0.0	0.0 0.0	16.6 0.4	0.0 0.0	64.7 0.3	26.0 0.1	250.8 1.2
31 Leather	1.3 0.0	0.0 0.0	3.0 0.0	3.3 0.0	0.0 0.0	0.0 0.0	5.2 0.0	0.0 0.0	5.5 0.0	3.6 0.0	21.8 0.1
32 Stone	233.0 1.2	16.0 0.1	76.0 0.4	49.5 0.2	0.0 0.0	0.0 0.0	696.3 3.5	0.0 0.0	99.6 0.5	130.9 0.7	1301.3 6.5
32 Stone	233.0 1.2	16.0 0.1	76.0 0.4	49.5 0.2	0.0 0.0	0.0 0.0	696.3 3.5	0.0 0.0	99.6 0.5	130.9 0.7	1301.3 6.5
33 Primary Metals	263.91 13.1	-50.5 -0.3	41.1 0.2	281.1 1.4	92.4 0.5	4.1 0.0	1315.0 6.5	-30.7 ^(c) -0.2	536.3 2.7	-25.6 -0.1	4802.3 23.9
34 Fabricated Metal	11.1 0.1	2.4 0.0	22.5 0.1	16.4 0.1	0.0 0.0	0.0 0.0	208.2 1.0	0.0 0.0	889.4 0.4	38.3 0.3	407.2 2.0

TABLE 5.2. (continued)

5.2a. MANUFACTURING

SIC Code	Coal-T	Coke	Distillate	Residual	Miscellaneous Petroleum	LPG	Natural Gas	Other Gas	Electricity	Other	All
35 Machinery	20.1 0.1	4.3 0.0	17.0 0.1	16.5 0.1	0.0 0.0	0.0 0.0	1654.3 0.8	0.0 0.0	90.7 0.5	48.2 0.2	361.2 1.8
36 Electric	13.2 0.1	0.6 0.0	11.1 0.1	10.3 0.1	0.0 0.0	0.0 0.0	96.9 0.5	0.0 0.0	84.2 0.4	30.4 0.2	46.8 1.2
37 Transportation Equipment	47.6 0.2	3.0 0.0	16.7 0.1	23.8 0.1	0.0 0.0	0.0 0.0	144.1 0.7	0.0 0.0	97.0 0.5	38.1 0.2	370.3 1.8
38 Instruments	-0.0 -0.0	0.0 0.0	3.3 0.0	9.4 0.0	0.0 0.0	0.0 0.0	15.8 0.1	0.0 0.0	15.6 0.1	6.4 0.0	50.4 0.3
39 Miscellaneous	0.8 0.0	0.0 0.0	4.4 0.0	4.1 0.0	0.0 0.0	0.0 0.0	18.8 0.1	0.0 0.0	13.4 0.1	9.0 0.0	50.5 0.3
All	3642.0 18.1	-20.1 -0.1	551.6 2.7	1495.7 7.4	1192.2 5.9	1180.5 5.9	7096.5 35.3	1012.4 5.0	2091.9 10.4	1863.0 9.3	20105.8 100.0

(a) Defined as 1 kWh equals 3412 Btus.

(b) Refinery off gases.

(c) Coke oven gas and blast furnace gas. Production was about 364.7 trillion Btu; consumption was estimated at 334 trillion Btu. In the long run, with perfect measurement, production, and consumption will be equal, and net consumption will be zero.

5.2b MINING

SIC Code	Coal-T	Coke	Distillate	Residual	Miscellaneous Petroleum	LPG	Natural Gas	Other Gas	Electricity ^(a)
10 Metals	18.5 1.0	2.1 0.1	24.6 1.3	4.8 0.3	1.3 0.1	77.5 4.0	39.3 2.0	6.1 0.3	174.1 9.0
11 Anthracite	0.3 0.0	0.2 0.0	1.0 0.1	0.2 0.0	0.1 0.0	0.0 0.0	0.8 0.0	0.6 0.0	3.1 0.2
12 Bituminous and Lignite	7.9 0.4	3.4 0.2	29.3 1.3	4.2 0.2	1.9 0.1	0.7 0.0	27.3 1.4	8.3 0.4	78.3 4.1
13 Oil and Gas Extraction	0.0 0.0	14.7 0.8	34.5 1.8	20.6 1.1	56.5 2.9	1140.4 59.1	46.1 2.4	49.2 2.6	1362.0 70.6
14 Non-Metallic Minerals	12.7 0.7	7.0 0.4	33.9 1.8	18.8 1.0	1.7 0.1	150.4 7.8	28.8 1.5	59.1 3.1	16.2 16.2
All	39.4 2.0	27.4 1.4	119.3 6.2	48.6 2.5	60.8 3.2	1369.0 70.9	142.1 7.4	123.4 6.4	1930.1 ^(b) 100.0

(a) Defined as 1 kWh equals 3412 Btus.

(b) Census Bureau estimate; Bureau of Mines estimate is about 500 trillion Btu higher.

Source: DOE 1978.

The Sixteen Largest Industrial Energy Consumers

Because of the relatively high concentration of energy consumption among the top 16 manufacturing energy users, many studies focus on energy conservation potential in these industries. Despite the high rate of energy use among industries such as steel mills and paper mills, energy costs rarely exceed 10 to 15% of the total cost of all inputs, including labor costs, in any particular firm or business. The small size of energy costs, relative to all other production costs is one reason that the industrial sector has been able to absorb large fuel price increases. Firms that must compete with more energy-efficient competitors have suffered the most damage.

Another important fact is that although these 16 manufacturing industries consume the largest amounts of energy, other industries exist whose energy costs comprise a larger proportion of their total costs, indicating that they have more to gain from each marginal decrease in energy costs than less energy-intensive industries. Still, Table 5.3 and Figures 5.5 and 5.6 indicate areas in which the largest increases fuel savings could take place. Section 5.2 provides the more detailed data.

TABLE 5.3. Sixteen Largest Energy Consumers in U.S. Industrial Sector, 1977-1979 (purchased fuels and electric energy consumed in Btus)

<u>Rank</u>	<u>SIC Code</u>	<u>Industry</u>	<u>Btus Consumed</u> <u>(trillions)</u>
			<u>1977</u>
1	3312	Blast furnaces and steel mills	1,519.2
2	2911	Petroleum refining	1,222.8
3	2869	Industrial organic chemicals, n.e.c.	1,095.9
4	2621	Papermills, except building paper	587.5
(X)		Largest 4 Industries	4,425.4
5	2631	Paperboard mills	482.8
6	3241	Cement, hydraulic	453.1
7	2819	Industrial inorganic chemicals, n.e.c.	422.2
8	3334	Primary aluminum	327.7
(X)		Largest 8 Industries	6,111.2
9	2873	Nitrogenous fertilizers	251.5
10	2821	Plastics, materials and resins	182.7
11	2865	Cyclic crudes and intermediates	171.9
12	2824	Organic fibers, noncellulosic	147.9
13	3221	Glass containers	144.5
14	3079	Miscellaneous plastics products	139.3
15	3714	Motor vehicle parts and accessories	137.0
16	2812	Alkalies and chlorine	126.9
(X)		Largest 16 Industries	7,412.9
(X)		Other Industries	5,516.1
		All industries	12,929.0

(X) Not applicable.

TABLE 5.3. (continued)

Rank	SIC Code	Industry	Btus Consumed (trillions)	
			1978	1979
1	3312	Blast furnaces and steel mills	1667.0	1633.6
2	2911	Petroleum refining	1033.9	1153.5
3	2869	Industrial organic chemicals, n.e.c.	1039.5	995.0
4	2621	Papermills, except building paper	571.1	602.7
(X)		Largest 4 Industries	4311.5	4384.8
5	2631	Paperboard mills	488.5	464.8
6	3241	Cement, hydraulic	469.2	456.3
7	2819	Industrial inorganic chemicals, n.e.c.	403.3	401.0
8	3334	Primary aluminum	329.3	349.9
(X)		Largest 8 Industries	6001.8	6056.80
9	2873	Nitrogenous fertilizers	276.9	248.6
10	2821	Plastics materials and resins	177.5	203.3
11	2865	Cyclic crudes and intermediates	156.8	144.0
12	2824	Organic fibers, noncellulosic	140.3	137.8
13	3321	Gray iron foundries	138.7	137.4
14	3221	Glass containers	147.8	136.1
15		Miscellaneous plastics products	137.3	131.1
16		Motor vehicle parts and accessories	139.2	128.3
(X)		Largest 16 Industries	7,316.3	7,323.5
(X)		Other Industries	5,607.1	5,478.0
		All Industries	12,923.4	12,801.5

(X) Not applicable.

Source: Department of Commerce 1980 and 1981b.

FIGURE 5.5. Fuels and Purchased Electric Energy Consumed by Largest 4, 8, and 16 Energy-Consuming Industries as a Percent of Total Consumed by All Manufacturing Industries, 1977-1979 (Department of Commerce 1980, 1981a, 1981b)

FIGURE 5.6. Fuels and Purchased Electric Energy Consumed by 8 Largest Consuming Industries: 1974-1979

Gross Consumption by End Use

Figure 5.7 depicts the amount of energy industry uses for each type of end use. The end-use categories shown were chosen so that similar applications could be traced through different industries. Although Figure 5.7 uses 1974 data, the relative size of each end use has not changed significantly since then. Obviously, more current data would be preferred, but the information presented here is the most current presently available. DOE is expected to release more recent industrial data late in 1981.

TOTAL: 20.1 QUADS

FIGURE 5.7. End-Use Energy Consumption in Manufacturing, 1974

5.2 AREAS OF SIGNIFICANT CONSUMPTION

Examination of energy consumption's most salient characteristics allows industrial energy use to be categorized into sixteen generic end uses. This categorization cannot be done as easily in the industrial sector as for other sectors because end uses seem to be much more distinct in transportation and residential/commercial use. Although this classification scheme may be arbitrary (due to overlapping processes and measurement problems), it does have advantages. Dividing end uses into sixteen categories and then aggregating totals across industrial groups simplifies the task of identifying conservation potential. If a particular end use can be linked to a distinct energy conservation strategy, the consequences of implementing that strategy can be easily traced across the whole economy or across the entire industry group without separately studying each type of machinery or every process linked to that end use.

Amount of Each Fuel Type Consumed by Each End Use

Information on the amount of each fuel type used in performing each type of end use, which is presented in Table 5.4, conveys an especially important aspect of industrial energy-use patterns. Each combination of end use and fuel type appearing in the table can probably be linked to one type of technology. If that technology is improved, its impact can be identified using the subsequent consumption data in this section (Table 5.6). Similarly, if a particular technology is known to be inefficient, the benefits of research and development in that area can be calculated. For example, the conservation potential of a newly developed coal-burning boiler technology can be determined by finding the intersection in Table 5.6 of coal use and process steam, which is the probable major application of any coal boiler technology. The size of current coal-process steam consumption indicates the potential savings.

Table 5.4 is set up in a matrix form with fuel types appearing in the left hand column and end uses listed at the top of each column (the box surrounding DIR-H-T indicates that the other direct heat headings are subsets; see the key for further explanation of the abbreviations). The two figures at

the intersection of each fuel type and end use specify 1) how many trillion Btus are provided for that end use by that fuel type and 2) what percentage of total industrial energy consumption that fuel end-use pair accounts for. Table 5.6 is divided into two sections, one for the manufacturing industries and one for the mining industries (no data were available for the construction sector). Unfortunately, the data used in Table 5.4 date back to 1974; however, as discussed in Section 5.1, these data are believed to be still relevant to today's industrial energy-use patterns.

TABLE 5.4. Gross Consumption by End-Use Type of Fuel Consumed by Industrial End Use, U.S., 1974 in 10¹² Btu and as a Percent of Total Consumed by Industrial End Uses^(a)

5.4a. MANUFACTURING

	Space-H	Space-C	Space-N	Light	Dir-H-T ^(a)	Dir-H-1	Dir-H-2	Dir-H-3	Dir-H-4	Dir-H-N	Raw-Mat	P-Steam	El-Genr	Coke-PR	Mach-Dr	Electrolyt	Other	All
Coal-T ^(b)	4.6 0.0	0.0 0.0	0.0 0.0	0.0 0.0	237.6 1.2	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	237.6 1.2	0.0 0.0	544.8 2.7	228.0 1.1	2363.1 11.8	0.0 0.0	0.0 0.0	263.9 1.3	3642.0 18.1
Coke	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	29.4 0.1	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	29.4 0.1	1462.5 7.3	1.7 0.0	2.4 0.0	1629.1 -8.1	0.0 0.0	0.0 0.0	113.1 0.6	-20.1 -0.1
Dist.	6.2 0.0	0.0 0.0	0.0 0.0	0.0 0.0	144.6 0.7	18.9 0.1	28.9 0.1	7.6 0.0	12.5 0.1	76.7 0.4	0.0 0.0	141.3 0.7	12.7 0.1	3.4 0.0	28.9 0.1	0.0 0.0	214.5 1.1	551.6 2.7
Resid.	7.4 0.0	0.0 0.0	0.0 0.0	0.0 0.0	578.6 2.9	56.8 0.3	198.2 0.8	10.6 0.1	16.7 0.1	269.4 1.3	0.0 0.0	555.5 3.8	99.8 0.5	0.0 0.0	15.7 0.1	0.0 0.0	238.6 1.2	1495.7 7.4
Misc.-P	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	382.2 1.9	0.0 0.0	0.0 0.0	372.1 1.9	0.0 0.0	10.1 0.1	808.1 4.0	0.0 0.0	0.8 0.0	0.0 0.0	1.1 0.0	0.0 0.0	0.0 0.0	1192.2 5.9
LPG	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	30.9 0.2	5.9 0.0	21.2 0.1	1.4 0.0	0.0 0.0	2.4 0.0	1074.3 5.3	9.8 0.0	0.7 0.0	0.0 0.0	0.6 0.0	0.0 0.0	64.2 0.3	1180.5 5.9
Nat. Gas	39.8 0.2	0.0 0.0	0.0 0.0	0.0 0.0	2705.9 13.5	256.5 1.3	636.8 3.2	234.4 1.2	126.2 0.6	1372.4 6.8	475.4 2.4	1699.5 8.5	376.9 1.9	1.2 0.0	118.4 0.6	0.0 0.0	1679.5 8.4	7096.5 35.3
Oth. Gas	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	1030.7 5.1	158.9 0.8	558.5 2.4	37.4 0.2	0.0 0.0	276.0 1.4	0.0 0.0	274.6 1.4	52.5 0.3	-268.1 -1.3	19.0 0.1	0.0 0.0	-96.6 -0.5	1012.4 5.0
Hydro	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.4 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.4 0.0	0.0 0.0	0.0 0.0	-25.1 -0.1	0.0 0.0	11.7 0.1	13.0 0.1	0.0 0.0	0.0 0.0
Elec. ^(b)	2.1 0.0	30.4 0.2	3.4 0.0	42.3 0.2	102.7 0.5	0.0 0.0	0.0 0.0	36.0 0.2	3.0 0.0	63.7 0.3	0.0 0.0	0.0 0.0	-292.5 -1.5	7.0 0.0	809.8 4.0	373.8 1.9	1013.0 5.0	2091.9 10.4
Other	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	61.3 0.3	0.0 0.0	0.0 0.0	25.3 0.1	0.0 0.0	35.9 0.2	55.6 0.3	1004.0 5.0	45.1 0.2	-125.1 -0.6	0.0 0.0	0.0 0.0	822.2 4.1	1863.0 9.3
All	60.1 0.3	30.4 0.2	3.4 0.0	42.3 0.2	5304.4 26.4	497.0 2.5	1403.6 7.0	724.8 3.6	158.4 0.8	2374.1 11.8	3875.9 19.3	4231.1 21.0	501.5 2.5	352.3 1.8	1005.1 5.0	386.9 1.9	4312.5 21.4	20105.3 100.0

(a) Brackets indicate subdivisions of direct heat.

(b) Defined as 1 kWh equals 3412 Btus.

Source: DOE 1978.

TABLE 5.4. (continued)

5.4b MINING

	Dir-H-T ^(a)	[Dir-H-1]	[Dir-H-3]	[Dir-H-N]	P-Steam	El-Genr	Mach-Dr	Electrolyt	Other	All
Coal-T	7.9 0.4	0.0 0.0	7.9 0.4	0.0 0.0	0.0 0.0	17.7 0.9	0.0 0.0	0.0 0.0	13.7 0.7	39.4 2.0
Mo-Gas	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	5.5 0.3	0.0 0.0	22.0 1.1	27.4 1.4
Dist	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.2 0.0	49.6 2.6	0.0 0.0	69.5 3.6	119.3 6.2
Resid	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	48.6 2.5	48.6 2.5
Misc-P	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	2.5 0.1	0.0 0.0	58.5 3.0	60.8 3.2
Nat. Gas	58.2 3.0	5.2 0.3	46.5 2.4	6.4 0.3	2.8 0.1	9.5 0.5	0.0 0.0	0.0 0.0	1298.5 67.3	1369.0 70.9
Elec. ^(b)	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	-10.7 -0.6	59.6 3.1	0.1 0.0	93.1 4.8	142.1 7.4
Other	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.3 0.0	0.1 0.0	0.0 0.0	0.0 0.0	123.0 6.4	123.4 6.4
All	66.1 3.4	5.2 0.3	54.4 2.8	6.4 0.3	3.1 0.2	16.9 0.9	117.2 6.1	0.1 0.0	1726.7 89.5	1930.1 ^(c) 100.0

(a) Brackets indicate subdivisions of direct heat.

(b) Defined as 1 kWh equals 3412 Btus.

(c) Total based on Bureau of Census data. Bureau of Mines estimates total mining consumption to be 500 trillion Btu higher.

TABLE 5.4. (continued)

<u>Abbreviations</u>	<u>Explanation</u>
Space-T	Space Conditioning Total (Heating and Cooling)
Space-C	Space Heating
Space-C	Space Cooling
Space-N	Space Conditioning, nsk ^(a)
Water-H	Water heating
Cooking	Cooking
Light	Lighting
Clo-Dry	Clothes Drying
Refrig	Refrigeration
Applian	Other Appliances
Dir-H-T	Direct Heat-Total
Dir-H-1	Direct Heat-Below 600 ^o F
Dir-H-2	Direct Heat-600 to 1000 ^o F
Dir-H-3	Direct Heat-1000 to 1500 ^o F
Dir-H-4	Direct Heat Above 1500 ^o F
Dir-H-N	Direct Heat, nsk ^(a)
Raw-Mat	Raw Material
P-Steam	Generation of Process Steam
El-Genr	Electricity Generation
Coke-Pr	Coke Production
Mach-Dr	Machine Drive
Eltrolyt	Electrolyte Processes
Farmveh	Farm Vehicles
Con-Veh	Construction Vehicles
Other	Other Uses, nak/nec ^(b)
Frght-T	Freight-Total

(a) Not specified by kind.

(b) Not elsewhere classified.

Amount of Each End Use Performed by Each Industry Group

Table 5.5 is another breakdown of the same data set presented in Tables 5.2 and 5.4. The data are dated, yet still relevant and hopefully will be updated soon. Table 5.5, which is presented in two sections (one for the manufacturing industries and one for the mining industries), contains data on how many trillion Btus each industry group consumed for every end use performed by that industry. Under each Btu figure is the percentage of total mining (or manufacturing) consumption used by that industry group for that end use. For example, Table 5.5 indicates that to apply direct heat the paper industries (SIC 26) consumed 146.4 trillion Btu, which accounted for 0.7% of all manufacturing energy consumption.

TABLE 5.5. Types of End Use Performed by 2-Digit SIC Industry Groups, U.S., in 10¹² Btu and as a Percent of All Industry Consumption

5.5A MANUFACTURING

	Space-H	Space-C	Space-N	Light	Dir-H-T	Dir-H-1	Dir-H-2	Dir-H-3	Dir-H-4	Dir-H-N	Raw-Mat	P-Steam	El-Genr	Coke-PR	Mach-Dr	Eltrolyt	Other	All
Food 20	30.6 0.2	0.0 0.0	3.4 0.0	31.2 0.2	94.1 0.5	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	94.1 0.5	0.0 0.0	477.8 2.4	18.4 0.1	0.0 0.0	98.7 0.5	0.0 0.0	180.6 0.9	934.7 4.6
Tbacco 21	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	19.1 0.1	19.1 0.1
Textil 22	10.6 0.1	30.4 0.2	0.0 0.0	11.1 0.1	26.0 0.1	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	26.0 0.1	0.0 0.0	144.3 0.7	2.7 0.0	0.0 0.0	44.2 0.2	0.0 0.0	47.5 0.2	316.7 1.6
Apparl 23	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	64.9 0.3	64.9 0.3
Lumber 24	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	253.3 1.3	253.3 1.3
Furnit 25	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	59.1 0.3	59.1 0.3
Paper 26	8.3 0.0	0.0 0.0	0.0 0.0	0.0 0.0	146.4 0.7	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	1549.8 7.7	111.5 0.6	0.0 0.0	226.0 1.1	0.0 0.0	181.6 0.9	2223.7 11.1
Print 27	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	-0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	88.7 0.4	88.7 0.4
Chem 28	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	573.4 2.9	112.9 0.6	27.8 0.1	274.3 1.4	158.4 0.8	0.0 0.0	2331.2 11.6	1322.2 6.6	129.3 0.6	0.0 0.0	449.5 2.2	126.8 0.6	278.6 1.4	5211.0 25.9
Petref 29	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	2210.4 11.0	384.1 1.9	1375.8 6.8	450.5 2.2	0.0 0.0	0.0 0.0	0.0 0.0	646.1 3.2	32.3 0.2	0.0 0.0	146.8 0.7	0.0 0.0	36.3 0.2	3071.9 15.3
Rubber 30	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	250.8 1.2	250.8 1.2
Leathr 31	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	21.8 0.1	21.8 0.1
Stone 32	10.6 0.1	0.0 0.0	0.0 0.0	0.0 0.0	1005.5 5.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	1005.5 5.0	0.0 0.0	0.0 0.0	4.3 0.0	0.0 0.0	20.5 0.1	0.0 0.0	260.0 1.3	1301.3 6.5
Pmetal 33	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	1248.4 6.2	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	1248.4 6.2	1544.7 2.7	90.9 0.5	203.1 1.0	352.3 1.8	19.1 0.1	260.1 1.3	1083.8 5.4	4802.3 23.9
Fabmet 34	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	407.2 2.0	407.2 2.0

TABLE 5.5. (continued)

5.5A MANUFACTURING

	Space-H	Space-C	Space-R	Light	Dir-H-T	Dir-H-1	Dir-H-2	Dir-H-3	Dir-H-4	Dir-H-N	Raw-Mat	P-Steam	El-Genr	Coke-PR	Mach-Dr	Electrolyt	Other	All
Machin 35	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	361.2 1.8	361.2 1.8
Elmach 36	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	246.8 1.2	246.8 1.2
Transp 37	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	370.3 1.8	370.3 1.8
Measure 38	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	50.4 0.3	50.4 0.3
Misman 39	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	50.5 0.3	50.5 0.3
Paper 26A(a)	8.3 0.0	0.0 0.0	0.0 0.0	0.0 0.0	146.4 0.7	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	1549.8 7.7	111.5 0.6	0.0 0.0	226.0 1.1	0.0 0.0	52.6 0.3	2104.7 10.5
Paper 26B(a)	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	119.0 0.6	119.0 0.6
Steel 33A(b)	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	1097.8 5.5	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	1097.8 5.5	1462.5 7.3	90.9 0.5	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	325.7 1.6	3421.4 17.0
Alumi 33B(b)	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	150.6 0.7	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	150.6 0.7	82.3 0.4	0.0 0.0	110.7 0.6	0.0 0.0	19.1 0.1	260.1 1.3	1.6 0.0	624.4 3.1
Othph 33C(b)	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	756.5 3.8	756.5 3.3
All-Ind	60.1 0.3	30.4 0.2	3.4 0.0	42.3 0.2	5304.4 26.4	497.0 2.5	1403.6 7.0	724.8 3.6	158.4 0.8	2374.1 11.8	3875.9 19.3	4231.1 21.0	501.5 2.5	352.3 1.8	1005.1 5.0	386.9 1.9	4312.5 21.4	20105.8 100.0

(a) Subdivisions of the Paper Industry.

(b) Subdivisions of the Primary Metals Industry.

TABLE 5.5. (continued)

5.5b MINING

	<u>Dir-H-T</u>	<u>Dir-H-1</u>	<u>Dir-H-3</u>	<u>Dir-H-N</u>	<u>P-Steam</u>	<u>El-Genr</u>	<u>Mach-Dr</u>	<u>Eltrolyt</u>	<u>Other</u>	<u>All</u>
Minemt 10	58.2 3.0	7.2 0.3	46.5 2.4	6.4 0.3	3.1 0.2	16.9 0.9	61.4 3.2	0.1 0.0	34.5 1.8	174.1 9.0
Minean 11	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	3.1 0.2	3.1 0.2
Minebl 12	7.9 0.4	0.0 0.0	7.9 0.4	0.0 0.0	0.0 0.0	0.0 0.0	55.8 2.9	0.0 0.0	14.6 0.8	78.3 4.1
Mineog 13	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	1362.0 70.6	1362.0 70.6
Minenm 14	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	0.0 0.0	312.4 16.2	312.4 16.2
All-Ind	66.1 3.4	7.2 0.3	54.4 2.8	6.4 0.3	3.1 0.2	16.9 0.9	117.2 6.1	0.1 0.0	1726.7 89.5	1930.1 ^(f) 100.0

Source: DOE 1978.

TABLE 5.5. (continued)

<u>Abbreviation</u>	<u>Explanation</u>
Food 20	Food and Kindred Products
Tbacco 21	Tobacco Manufacturers
Textil 22	Textile Mills
Apparl 23	Apparel
Lumber 24	Lumber
Furnit 25	Furniture
Paper 26	Paper (total)
Print 27	Printing and Publishing
Chem 28	Chemicals (total)
Petref 29	Petroleum Refining
Rubber 30	Rubber and Miscellaneous Plastics
Leathr 31	Leather and Leather Products
Stone 32	Stone, Clay, Glass, Concrete (total)
Pmetal 33	Fabricated Metal Products
Fabmet 34	Fabricated Metal Products
Machin 35	Machinery (except electrical)
Transp 37	Transportation Equipment
Measure 38	Measuring Equipment, etc.
Misman 39	Miscellaneous Manufacturing Industries
Minemt 10	Mining of Metals
Minean 11	Mining of Anthracite Coal
Minebl 12	Mining of Bituminous and Lignite Coal
Mineog 13	Oil and Gas Extraction
Minenm 14	Mining of Nonmetallic Minerals
All-Ind	All Industries (within the sector under consideration)

Breakdown of Energy Use Within the Largest Energy Users

Energy use in the manufacturing industrial sector is dominated by the sixteen largest energy consuming industries (see Section 5.1). In 1977 these industries consumed 56.3% of all manufacturing industrial energy consumption. Highly aggregated consumption data are provided for these industries in Tables 5.1 through 5.5. In Table 5.6, seven of the top energy-using industry groups are further disaggregated so that energy consumed for each product type could be examined. These seven industries were chosen because of their relative diversity, which warrants greater disaggregation than do the other industry groups.

Similar data are not available for the construction and mining industries; those industries consume a very small portion of total industrial energy consumption. A breakdown of fuel consumption and end uses to the 4-digit SIC level (such as exists for the 21-digit level in Tables 5.2 and 5.4) is needed for a better analysis of energy use in the industrial section; however, such a nationwide data base does not presently exist. Some regional or state data are available.

TABLE 5.6. Energy Consumption (purchased fuels and electric energy)
Used for Heat and Power Among 7 Significant Energy-Using
Industries, 1976-1978

SIC Code	Industry Group and Industry	1976 Purchased Fuels and Electric Energy		1977 Purchased Fuels and Electric Energy		1978 Purchased Fuels and Electric Energy	
		British Thermal units (trillions)	Total cost million dollars)	British Thermal units (trillions)	Cost million dollars)	British Thermal units (trillions)	Cost million dollars)
26	Paper and allied products	1,300.2	2,526.6	1,306.7	2,957.0	1,301.1	3,173.9
2611	Pulpmills	96.0	176.8	95.4	197.4	92.4	201.1
2621	Papermills, except building paper	592.3	1,118.0	586.4	1,291.7	571.1	1,353.4
2631	Paperboard mills	467.4	826.4	481.6	987.3	488.5	1,066.4
264	Miscellaneous converted paper products	55.6	169.5	58.4	215.5	61.6	252.0
2641	Paper coating and glazing	16.6	46.0	16.8	55.4	17.3	63.6
2642	Envelopes	2.4	10.8	2.4	12.2	2.5	14.1
2643	Bags, except textile bags	8.3	28.2	9.6	44.0	10.2	54.1
2645	Die-cut paper and board	3.4	8.5	2.9	9.1	3.2	10.6
2646	Pressed and molded pulp goods	8.1	20.8	7.6	23.7	7.4	24.6
2647	Sanitary paper products	10.2	31.9	11.5	41.2	12.1	47.5
2648	Stationary products	1.4	5.4	1.3	5.2	1.3	6.2
2649	Converted paper products, n.e.c.	5.3	18.0	6.3	24.8	7.5	31.4
265	Paperboard containers and boxes	52.9	162.8	55.4	191.7	56.7	217.5
2651	Folding paperboard boxes	6.8	24.3	8.0	30.7	7.9	34.4
2652	Setup paperboard boxes	1.3	4.6	1.3	4.7	1.3	5.2
2653	Corrugated and solid fiber boxes	34.7	96.5	36.7	116.3	38.4	133.9
2654	Sanitary food containers	7.3	27.6	6.5	28.9	6.4	32.0
2655	Fiber cans, drums, and similar products	2.9	9.8	2.8	11.1	2.8	12.1
2661	Building paper and board mills	35.8	73.1	29.5	73.4	30.9	83.4
28	Chemicals and allied products	2,989.3	5,430.6	2,983.3	6,439.0	2,905.3	7,079.8
281	Industrial inorganic chemicals	706.4	1,697.5	668.1	1,876.0	646.2	2,085.8
2812	Alkalies and chlorine	145.7	311.9	126.9	327.4	121.8	354.9
2813	Industrial gases	90.7	262.0	73.9	301.7	77.7	371.5
2815	Inorganic pigments	46.8	95.4	46.3	108.7	43.4	115.7
2819	Industrial inorganic chemicals, n.e.c.	423.2	1,027.4	421.0	1,138.2	403.3	1,243.7
282	Plastics materials and synthetics	401.4	812.3	432.6	1,024.1	424.7	1,121.4
2821	Plastics materials and resins	171.0	379.1	182.7	478.7	177.5	532.8
2822	Synthetic rubber	41.0	81.5	43.5	95.7	42.9	109.5
2823	Cellulosic manmade fibers	56.7	71.6	58.4	84.8	64.0	100.6
2824	Organic fibers, noncellulosic	132.6	280.1	147.9	364.9	140.3	378.5
283	Drugs	67.1	187.7	71.5	228.7	71.3	247.3
2831	Biological products	2.7	9.8	3.3	13.7	3.3	14.5
2833	Medicinals and botanicals	26.1	60.4	28.2	72.1	27.5	76.5
2834	Pharmaceutical preparations	38.3	117.4	40.1	143.0	40.5	156.4
284	Soaps, cleaners, and toilet goods	49.0	125.5	46.5	136.9	49.8	163.0
2841	Soap and other detergents	25.0	55.3	25.4	66.5	25.9	75.6
2842	Polishes and sanitation goods	7.4	22.2	5.2	17.5	5.5	21.3
2843	Surface active agents	10.4	25.4	9.6	26.3	11.6	35.1
2844	Toilet preparations	6.2	22.6	6.3	26.6	6.8	31.0

TABLE 5.6. (continued)

SIC Code	Industry Group and Industry	1976 Purchased Fuels and Electric Energy		1977 Purchased Fuels and Electric Energy		1978 Purchased Fuels and Electric Energy	
		British Thermal units (trillions)	Total cost (million dollars)	British Thermal units (trillions)	Cost (million dollars)	British Thermal units (trillions)	Cost (million dollars)
2851	Paints and allied products	18.6	52.2	19.3	60.0	21.1	73.6
286	Industrial organic chemicals	1,251.0	1,831.3	1,269.1	2,240.1	1,206.9	2,387.1
2861	Gum and wood chemicals	8.9	17.5	6.3	18.3	10.6	28.7
2865	Cyclic crudes and intermediates	171.8	325.7	171.9	384.7	156.8	400.4
2869	Industrial organic chemicals, n.e.c.	1,070.4	1,488.1	1,090.9	1,837.1	1,039.5	1,957.9
287	Agricultural chemicals	385.2	532.7	361.9	641.7	372.6	732.9
2873	Nitrogenous fertilizers	289.7	339.2	265.5	423.5	276.9	467.7
2874	Phosphatic fertilizers	63.6	126.4	64.8	137.1	65.4	175.0
2875	Fertilizers, mixing only	4.4	12.5	4.9	15.7	4.8	17.4
2879	Agricultural chemicals, n.e.c.	27.4	54.7	26.7	65.4	25.5	72.8
289	Miscellaneous chemical products	110.6	191.4	114.2	231.5	112.7	268.7
2891	Adhesives and sealants	8.8	22.7	8.1	25.9	7.2	26.7
2892	Explosives	19.4	32.5	16.9	32.9	16.5	35.8
2893	Printing ink	2.7	8.0	3.0	9.8	2.6	10.1
2895	Carbon black	28.2	36.1	29.5	49.9	25.0	53.1
2899	Chemical preparations, n.e.c.	51.5	92.0	56.7	113.0	61.4	143.0
29	Petroleum and coal products	1,304.8	2,108.2	1,238.4 ^r	2,416.0	1,122.7	2,536.5
2911	Petroleum refining	1,229.2	1,954.5	1,157.9 ^r	2,217.7	1,033.9	2,297.4
295	Paving and roofing materials	62.9	129.0	66.6	165.1	74.7	201.5
2951	Paving mixtures and blocks	33.8	74.6	36.0	93.9	40.3	115.1
2952	Asphalt felts and coatings	29.1	54.4	30.7	71.2	34.5	86.4
299	Miscellaneous petroleum and coal products	12.7	24.7	13.9	33.2	14.1	37.7
2992	Lubricating oils and greases	5.4	12.5	6.2	17.6	6.7	19.9
2999	Petroleum and coal products, n.e.c.	7.4	12.2	7.7	15.6	7.4	17.8
30	Rubber and miscellaneous plastics products	250.3	765.3	272.3	962.3	261.0	1,064.2
3011	Tires and inner tubes	75.1	180.8	272.3	962.3	261.0	1,064.2
3021	Rubber and plastics footwear	2.4	9.0	82.8	236.8	70.4	233.2
3031	Reclaimed rubber	0.9	2.6	2.1	8.5	2.0	9.2
3041	Rubber and plastics hose and belting	13.8	29.4	1.1	3.3	1.0	4.1
3069	Fabricated rubber products, n.e.c.	30.6	86.7	13.9	36.9	18.1	47.0
3079	Miscellaneous plastics products	127.4	456.9	33.1	109.2	32.2	118.5
				139.4	567.8	137.3	652.4
323	Stone, clay and glass products	1,226.9	2,167.8	1,251.1	2,587.5	1,299.8	3,005.6
3211	Flat glass	53.7	99.8	59.8	135.5	60.5	153.2

TABLE 5.6. (continued)

SIC Code	Industry Group and Industry	1976 Purchased Fuels and Electric Energy		1977 Purchased Fuels and Electric Energy		1978 Purchased Fuels and Electric Energy	
		British Thermal units (trillions)	Total cost million dollars	British Thermal units (trillions)	Cost million dollars	British Thermal units (trillions)	Cost million dollars
322	Glass and glassware pressed or blown	214.6	425.1	212.2	525.3	216.9	589.7
3221	Glass containers	147.5	292.0	144.5	360.9	147.8	402.8
3229	Pressed and blown glass, n.e.c.	67.1	133.1	67.7	164.3	69.2	187.0
3231	Products of purchased glass	18.3	40.1	14.8	43.0	15.0	50.8
3241	Cement, hydraulic	433.0	616.6	453.1	732.9	469.2	847.4
325	Structural clay products	111.7	190.6	115.5	225.7	113.3	262.6
3251	Brick and structural clay tile	62.5	103.3	69.6	130.7	69.7	157.6
3253	Ceramic wall and floor tile	6.5	12.3	6.8	15.3	6.4	15.9
3255	Clay refractories	23.7	46.1	21.1	47.6	21.5	55.0
3259	Structural clay products, n.e.c.	18.9	28.9	18.0	32.1	15.7	34.0
326	Pottery and related products	24.7	50.4	25.7	61.1	25.5	66.4
3261	Nitreous plumbing fixtures	8.3	17.1	8.8	20.9	9.8	24.7
3262	Vitreous china food utensils	2.8	5.7	3.0	7.6	3.0	7.6
3263	Fine earthenware food utensils	1.4	3.2	2.0	4.9	2.0	5.4
3264	Porcelain electrical supplies	6.0	13.6	6.0	15.8	5.7	17.1
3269	Pottery products, n.e.c.	6.2	10.8	5.9	11.9	5.0	11.5
327	Concrete, gypsum, and plaster products	217.9	406.1	222.7	467.3	239.8	563.4
3271	Concrete block and brick	15.8	35.0	14.2	34.6	15.4	41.6
3272	Concrete products, n.e.c.	20.9	45.8	20.0	49.8	22.2	61.5
3273	Ready-mixed concrete	42.4	107.1	43.8	120.1	46.3	143.5
3274	Lime	97.5	142.3	98.2	160.3	105.1	191.0
3275	Gypsum products	41.5	75.8	46.5	102.5	50.8	125.8
3281	Cut stone and stone products	4.1	13.5	3.9	13.3	4.0	16.3
329	Miscellaneous nonmetallic mineral products	148.9	325.6	143.4	383.4	155.6	455.9
3291	Abrasive products	12.7	35.2	14.5	45.4	16.3	54.7
3292	Asbestos products	10.7	30.7	9.4	30.4	9.6	33.9
3293	Gaskets, packing, and sealing devices	5.8	17.4	5.9	21.1	6.2	25.0
3295	Minerals, ground or treated	37.4	67.1	33.0	75.5	37.4	92.3
3296	Mineral wool	54.4	121.8	54.9	152.2	58.0	178.6
3297	Nonclay refractories	19.8	37.4	17.3	39.8	19.5	50.2
3299	Nonmetallic mineral products, n.e.c.	8.2	16.0	8.3	19.1	8.6	21.3
33	Primary metal industries	2,470.6	5,752.2	2,559.8	7,043.3	2,710.9	8,388.7
331	Blast furnace and basic steel products	1,593.4	3,638.4	1,650.4	4,510.2	1,781.7	5,377.0
3312	Blast furnaces and steel mills	1,496.6	3,372.3	1,540.0	4,161.1	1,667.0	4,974.3
3313	Electrometallurgical products	54.0	140.5	57.6	171.3	58.9	197.1
3315	Steel wire and related products	14.4	44.2	14.4	51.7	14.8	59.8
3316	Cold finishing of steel shapes	16.3	48.0	17.6	64.0	18.3	71.9
3317	Steel pipe and tubes	12.1	33.4	20.7	62.1	22.7	73.8

TABLE 5.6. (continued)

SIC Code	Industry Group and Industry	1976 Purchased Fuels and Electric Energy		1977 Purchased Fuels and Electric Energy		1978 Purchased Fuels and Electric Energy	
		British Thermal units (trillions)	Total cost (million dollars)	British Thermal units (trillions)	Cost (million dollars)	British Thermal units (trillions)	Cost (million dollars)
332	Iron and steel foundries	166.9	605.5	175.4	746.6	189.7	897.1
3321	Gray iron foundries	114.3	433.6	121.8	548.1	138.7	676.4
3322	Malleable iron foundries	16.0	56.2	17.0	63.0	14.5	64.5
3324	Steel investment foundries	3.5	12.1	2.9	11.6	3.0	14.2
3325	Steel foundries, n.e.c.	33.1	103.6	33.6	124.0	33.5	141.9
333	Primary nonferrous metals	442.5	835.7	462.6	988.4	462.2	1,193.5
3331	Primary copper	69.5	111.8	66.3	122.9	65.6	146.7
3332	Primary lead	13.3	32.8	12.5	34.4	13.0	39.0
3333	Primary zinc	26.7	49.5	25.4	51.4	25.1	55.8
3334	Primary Aluminum	297.1	541.8	327.7	695.1	329.3	865.3
3339	Primary nonferrous metals, n.e.c.	36.0	99.8	30.7	84.6	29.1	86.6
3341	Secondary nonferrous metals	36.7	76.1	37.0	90.5	39.5	108.3
335	Nonferrous rolling and drawing	155.5	405.0	164.7	502.3	165.8	569.5
3351	Copper rolling and drawing	24.5	80.7	25.0	95.5	24.6	105.8
3353	Aluminum sheet, plate, and foil	67.4	133.4	71.4	171.2	72.5	198.3
3354	Aluminum extruded products	19.2	49.0	21.3	63.4	21.0	72.2
3355	Aluminum rolling, drawing, n.e.c.	8.1	17.4	7.4	18.0	8.5	23.3
3356	Nonferrous wiring and drawing, n.e.c.	12.7	36.0	12.8	41.1	13.4	49.1
3357	Nonferrous wiredrawing, insulating	23.6	88.5	26.9	113.0	25.7	120.9
336	Nonferrous foundries	40.5	105.0	40.5	120.0	43.2	145.8
3361	Aluminum foundries	29.0	70.3	29.7	81.4	32.1	100.9
3362	Brass, bronze, and copper foundries	4.6	14.7	4.0	15.3	4.1	18.0
3369	Nonferrous foundries, n.e.c.	7.0	19.9	6.9	23.2	7.0	26.9
339	Miscellaneous primary metal products	35.0	86.6	29.2	85.4	28.7	97.6
3398	Metal heat treating	22.8	50.7	21.0	57.1	20.4	64.8
3399	Primary metal products, n.e.c.	12.2	35.9	8.2	28.2	8.4	32.8
34	Fabricated metal products	382.6	1,128.7	394.1	1,348.5	400.2	1,538.3
341	Metal cans and shipping containers	36.5	99.2	37.2	119.6	36.1	134.0
3411	Metal cans	31.4	85.4	32.0	103.5	30.7	115.1
3412	Metal barrels, drums, and pails	5.1	13.7	5.2	16.1	5.4	18.8
342	Cutlery, handtools and hardware	31.2	99.6	32.0	116.9	32.2	130.5
3421	Cutlery	2.6	9.4	2.8	10.4	3.0	11.3
3423	Hand and edge tools, n.e.c.	8.9	25.9	10.9	35.8	10.3	38.7
3425	Handsaws and saw blades	1.0	4.3	1.1	5.4	1.1	6.4
3429	Hardware, n.e.c.	18.7	60.0	17.3	65.3	17.8	74.1
343	Plumbing and heating, except electric	14.0	39.3	13.7	45.9	14.8	54.9
3431	Metal sanitary ware	5.8	13.3	6.0	15.7	6.9	20.5
3432	Plumbing fittings, brass goods	3.7	12.5	3.1	12.7	2.8	13.9
3433	Heating equipment, except electric	4.5	13.5	4.6	17.4	5.1	20.5

TABLE 5.6. (continued)

SIC Code	Industry Group and Industry	1976 Purchased Fuels and Electric Energy		1977 Purchased Fuels and Electric Energy		1978 Purchased Fuels and Electric Energy	
		British Thermal units (trillions)	Total cost (million dollars)	British Thermal units (trillions)	Cost (million dollars)	British Thermal units (trillions)	Cost (million dollars)
344	Fabricated structural metal products	67.2	209.5	70.4	249.1	69.8	283.3
3441	Fabricated structural metal	14.6	48.2	14.1	52.5	13.8	58.1
3442	Metal doors, sash, and trim	8.0	25.7	8.1	28.6	7.9	32.5
3443	Fabricated plate work, boiler shops	22.3	65.7	25.2	86.8	24.5	96.7
3444	Sheet metalwork	12.6	34.7	12.6	38.8	12.9	46.2
3446	Architectural metalwork	2.7	9.9	2.9	10.8	3.1	13.2
3448	Prefabricated metal buildings	2.8	10.2	3.4	13.8	3.4	16.2
3449	Miscellaneous metalwork	4.2	15.3	4.1	17.9	4.3	20.4
345	Screw machine products, bolts, etc.	20.2	67.0	21.6	82.7	22.1	94.8
3451	Screw machine products	4.7	18.0	5.1	22.9	5.1	26.8
3452	Bolts, nuts, rivets, and washers	15.5	49.0	16.5	59.8	16.9	68.0
346	Metal forgings and stampings	100.4	275.6	106.0	345.0	108.0	387.5
3462	Iron and steel forgings	44.1	90.9	47.9	125.4	48.7	137.6
3463	Nonferrous forgings	5.9	13.6	5.7	15.8	6.4	19.0
3465	Automotive stampings	31.6	111.5	31.3	126.0	31.3	144.3
3466	Crowns and closures	2.6	7.3	2.5	8.7	2.4	9.1
3469	Metal stampings, n.e.c.	16.3	52.3	18.7	69.2	19.2	77.5
347	Metal services, n.e.c.	39.3	111.4	41.9	131.2	43.2	152.0
3471	Plating and polishing	22.8	70.9	23.9	82.2	24.2	93.4
3479	Metal coating, allied services	16.5	40.5	18.0	49.0	19.0	58.6
348	Ordnance and accessories, n.e.c.	20.8	55.2	19.0	60.7	20.4	69.1
3482	Small arms ammunition	4.1	9.9	3.7	11.0	3.7	11.7
3483	Ammunition, except for small arms, n.e.c.	8.6	22.7	7.1	21.7	7.6	25.4
3484	Small arms	2.0	8.7	2.1	9.5	2.2	10.6
3489	Ordnance and accessories, n.e.c.	6.1	13.9	6.1	18.5	6.9	21.4
349	Miscellaneous fabricated metal products	53.0	171.9	52.4	197.3	53.6	232.2
3493	Steel springs, except wire	4.8	12.4	5.3	13.8	4.8	15.0
3494	Valves and pipe fittings	19.3	64.8	19.4	78.4	19.6	88.8
3495	Wire springs	2.4	8.2	2.6	11.0	2.9	12.9
3496	Miscellaneous fabricated wire products	4.6	15.7	5.0	19.6	5.2	22.5
3497	Metal foil and leaf	2.5	9.6	3.3	14.0	3.7	18.7
3498	Fabricated pipe and fittings	4.1	13.7	4.7	17.6	5.1	21.2
3499	Fabricated metal products, n.e.c.	15.2	47.6	12.1	42.9	12.4	53.1

Source: Department of Commerce 1980 and 1981a.

Energy Consumption of Selected Processes

This section contains the most disaggregated information on industrial energy use presented in the industrial portion of this report. Several industrial processes were selected because they consume a relatively large portion of the industrial sector's total energy requirement, because they are high-priority industrial processes, and because more highly aggregated data on these processes do not actually reveal energy-use patterns in these industries. Figures 5.8 through 5.10 and Tables 5.7 through 5.13 list the actual energy requirements of each process used in the overall production of eight important products. The figures estimate fuel use per unit of output (e.g., 1,000,000 Btu per ton of steel slab produced is presented in Table 5.8). Each table states the conversion factor for electrical energy.

The data contained in these tables are several years old. However, they describe processes that still dominate each of the respective industries.

SOURCE: BCL 1975

FIGURE 5.8. Production of Steel Slabs from Ingots by Steelmaking Process (10^6 Btu consumed per net ton of steel produced)

(a) Does not include the embodied energy of the scrap metal input.

SOURCE: BCL 1975

FIGURE 5.9. Production of Continuous-Cast Steel Slabs by Steelmaking Process (10^6 Btu consumed per net ton of steel produced)

(a) Does not include the embodied energy of the scrap metal input.

**1973 U.S. STEEL PRODUCTION
BY STEELMAKING PROCESS**

PROCESS	PERCENT OF TOTAL
OPEN HEARTH	26.4
BASIC OXYGEN	55.2
ELECTRIC ARC FURNACE	18.4
	<hr/>
	100.0

SOURCE: BCL 1975

FIGURE 5.10. Weighted Average Energy Consumption of Steelmaking Process in the U.S. for 1973 - Ingot Casting Versus Continuous Casting to Produce Slabs [10^6 Btu consumed per net ton of steel produced (except where units are noted)]

TABLE 5.7. Aluminum Production

	Unit	Units per Net Ton of Aluminum	10 ⁶ Btu Per Unit	10 ⁶ Btu ⁶ Per Net Ton of Aluminum
Mining				
Drilling	kWh	1.0	0.0105	0.01
Drill bits, drilling machines	lb	Negligible		
Explosives	lb	0.80	0.030	<u>0.02</u>
			Subtotal	0.03
Shovel loading				
Electrical energy	kWh	10.25	0.0105	0.11
Materials, repair, and maintenance	Btu	0.03 x 10 ⁶		<u>0.03</u>
			Subtotal	0.14
Truck transportation				
Diesel fuel oil	gal	0.70	0.139	0.10
Truck materials, tires, and repair	Btu	0.02 x 10 ⁶		<u>0.02</u>
			Subtotal	0.12
Crushing, washing, and screening				
Crushing and screening electrical energy	kWh	12.5	0.0105	0.13
Pumping electrical energy	kWh	6.4	0.0105	0.07
Machinery wear and service energy	Btu	0.02 x 10 ⁶		<u>0.02</u>
			Subtotal	0.22
Drying	Btu	1.90 x 10 ⁶		1.90
Transportation	net ton-mile	9,500.0	0.00025	2.38
Bayer processing				
Crushing and grinding				
Electrical energy	kWh	31.43	0.0105	0.13
Lime	net ton	0.10	8.5(9)	<u>0.85</u>
			Subtotal	1.18
Digestion				
Steam	lb	12,143.0	0.0014	17.00
Caustic soda	net ton	0.15	30.00(10)	<u>4.50</u>
			Subtotal	21.50
Clarification				
Electrical energy	kWh	30.48	0.0105	0.32
Starch	--	--	--	0.00
Cooling				
Electrical energy	kWh	5.71	0.0105	0.06
Precipitation-filtration				
Electrical energy	kWh	66.67	0.0105	0.70

TABLE 5.7. (continued)

	Unit	Units per Net Ton of Aluminum	10 ⁶ Btu Per Unit	10 ⁶ Btu ⁶ Per Net Ton of Aluminum
Evaporation				
Steam	lb	6,829.0	0.0014	9.56
Spent liquor recovery				
Electrical energy	kWh	69.52	0.0105	0.73
Net steam usage	lb	593.0	0.0014	0.83
			Subtotal	1.56
Calcination				
Natural gas	ft ³	7,720.0	0.001	7.72
Carbon anode manufacture	net ton	0.425	30.0	12.75
Raw petroleum coke				
Coke transportation (500 mi by rail)	ton-mile	212.5	0.00067	0.14
Calcining				
Hydrocarbon fuels	Btu	--	--	1.0
Electrical energy	kWh	20.0	0.0105	0.21
Crushing and grinding				
Electrical energy	kWh	5.0	0.0105	0.05
Pitch binder	gal	28.44	0.16	4.55
Pitch transportation (400 mi by rail)	net ton-mile	52.4	0.00067	0.04
Natural gas for baking	ft ³	2,094.0	0.001	2.09
			Subtotal	20.83
Carbon cathode manufacture				
Anthracite	net ton	0.02	25.94	0.52
Anthracite transportation (500 mi by rail)	net ton-mile	10.0	0.00067	0.07
Electrical energy for calcining	kWh	40.0	0.0105	0.42
Crushing and grinding				
Electrical energy	kWh	0.2	0.0105	0.00
Pitch binder	gal	0.74	0.16	0.12
Pitch transportation (500 mi by rail)	net ton-mile	0.17	0.00067	0.00
Electrical energy for baking	kWh	8.0	0.0105	0.08
			Subtotal	1.21
Reduction				
Makeup cryolite (Na ₃ AlF ₆)	net ton	0.035	155.0	5.44
Cryolite transportation (300 mi by rail)	net	10.5	0.00067	0.01
4 cup aluminum fluoride	net ton	0.02	51.4	1.02
Aluminum fluoride transportation (300 mi by rail)	net ton-mile	6.0	0.00067	0.00
Fluorspar (CaF ₂)	net ton	0.003	1.59	0.00
Electrical energy	kWh	16,000.0	0.0105	168.00
			Subtotal	174.47
Total				243.90

Source: BCL 1975.

TABLE 5.8. Cement Production

	Unit	Units per Net Ton of Cement	10 ⁶ Btu Per Unit	10 Btu ⁶ Per Net Ton of Aluminum
Limestone				
Mining	net ton	1.370	0.046	0.063
Truck transportation (3 mi)	net ton-mile	4.1	0.0024	0.010
Drying, natural gas	ft ³	320.0	0.001	<u>0.320</u>
			Subtotal	0.393
Clay and shale				
Mining	net ton	0.144	0.0700	0.010
Truck transportation (3 mi)	net ton-mile	0.432	0.0024	<u>0.001</u>
			Subtotal	0.011
Sand and miscellaneous				
Mining	net ton	0.057	0.605	0.034
Rail transportation	net ton-mile	5.7	0.00067	<u>0.004</u>
			Subtotal	0.038
Crushing and milling				
Crushing	kWh	9.0	0.0105	0.095
Milling	kWh	30.0	0.0105	0.315
Other	kWh	2.0	0.0105	<u>0.021</u>
			Subtotal	0.431
Clinker burning				
Coal	net ton	0.0908	25.27	2.295
Coal transportation (400 mi by rail)	net ton-mile	36.3	0.00067	0.024
Residual fuel oil	gal	6.8334	0.139	0.950
Natural gas	ft ³	2,636.0 ⁽⁶⁾	0.001	2.636
Refractories	net ton	0.001	9.0	0.009
Electrical energy	kWh	12.0	0.0105	0.126
Electrical energy (cooler fan)	kWh	7.0	0.0105	<u>0.074</u>
			Subtotal	6.114
Air pollution control				
Electrical energy	kWh	5.0	0.0105	0.053
Clinker milling				
Electrical energy	kWh	50	0.105	0.525
Other	kWh	4	0.0105	0.042
Gypsum	net ton	0.048	0.0700	0.003
Gypsum transport	net ton-mile	4.8	0.00067	0.003
Grinding balls	lb	2	0.0175	<u>0.035</u>
			Subtotal	<u>0.608</u>
Total				7.648

Source: BCL 1975.

TABLE 5.9. Ammonia Production

	Unit	Units per Net Ton of Ammonia	10 ⁶ Btu Per Unit	10 Btu ⁶ Per Net Ton of Ammonia
Reforming				
Natural gas (feed)	ft ³	22,310.0	0.001	22.31
Steam (feed)(a)	lb	4,545.0	--	--
Natural gas (fuel)	ft ³	8,420.0	0.001	8.42
Catalyst	lb	0.5	0.003(5)	<u>0.002</u>
			Subtotal	30.73
Shift reaction				
Catalyst	lb	0.3	0.003	0.001
Electrical energy	kWh	4.0	0.0105	<u>0.04</u>
			Subtotal	0.04
Carbon dioxide removal				
Electrical energy	kWh	14.0	0.0105	0.15
Ethanolamine	lb	0.3	0.020(8)	<u>0.006</u>
			Subtotal	0.16
Methanation				
Electrical energy	kWh	2.0	0.0105	0.02
Catalyst	lb	0.5	0.003	<u>0.002</u>
			Subtotal	0.02
Compressing synthesis gases				
Natural gas (fuel)	ft ³	7,190.0	0.001	7.19
Synthesis				
Natural gas (fuel)	ft ³	420.0	0.001	0.42
Electrical energy	kWh	8.0	0.0105	0.08
Catalyst	lb	0.5	0.003	<u>0.002</u>
			Subtotal	0.50
Total				38.64

(a) Steam is a chemical reactant in the reforming stage. Although it is formed elsewhere in the process, the energy required to form steam and heat it to reaction temperature is included in the natural gas (fuel) units.

Source: BCL 1975.

TABLE 5.10. Production of Refined Copper

	Unit	Units per Net Ton of Copper	10 ⁶ Btu Per Unit	10 ⁶ Btu ⁶ Per Net Ton of Copper
Mine				
Excavation				
Electrical energy	kWh	788.8	0.0105	8.282
Natural gas	Ft ³	220.5	0.0010	0.221
Petroleum fuels (diesel)	gal	38.62	0.1390	5.368
Coal	net ton	0.0013	25.27	0.033
Coal transportation (500 mi by rail)	net ton-mile	0.65	0.00067	0.000
Explosives	lb	155.0	0.030	4.650
			Subtotal	18.554
Transportation				
Waste stock to dumps (truck 2 mi)	net ton-mile	921.4	0.0024	2.210
Ore to mill (electric rail 8 mi)	net ton-mile	1,261.3	0.00067	0.845
			Subtotal	3.055
Concentrator				
Crushing				
Electrical energy	kWh	396.3	0.0105	4.161
Grinding				
Electrical energy	kWh	2,013.9	0.0105	21.146
Steel balls and rods	lb	273.00	0.0175	4.778
			Subtotal	25.924
Flotation				
Electrical energy	kWh	547.0	0.0105	5.743
Natural gas	ft ³	2,465.0	0.0010	2.465
Petroleum fuels	gal	1.62	0.1500	0.243
Steam	lb	366.43	0.0014	0.513
Inorganic reagents	lb	541.0	0.0050	2.710
Organic reagents	lb	28.5	0.0200	0.570
			Subtotal	12.244
Smelter				
Cement copper	net ton	0.10	86.84	8.684
Charge preparation and drying				
Electrical energy	kWh	53.15	0.0105	0.558
Natural gas	ft ³	1,395.0	0.0010	1.395
			Subtotal	1.953

TABLE 5.10. (continued)

	Unit	Units per Net Ton of Copper	10 ⁶ Btu Per Unit	10 ⁶ Btu ⁶ Per Net Ton of Copper
Smelter (continued)				
Reverberatory furnace				
Electrical energy	kWh	59.65	0.0105	0.626
Natural gas	ft ³	12,799.0	0.0010	12.799
Petroleum fuels	gal	74.8	0.1500	<u>11.220</u>
			Subtotal	24.645
Steam (credit)	lb	6,675.0	0.0014	-9.350
Converter				
Electrical energy	kWh	38.58	0.0105	0.405
Natural gas	ft ³	852.5	0.0010	0.853
Petroleum fuel	gal	0.292	0.1500	0.040
Process steam	lb	3,265.0	0.0014	<u>4.571</u>
			Subtotal	5.869
Anode refining furnace				
Electrical energy	kWh	6.44	0.0105	0.068
Natural gas	ft ³	3,139.0	0.0010	3.139
Petroleum fuels	gal	1.50	0.1500	0.225
Process steam	lb	169.22	0.0014	0.237
Coal	net ton	0.005	25.27	0.126
Coal transportation (500 mi by rail)	net ton-mile	2.5	0.00067	0.002
			Subtotal	<u>3.797</u>
Gas cleaning				
Electrical energy	kWh	30.76	0.0105	0.323
Acid plant				
Electrical energy	kWh	257.14	0.0105	2.700
Natural gas	ft ³	1,510.00	0.0010	<u>1.510</u>
				4.210
Sulfuric acid produced	net ton	2.3	0.83	<u>-1.909</u>
			Subtotal	2.301
Refining				
Electrolytic refining				
Electrical energy	kWh	307.49	0.0105	3.229
Natural gas	ft ³	1,165.00	0.0010	1.165
Petroleum fuel	gal	19.92	0.1500	2.988
Coal	net ton	0.007	25.27	0.177
Coal transportation (500 mi by rail)	net ton-mile	3.5	0.00067	0.002
Sulfuric acid	net ton	0.0169	0.83	<u>0.014</u>
			Subtotal	7.575
Cathode melting				
Electrical energy	kWh	7.37	0.0105	0.077
Natural gas	ft ³	1,069.7	0.0010	<u>1.870</u>
			Subtotal	1.947
Rail transportation-anodes (2,000 mi)	net ton-mile	910.0	0.00067	<u>0.610</u>
			Subtotal	<u>0.610</u>
Total				112.292

Source: BCL 1975.

TABLE 5.11. Glass Container Production

	<u>Unit</u>	<u>Units per Net Ton of Glass Containers</u>	<u>10⁶ Btu Per Unit</u>	<u>10⁶ Btu Per Net Ton of Glass Containers</u>
Sand				
Mining	net ton	0.5918	0.722	0.427
Transportation (500 mi rail)	net ton-mile	296.0	0.00067	<u>0.198</u>
			Subtotal	0.625
Limestone				
Mining and crushing	net ton	0.1817	0.104	0.019
Transportation (100 mi rail)	net ton-mile	18.17	0.00067	<u>0.013</u>
			Subtotal	0.032
Feldspar				
Mining	net ton	0.0838	1.301	0.109
Transportation (1,000 mi rail)	net ton-mile	83.80	0.00067	<u>0.056</u>
			Subtotal	0.165
Soda ash (synthetic)				
Processing	net ton	0.1182	18.300	2.163
Transportation (500 mi rail)	net ton-mile	59.10	0.00067	<u>0.040</u>
			Subtotal	2.203
Soda ash (natural)				
Mining and processing	net ton	0.0788	8.200	0.646
Transportation (1,500 mi rail)	net ton-mile	118.0	0.00067	<u>0.079</u>
			Subtotal	0.725
Other	net ton	0.0138	0.300	0.004
Cullett	net ton	0.1000	--	--
Botch handling and cullet crushing				
Electrical energy	kWh	23.1	0.0105	0.243
Melting				
Natural gas	ft ³	5,948.0	0.001	5.948
Electrical energy	kWh	64.5	0.0105	0.677
Distillate fuel oil	gal	7.35	0.139	1.022
Residual oil	gal	3.03	0.150	0.455
Propane/butane	gal	0.346	0.095	<u>0.033</u>
			Subtotal	8.135

TABLE 5.11. (continued)

	Unit	Units per Net Ton of Glass Containers	10 ⁶ Btu Per Unit	10 ⁶ Btu Per Net Ton Glass Containers
Finishing and conditioning(a)				
Natural gas	ft ³	1,641.0	0.001	1.641
Electrical energy	kWh	5.0	0.0105	<u>0.053</u>
			Subtotal	1.694
Forming				
Natural gas	ft ³	229.8	0.001	0.230
Electrical energy	kWh	107.9	0.0105	1.133
Propane/butane	gal	0.0065	0.095	<u>0.001</u>
			Subtotal	1.364
Post forming				
Natural gas	ft ³	1,008.0	0.001	1.008
Electrical energy	kWh	25.6	0.0105	0.269
Propane/butane	gal	0.171	0.095	<u>0.016</u>
			Subtotal	1.293
Product handling				
Natural gas	ft ³	186.0	0.001	0.186
Electrical energy	kWh	14.9	0.0105	0.156
Gasoline	gal	0.10	0.125	0.013
Residual oil	gal	0.002	0.150	0.000
Propane/butane	gal	0.117	0.095	<u>0.011</u>
			Subtotal	0.366
Space heating				
Natural gas	ft ³	362.8	0.001	0.363
Electrical energy	kWh	8.4	0.0105	0.088
Distillate oil	gal	0.394	0.139	0.055
Residual oil	gal	0.505	0.150	0.076
Propane/butane	gal	0.021	0.095	<u>0.002</u>
			Subtotal	<u>0.584</u>
			Total	17.433

(a) "Finishing" refers to removal of trapped gas after melting; "conditioning" refers to mixing and cooling the melted raw materials.

Source: BCL 1975.

TABLE 5.12. Chlorine Production

	Unit	Units per Net Ton of Chlorine	10 ⁶ Btu Per Unit	10 ⁶ Btu Per Net Ton of Chlorine
Salt mining, solution				
Electrical energy	kWh	18.9	0.0105	0.198
Brine purification				
Soda ash	lb	56.0	0.009	0.504
Soda ash transportation (300 mi by retail)	net ton-mile	8.4	0.00067	0.006
Caustic soda	lb	25.0	0.015	0.400
Steam	lb	540.0	0.0014	0.756
Electrical energy	kWh	4.45	0.0105	<u>0.047</u>
			Subtotal	1.713
Brine heating				
Steam	lb	1,460.0	0.0014	2.044
Brine electrolysis, diaphragm cells				
Graphite	lb	6.0	0.08	0.480
Graphite transportation (500 mi by rail)	net ton-mile	1.5	0.00067	0.001
Asbestos	lb	1.2	0.004	0.005
Asbestos transportation (500 mi by rail)	net ton-mile	0.3	0.00067	0.000
Electrical energy	kWh	3,100.0	0.0105	<u>32.550</u>
			Subtotal	33.036
Subtotal for 4,297 lbs of products (Cl ₂ , NaOH, H ₂)(a)				36.991
Wet chlorine intermediate				17.217
Chlorine cooling/drying				
Sulfuric acid	lb	25.0	0.0004	0.010
Acid transportation (200 mi by rail)	net ton-mile	2.5	0.00067	0.002
Electrical energy	kWh	2.24	0.0105	<u>0.024</u>
			Subtotal	0.036
Chlorine compressing				
Electrical energy	kWh	75.0	0.0105	<u>0.788</u>
Total gaseous chlorine				18.041
Chlorine liquefying				
Electrical energy	kWh	250.0	0.0105	<u>2.625</u>
Total liquid chlorine				20.566
Dilute caustic soda solution				19.283
Caustic soda evaporation				
Steam	lb	9,015.0	0.0014	12.621
Electrical energy	kWh	150.0	0.0105	<u>1.575</u>
			Subtotal	14.196
Salt separation by centrifuging				
Electrical energy	kWh	2.5	0.0105	<u>0.026</u>
Caustic soda (50%) solution				
Total (1.12 ton NaOH)				33.505
Or per ton of caustic soda				29.915

(a) Allocated: Cl₂-17.217 x 10⁶ Btu; NaOH-19.283 x 10⁶ Btu; H₂-0.491 x 10⁶ Btu.
Source: BCL 1975

TABLE 5.13. Quicklime Production

	Unit	Units per Net Ton of Quicklime	10 ⁶ Btu Per Unit	10 ⁶ Btu Per Net Ton of Quicklime
Limestone quarrying or mining				
Diesel fuel oil	gal	0.439	0.139	0.061
Other fuels	Btu	--	--	0.031
Electrical energy	kWh	0.857	0.0105	0.009
Explosives	lb	1.067	0.030	0.032
			Subtotal	0.133
Crushing				
Coal (space heating)	ret ton	0.0005	25.27	0.013
Coal transportation (200 mi by rail)	net ton-mile	0.1	0.00067	0.000
Natural gas (space heating)	ft ³	35.3	0.001	0.035
Gasoline	gal	0.048	0.125	0.006
Other fuels	Btu	--	--	0.014
Electrical energy	kWh	9.62	0.0105	0.101
			Subtotal	0.168
Transportation 200 mi average haul via water and rail	net ton-mile	70.0	0.00067	0.047
Calcining				
Coal	net ton	0.1552	25.27	3.922
Coal transportation (200 mi by rail)	net ton-mile	31.0	0.00067	0.021
Distillate fuel oil	gal	1.080	0.139	0.150
Residual fuel oil	gal	2.993	0.150	0.449
Natural gas	ft ³	2,980.0	0.001	2.980
Other fuels	Btu	--	--	0.122
Electrical energy	kWh	38.10	0.0105	0.400
Dust collection	kWh	8.95	0.0105	0.094
			Subtotal	8.138
Total				8.487

Source: BCL 1975.

5.3 SOURCES OF LOSSES

This section characterizes those areas in industry where waste heat is released. Several situations can cause waste heat to occur. Improper insulation can cause systems containing or transporting heat to vent off heat, or an unnecessarily high-quality heat source used to perform a process can waste heat. Heat losses also occur when some of the heat in a heat transfer application (e.g., coal flame to boiler contents) is not absorbed into the desired source, thereby causing energy to be vented. Sources of losses usually relate to a system's overall structure and design in addition to individual pieces of equipment (see Section 5.4 for information on equipment efficiencies). Locating sources of losses is an important part of improving industrial energy-use efficiency because it tells where waste heat can be reduced or tapped. Conventional schemes to use waste heat include cogeneration, cascading heat flows of decreasing quality, and insulation.

Heat Loss in Industry

Table 5.14 lists heat loss estimates in six industry groups. The products, which appear in the left-hand column, are associated with certain production processes. Heat loss, or rejected heat, is then broken down into five categories and is shown in terms of the total amount of rejected heat lost in the production of that product during an entire year throughout the entire U.S. economy. Unfortunately, the data presented in Table 5.14 are slightly dated, but more recent data are not currently available. Information on heat loss that occurs in specific processes and that can be associated with specific types of equipment and levels of output is not currently available either, but would be very valuable if developed.

Figure 5.11 describes a particular type of heat loss, steam leaks. This heat loss occurs primarily when process steam, one of the largest industrial end uses, is being generated. Steam loss can occur either in the boiler system itself or in pipes and tubing used to transport steam.

Figure 5.11 relates hole size (through which a leak occurs) to the pressure of the steam being used and the subsequent annual heat loss that can occur

the leak is allowed to exist for one year of standard operation. For example, by finding the curve for steam at 100 psig, the annual heat loss in million Btu can be found for holes ranging between 0.025 and 0.10 inches in size.

TABLE 5.14. Estimated Heat Rejection in Six Industries (1972-1973)

Industry (or Process) and Operation	Radiation, Convection, Conduction, and Unaccounted Losses ^(b)	Rejected Heat, (10 ¹² Btu/year) ^(a)				Total All Ranges
		Below 100°C	100- 250°C	250- 800°C	800- 1800°C	
<u>Chemical</u>						
Chlorine/Caustic Soda	40	254	51			
Ethylene/Propylene	20	151	79	40		
Ammonia	32	115	139	40		
Ethylbenzene/Styrene	1	24	28			
Carbon Black	2		32			
Sodium Carbonate	2	36	16			
Oxygen/Nitrogen	1	171	147			
Cumene		4	4			
Phenol/Acetone		8	8			
Other	<u>150</u>	<u>628</u>	<u>290</u>	<u>79</u>		
Total	248	1391	794	159		2,345
<u>Primary Metals</u>						
Steel	298	79	397	596	795	
Aluminum	119	378	79	20	79	
Other	<u>119</u>	<u>397</u>	<u>119</u>	<u>40</u>	<u>79</u>	
Total	536	854	595	656	953	3,058
<u>Petroleum</u>	318	994	497	695	2,186	
<u>Paper</u>	199	1391	755	119	2,265	
<u>Glass-Cement-Other</u>						
Cement	119	79	40	219		
Glass	99	60	12	87	36	
Other	<u>99</u>	<u>79</u>	<u>40</u>	<u>159</u>	<u>20</u>	
Total	317	218	92	465	56	1,049
<u>Food</u>	60	795	159	119	1,073	
GRAND TOTALS	1679	5643	3110	2213	1009	11,975
Ratio to Grand Total		0.47	0.26	0.18	0.09	

(a) To convert to 10^{15} J/year, multiply by 1.0543. The estimated accuracy of the values is $\pm 20\%$.

(b) Radiation losses etc., are distributed within other losses shown in the table.

Source: Chiogioji 1979.

FIGURE 5.11. Heat Loss from Steam Leaks

5.4 EFFICIENCIES

The efficiencies of industrial processes can be improved as new capital stock is purchased and as old capital stock is retrofitted and also from better use of total systems (see Section 5.3). The information contained in this section indicates that efficiencies in the industrial sector are well below possible levels. Reduction of heat loss, cascading energy flows, cogeneration, and matching energy-quality produced to energy-quality requirements are the major strategies usually mentioned for improving the conservation potential in the industrial sector.

The tables contained in this section comprise only a small part of the efficiency information needed to reasonably assess conservation potential. Included are efficiency data on some industrial processes and only one category of equipment. This sketchy picture, however, reflects the nature of information on the efficiency of industrial equipment. Comparing findings is difficult because most of the currently existing data on efficiency 1) are based on numerous assumptions, 2) refer to generalized categories or equipment-types, and 3) are scattered among numerous reports and studies. A standardized collection of efficiency calculations that are accompanied by detailed assumptions and measurements and that covers numerous processes and pieces of equipment across the entire industrial sector is badly needed.

Efficiencies of Industrial Processes

Table 5.15 presents estimates for the first-law efficiencies and the second-law effectiveness of several industrial processes; losses in electrical generation and transmission are not included in the Direct Equivalent column but are included in the Fuel Equivalent column. Effectiveness is defined as the ratio of the increase in energy availability to the decrease of energy availability in the process (see glossary).

Table 5.16 lists some second-law efficiencies (see glossary) calculated in a study by Ross and Williams (1977). This information can be compared to Tables 5.17 and 5.18, which were selected from other sources. These tables present second-law efficiency calculations and also contain information on both potential fuel savings using the most advanced technology existing in 1973 (Table 5.19) and on the potential level of efficiency attainable in the year 2000 compared to those existing in 1972. The zeroes that appear under the Second-Law Minimum column for Table 5.18 indicate that theoretically, the net energy used in paper and chemical production should be zero.

TABLE 5.15. Efficiency and Effectiveness Summary for Seven Industries

Industry	Percent			
	Direct Equivalent		Fuel Equivalent	
	Efficiency	Effectiveness	Efficiency	Effectiveness
Steel	42.0	40.1	41.0	39.0
Copper	3.5	9.2	2.7	7.10
Aluminum	29.6	32.6	14.2	15.1
Container glass	23.9	22.1	21.3	19.5
Rubber				
High temperature	92.4	96.2	92.4	96.2
Selected plastics				
Polyethylene				
Low-density	83.5	93.1	79.0	88.0
High-density	75.1	87.9	73.4	85.5
Polystyrene	82.7	97.9	82.2	97.2
Polyvinyl chloride	65.5	90.3	65.0	89.5
Paper	44.3	44.5	44.3	44.5

Source: Chiogioji 1979.

TABLE 5.16. Second-Law Efficiencies in the Industrial Sector

<u>Industry</u>	<u>Efficiency (%)</u>
Iron and Steel	35
Petroleum Refining	12
Paper	0.4
Primary Aluminum Production	17
Cement Manufacturing	17
Electric Power Generation	33
Process-Steam Production	33

Source: Chiogiogi 1979 and Ross and Williams 1977.

TABLE 5.17. Actual Fuel Consumption and Theoretical Minimum for Five Industries

	<u>Consumption (Btu/ton)</u>	<u>Potential Specific Fuel Consumption Using Technology Existing in 1973 (Btu/ton)</u>	<u>Theoretical Minimum Specific Fuel Consumption Based Upon Thermodynamic Availability Analysis (Btu/ton)</u>
Iron and Steel	26.5×10^6	17.2×10^6	6.0×10^6
Petroleum Refining	4.4×10^6	3.3×10^6	0.4×10^6
Paper	39.0×10^6	23.8×10^6	Greater than -0.2×10^6 Smaller than $+0.1 \times 10^6$
Primary Aluminum Production	190×10^6	152×10^6	25.2×10^6
Cement	7.9×10^6	4.7×10^6	0.8×10^6

Source: Chiogiogi 1979.

TABLE 5.18. Energy Conservation Potential in Seven Industries
(1972 = 100)

<u>Industry</u>	<u>Savings Attainable by 2000</u>	<u>Technological Minimum</u>	<u>Second Law Minimum</u>
Paper	75	69	0
Cement	75	60	10
Chemicals	80	50	0
Aluminum	60	45	29
Steel	75	50	30
Glass	75	35	20
Petroleum Refining	80	70	10

Source: Chiogiogi 1979

Efficiencies of Industrial Equipment

Table 5.19 depicts data on the efficiencies of several types of electric motors. Additional testing is required to develop efficiency data on additional types of equipment.

TABLE 5.19. Electric Motor Efficiencies

	<u>Current</u>			<u>Future</u>
	<u>Worst</u>	<u>Best</u>	<u>Average</u>	<u>Improved Efficiency Models</u>
1 HP	68	78	73	85.5
5 HP	78	81.5	80	89
10 HP	81	88	85	90
50 HP	88.5	92.0	90	92.5
100 HP	90.5	92.5	91.5	93
200 HP	94	95	94.5	95

Source: Chiogiogi 1979.

5.5 STOCK CHARACTERISTICS

Information on the quantity and useful life of industrial equipment and machinery is an important component of any assessment of conservation potential. Retrofitting existing capital stock to improve energy efficiency is often blocked by institutional and other structural problems. As the capital stock is replaced or "turned over" due to attrition, fewer impediments to introducing energy-efficient capital exist (assuming, of course, that the price of energy inputs continues to increase relative to all other inputs). The profiles of the industrial capital stock appearing in this section are intended to help determine how consumption patterns will change as the capital stock shifts its character. Knowing the number of units of a particular type currently in use, combined with the expected useful life and age of that equipment, the current efficiency, and the expected efficiency of new stock, allows a calculation of conservation potential to be made (with some adjustments needed for market rates of penetration). Hopefully data in this section will be expanded in a supplement to cover all types of industrial capital stock that are the subject of ECUT research activities.

Industrial Machinery and Equipment

Tables 5.20 through 5.31 depict very interesting information on the size (in 1972 dollars) age (in years) of the capital stock in several industries. Each table presents data on a different type of equipment or machinery and shows how stocks have changed from 1960 to 1980.

The most information conveyed by these tables are contained in the columns marked NET-GR, Average Age Gross and Average Age Net. The ratio of net stock to gross stock indicates the percentage of the stock that did not turn over that year. Categories of equipment or machinery with a high Net-GR ratio are replaced more slowly than those with a low Net-GR ratio. The other two columns provide important information on the age of the stock.

Tables 5.20 through 5.31 were prepared by the Bureau of the Census from national income and product account (NIPA) estimates of private fixed investment. Actual service lives are based on 85% of the 1942 edition of IRS bulletins F. Constant value valuation and straight-line depreciation were used in computing this data.

TABLE 5.20. Engines and Turbines Stocks, 1960-1980

Year	Millions of 1972 Dollars						
	End of Year		Annual Totals		Net/GR Ratio	End of Year	
	Gross Stock	Net Stock	Depre- ciation	Dis- cards		Average Age	
						Gross	Net
1960	11777	7114	563	251	0.604	8.42	6.06
1961	12237	7243	587	270	0.592	8.69	6.30
1962	12600	7277	606	291	0.578	9.01	6.58
1963	12940	7295	621	312	0.564	9.33	6.84
1964	13237	7288	635	345	0.551	9.64	7.07
1965	13527	7295	648	377	0.539	9.91	7.25
1966	13890	7401	662	410	0.533	10.08	7.29
1967	14455	7731	682	446	0.535	10.08	7.10
1968	15158	8211	712	489	0.542	9.96	6.82
1969	15974	8800	748	521	0.551	9.80	6.53
1970	16836	9426	787	551	0.560	9.63	6.29
1971	17771	10099	830	569	0.568	9.48	6.09
1972	18827	10906	878	629	0.579	9.25	5.89
1973	19849	11644	929	645	0.587	9.10	5.80
1974	20911	12390	980	664	0.593	8.97	5.74
1975	21625	12769	1023	689	0.590	9.01	5.88
1976	22165	12954	1054	699	0.584	9.13	6.09
1977	22734	13170	1081	728	0.579	9.22	6.27
1978	23280	13342	1109	734	0.573	9.34	6.45
1979	23804	13477	1135	747	0.566	9.47	6.63
1980	23980	13251	1152	750	0.553	9.75	6.96

Source: U.S. Department of Commerce 1981c.

TABLE 5.21. Mining and Oil Field Machinery Stocks, 1960-1980

Year	Millions of 1972 Dollars						
	End of Year		Annual Totals		Net/GR Ratio	End of Year	
	Gross Stock	Net Stock	Depre- ciation	Dis- cards		Average Age	
						Gross	Net
1960	7551	3660	741	714	0.485	5.55	3.87
1961	7380	3495	727	732	0.474	5.69	3.96
1962	7187	3345	707	751	0.465	5.80	4.01
1963	7137	3368	693	766	0.472	5.76	3.84
1964	7167	3483	692	776	0.486	5.63	3.63
1965	7293	3685	700	777	0.505	5.43	3.42
1966	7466	3905	717	765	0.523	5.22	3.28
1967	7413	3868	725	740	0.522	5.21	3.40
1968	7402	3842	725	710	0.519	5.21	3.50
1969	7458	3849	729	681	0.516	5.21	3.56
1970	7783	4090	749	664	0.525	5.08	3.43
1971	8234	4415	789	664	0.536	4.96	3.29
1972	8447	4484	822	677	0.531	5.02	3.37
1973	8783	4675	848	703	0.532	5.01	3.35
1974	9353	5086	893	734	0.544	4.89	3.22
1975	10100	5639	960	765	0.558	4.73	3.08
1976	10781	6079	1033	792	0.564	4.66	3.07
1977	11552	6553	1107	810	0.567	4.60	3.00
1978	12380	7026	1188	833	0.567	4.58	3.10
1979	13303	7539	1277	867	0.567	4.58	3.12
1980	14016	7809	1358	916	0.557	4.67	3.23

Source: U.S. Department of Commerce 1981c.

TABLE 5.22. Construction Machinery Stocks, 1960-1980

Year	Millions of 1972 Dollars						
	End of Year		Annual Totals		Net/GR Ratio	End of Year	
	Gross Stock	Net Stock	Depre- ciation	Dis- cards		Average Age	
						Gross	Net
1960	11071	5666	1306	1253	0.512	4.37	2.92
1961	11043	5564	1311	1262	0.504	4.43	3.01
1962	11082	5562	1309	1258	0.502	4.44	3.01
1963	11567	5968	1343	1278	0.516	4.32	2.85
1964	12382	6634	1423	1305	0.536	4.15	2.67
1965	13427	7428	1538	1325	0.553	3.99	2.55
1966	14588	8267	1673	1362	0.567	3.85	2.49
1967	15617	8875	1812	1392	0.568	3.80	2.55
1968	16741	9442	1947	1380	0.564	3.81	2.62
1969	17964	9991	2092	1416	0.556	3.86	2.69
1970	19017	10334	2227	1524	0.543	3.98	2.78
1971	19848	10515	2334	1691	0.530	4.11	2.87
1972	20940	11059	2440	1889	0.528	4.15	2.83
1973	22286	11899	2581	2072	0.534	4.12	2.75
1974	23542	12674	2734	2251	0.538	4.09	2.71
1975	23890	12566	2829	2373	0.526	4.20	2.86
1976	24007	12303	2853	2472	0.512	4.32	2.99
1977	25123	13049	2926	2556	0.519	4.25	2.88
1978	26517	14012	3077	2646	0.528	4.18	2.78
1979	27689	14704	3230	2750	0.531	4.16	2.76
1980	27974	14563	3314	2888	0.521	4.25	2.89

Source: U.S. Department of Commerce 1981c.

TABLE 5.23. Metalworking Machinery Stocks, 1960-1980

Year	Millions of 1972 Dollars						
	End of Year		Annual Totals		End of Year		
	Gross	Net	Depre-	Dis-	Net/GR	Average Age	
	Stock	Stock	ciation	cards	Ratio	Gross	Net
1960	38116	19455	2358	2269	0.510	8.39	5.59
1961	38163	19346	2372	2326	0.507	8.43	5.70
1962	38378	19445	2381	2348	0.507	8.42	5.72
1963	39195	20007	2414	2234	0.510	8.34	5.62
1964	40210	20755	2474	2276	0.516	8.23	5.50
1965	41991	22172	2565	2271	0.528	8.01	5.25
1966	44434	24195	2702	2354	0.545	7.72	4.96
1967	47790	26964	2888	2328	0.564	7.38	4.65
1968	50567	28971	3087	2343	0.573	7.22	4.57
1969	53285	30793	3267	2421	0.578	7.13	4.57
1970	55694	32198	3434	2479	0.578	7.11	4.64
1971	57028	32487	3555	2546	0.570	7.23	4.87
1972	58664	33055	3651	2612	0.563	7.32	5.02
1973	61354	34544	3791	2621	0.563	7.30	5.03
1974	64487	36335	3979	2665	0.563	7.27	5.01
1975	66336	36860	4136	2821	0.556	7.39	5.15
1976	68056	37249	4244	2904	0.547	7.52	5.28
1977	70147	37977	4357	2995	0.541	7.63	5.35
1978	72701	39182	4496	3145	0.539	7.69	5.33
1979	75624	40794	4662	3351	0.539	7.70	5.26
1980	78206	42095	4828	3548	0.538	7.74	5.24

Source: U.S. Department of Commerce 1981c.

TABLE 5.24. Special Industry Machinery Stocks (not elsewhere classified), 1960-1980

Year	Millions of 1972 Dollars						
	End of Year		Annual Totals		Net/GR Ratio	End of Year	
	Gross Stock	Net Stock	Depre- ciation	Dis- cards		Average Age	
						Gross	Net
1960	40221	21204	2491	1751	0.527	7.88	5.50
1961	41095	21425	2549	1903	0.521	8.02	5.54
1962	42023	21830	2599	2084	0.519	8.09	5.52
1963	42771	22133	2645	2200	0.517	8.16	5.52
1964	43911	22833	2700	2261	0.520	8.14	5.42
1965	45770	24309	2793	2409	0.531	7.97	5.18
1966	47782	25956	2918	2553	0.543	7.77	4.99
1967	49379	27087	3035	2569	0.549	7.68	4.95
1968	51121	28250	3143	2564	0.553	7.60	4.93
1969	52974	29445	3261	2603	0.556	7.53	4.92
1970	54772	30549	3381	2687	0.558	7.47	4.94
1971	56266	31247	3489	2693	0.555	7.49	5.03
1972	58091	32190	3597	2715	0.554	7.49	5.08
1973	604453	33531	3732	2711	0.555	7.46	5.07
1974	62648	34648	3877	2799	0.553	7.48	5.10
1975	63798	34741	3981	2925	0.545	7.62	5.26
1976	64827	34723	4044	2997	0.536	7.77	5.42
1977	65490	34371	4090	3075	0.525	7.96	5.59
1978	65986	33952	4117	3202	0.515	8.15	5.73
1979	66243	33465	4130	3386	0.505	8.32	5.85
1980	66002	32679	4119	3573	0.495	8.52	6.00

Source: U.S. Department of Commerce 1981c.

TABLE 5.25. Fabricated Metal Products Stocks, 1960-1980

Year	Millions of 1972 Dollars						
	End of Year		Annual Totals		Net/GR Ratio	End of Year	
	Gross Stock	Net Stock	Depre- ciation	Dis- cards		Average Age Gross	Net
1960	18235	10471	1035	505	0.574	7.67	5.57
1961	18776	10502	1066	557	0.559	7.97	5.79
1962	19157	10416	1089	622	0.544	8.29	6.03
1963	19607	10442	1109	685	0.533	8.53	6.16
1964	20170	10630	1134	759	0.527	8.68	6.16
1965	20908	11029	1168	830	0.528	8.71	6.04
1966	21772	11582	1212	901	0.532	8.67	5.86
1967	22521	12045	1256	969	0.535	8.65	5.76
1968	23388	12649	1301	1037	0.541	8.56	5.62
1969	24531	13514	1358	1081	0.551	8.39	5.43
1970	25958	14614	1432	1104	0.563	8.17	5.22
1971	27330	15611	1514	1139	0.571	8.02	5.12
1972	28680	16543	1594	1176	0.577	7.90	5.08
1973	30446	17830	1686	1206	0.586	7.72	4.98
1974	32430	19241	1798	1225	0.593	7.55	4.91
1975	34290	20436	1913	1248	0.596	7.46	4.94
1976	36410	21785	2031	1260	0.598	7.39	4.95
1977	38288	22805	2149	1292	0.596	7.41	5.04
1978	40275	23873	2262	1343	0.593	7.44	5.13
1979	42427	25015	2383	1373	0.590	7.48	5.20
1980	43954	25473	2488	1419	0.580	7.65	5.39

Source: U.S. Department of Commerce 1981c.

TABLE 5.26. Agricultural Machinery Stocks (except tractors),
1960-1980

Millions of 1972 Dollars							
Year	End of Year		Annual Totals		Net/GR Ratio	End of Year	
	Gross Stock	Net Stock	Depre- ciation	Dis- cards		Average Age	
						Gross	Net
1960	27228	14350	1617	1024	0.527	8.23	5.88
1961	27617	14272	1640	1172	0.517	8.45	5.99
1962	27943	14225	1655	1282	0.509	8.64	6.06
1963	28479	14435	1674	1348	0.507	8.73	6.01
1964	28946	14661	1699	1458	0.506	8.78	5.94
1965	29623	15146	1730	1539	0.511	8.74	5.79
1966	30433	15777	1773	1594	0.518	8.64	5.61
1967	31320	16514	1824	1673	0.527	8.50	5.45
1968	31935	16978	1870	1719	0.532	8.42	5.41
1969	32677	17548	1912	1740	0.537	8.32	5.36
1970	33632	18272	1966	1736	0.543	8.19	5.30
1971	34547	18886	2026	1725	0.547	8.10	5.29
1972	35310	19326	2080	1757	0.547	8.07	5.34
1973	36854	20468	2153	1751	0.555	7.90	5.22
1974	38412	21511	2250	1735	0.560	7.79	5.17
1975	40214	22703	2355	1744	0.565	7.69	5.12
1976	41735	23512	2457	1746	0.563	7.69	5.16
1977	43314	24328	2551	1788	0.562	7.71	5.21
1978	44507	24749	2634	1862	0.556	7.80	5.33
1979	45603	25068	2701	1923	0.550	7.91	5.45
1980	46299	24992	2752	1980	0.540	8.08	5.64

Source: U.S. Department of Commerce 1981c.

TABLE 5.27. Tractor Stocks, 1960-1980

Year	Millions of 1972 Dollars						
	End of Year		Annual Totals		Net/GR Ratio	End of Year	
	Gross Stock	Net Stock	Depre- ciation	Dis- cards		Average Age	
						Gross	Net
1960	10396	5060	1380	1516	0.487	4.20	2.84
1961	10146	4899	1331	1436	0.483	4.23	2.87
1962	10014	4864	1306	1402	0.486	4.20	2.82
1963	10126	5076	1306	1401	0.501	4.07	2.67
1964	10625	5585	1349	1351	0.526	3.87	2.47
1965	11262	6125	1430	1329	0.544	3.71	2.37
1966	12413	7077	1556	1343	0.570	3.47	2.24
1967	13287	7557	1700	1292	0.569	3.44	2.33
1968	14095	7826	1816	1265	0.555	3.53	2.46
1969	14577	7770	1900	1348	0.533	3.69	2.64
1970	15006	7700	1953	1450	0.513	3.87	2.75
1971	14997	7375	1968	1651	0.492	4.08	2.87
1972	15384	7613	1980	1825	0.495	4.09	2.75
1973	16267	8442	2060	1999	0.519	3.92	2.51
1974	16857	8965	2161	2086	0.532	3.82	2.45
1975	17425	9355	2245	2068	0.537	3.76	2.48
1976	17892	9530	2321	2029	0.533	3.76	2.56
1977	18566	9808	2401	2005	0.528	3.78	2.61
1978	19221	10011	2487	2035	0.521	3.83	2.65
1979	19907	10255	2570	2128	0.515	3.89	2.66
1980	19458	9569	2575	2338	0.492	4.10	2.86

Source: U.S. Department of Commerce 1981c.

TABLE 5.28. General Industrial, Including Materials Handling,
Equipment Stocks, 1960-1980

Year	Millions of 1972 Dollars						
	End of Year		Annual Totals		Net/GR Ratio	End of Year	
	Gross Stock	Net Stock	Depre- ciation	Dis- cards		Average Age	
						Gross	Net
1960	33520	17546	2311	1999	0.523	7.24	4.84
1961	34048	17757	2353	2054	0.522	7.27	4.87
1962	34683	18122	2394	2141	0.523	7.26	4.87
1963	35729	18818	2454	2120	0.527	7.19	4.79
1964	37175	19886	2543	2181	0.535	7.06	4.65
1965	38920	21219	2658	2254	0.545	6.89	4.50
1966	41199	22908	2805	2221	0.556	6.72	4.35
1967	42973	24030	2951	2306	0.559	6.65	4.35
1968	44537	24865	3072	2349	0.558	6.65	4.42
1969	46517	26035	3199	2403	0.560	6.62	4.43
1970	48435	27042	3340	2448	0.558	6.63	4.48
1971	49995	27628	3464	2509	0.553	6.71	4.58
1972	51656	28280	3577	2588	0.547	6.78	4.66
1973	53950	29541	3715	2701	0.548	6.77	4.64
1974	56589	31089	3888	2818	0.549	6.74	4.59
1975	58125	31518	4031	2923	0.542	6.85	4.69
1976	59480	31824	4127	3077	0.535	6.97	4.79
1977	61210	32586	4229	3262	0.532	7.02	4.80
1978	62964	33429	4346	3435	0.531	7.06	4.80
1979	65212	34770	4483	3575	0.533	7.04	4.73
1980	67315	35984	4633	3745	0.535	7.03	4.70

Source: U.S. Department of Commerce 1981c.

TABLE 5.29. Office, Computing, and Accounting Machinery Stocks, 1960-1980

Year	Millions of 1972 Dollars						
	End of Year		Annual Totals		Net/GR Ratio	End of Year	
	Gross Stock	Net Stock	Depre- ciation	Dis- cards		Average Age Gross	Net
1960	9700	5324	1238	922	0.549	3.60	2.45
1961	10217	5466	1318	998	0.535	3.72	2.56
1962	10608	5527	1374	1098	0.521	3.84	2.65
1963	11385	5989	1448	1201	0.526	3.82	2.55
1964	12250	6547	1555	1323	0.534	3.76	2.46
1965	13301	7255	1683	1434	0.545	3.68	2.39
1966	15173	8639	1883	1512	0.569	3.48	2.22
1967	17080	9894	2141	1610	0.579	3.38	2.21
1968	18787	10778	2388	1690	0.574	3.40	2.30
1969	21144	12134	2662	1768	0.574	3.38	2.31
1970	23427	13260	2972	1929	0.566	3.44	2.36
1971	25357	14014	3246	2183	0.553	3.55	2.46
1972	27990	15376	3543	2450	0.549	3.59	2.44
1973	31058	17186	3915	2853	0.553	3.57	2.38
1974	34965	19762	4378	3258	0.565	3.48	2.29
1975	37778	21296	4818	3539	0.564	3.48	2.35
1976	42013	23914	5297	3681	0.569	3.42	2.32
1977	47780	27665	5975	3959	0.579	3.33	2.25
1978	54280	31606	6802	4242	0.582	3.30	2.24
1979	62077	36360	7763	4720	0.586	3.27	2.22
1980	72278	42867	8975	5282	0.593	3.20	2.18

Source: U.S. Department of Commerce 1981c.

TABLE 5.30. Service Industry Machinery Stocks, 1960-1980

Year	Millions of 1972 Dollars						
	End of Year		Annual Totals		Net/GR Ratio	End of Year	
	Gross Stock	Net Stock	Depre- ciation	Dis- cards		Average Age Gross	Net
1960	14987	7845	1458	1261	0.524	5.12	3.47
1961	15240	7897	1486	1292	0.518	5.16	3.53
1962	15554	8011	1513	1321	0.515	5.19	3.55
1963	15815	8089	1540	1357	0.511	5.24	3.57
1964	16196	8305	1569	1404	0.513	5.23	3.52
1965	16836	8782	1619	1456	0.522	5.15	3.40
1966	17683	9443	1693	1507	0.534	5.02	3.26
1967	18465	9995	1776	1546	0.541	4.94	3.22
1968	19443	10676	1866	1569	0.549	4.84	3.18
1969	20538	11382	1974	1584	0.554	4.77	3.17
1970	21595	11957	2084	1603	0.554	4.75	3.21
1971	22672	12479	2192	1638	0.550	4.77	3.26
1972	23703	12905	2297	1693	0.544	4.83	3.32
1973	24851	13428	2404	1778	0.540	4.87	3.35
1974	25737	13705	2501	1892	0.533	4.97	3.42
1975	25967	13410	2549	2025	0.516	5.15	3.59
1976	26346	13384	2572	2166	0.508	5.26	3.64
1977	26913	13641	2612	2302	0.507	5.29	3.60
1978	27319	13820	2655	2428	0.506	5.32	3.58
1979	27695	14039	2689	2532	0.507	5.32	3.55
1980	28156	14375	2729	2604	0.511	5.29	3.50

Source: U.S. Department of Commerce 1981c.

TABLE 5.31. Electrical and Communications Equipment Stocks, 1960-1980

Year	Millions of 1972 Dollars						
	End of Year		Annual Totals		Net/GR Ratio	End of Year	
	Gross Stock	Net Stock	Depre- ciation	Dis- cards		Average Age	
						Gross	Net
1960	55401	32061	3806	2023	0.579	6.19	4.34
1961	59399	34275	4076	2312	0.577	6.24	4.33
1962	63715	36740	4366	2528	0.577	6.26	4.30
1963	67843	38925	4660	2731	0.574	6.32	4.31
1964	72220	41409	4956	3076	0.573	6.33	4.31
1965	77376	44577	5290	3314	0.576	6.30	4.26
1966	83464	48509	5688	3551	0.581	6.23	4.18
1967	89137	51872	6106	3808	0.582	6.22	4.18
1968	94525	54804	6498	4053	0.580	6.25	4.23
1969	101151	58846	6925	4354	0.582	6.22	4.21
1970	108585	63411	7427	4574	0.584	6.18	4.19
1971	115126	66838	7925	4842	0.581	6.23	4.25
1972	121411	69823	8377	5096	0.575	6.30	4.34
1973	129568	74555	8887	5479	0.575	6.30	4.32
1974	138384	79761	9488	5895	0.576	6.28	4.29
1975	144908	82463	10024	6202	0.569	6.40	4.40
1976	151192	84935	10466	6654	0.562	6.51	4.51
1977	160250	90135	10998	7140	0.562	6.51	4.46
1978	171809	97636	11724	7666	0.568	6.43	4.34
1979	184863	106283	12596	8189	0.575	6.33	4.23
1980	198486	115051	13544	8690	0.580	6.27	4.17

Source: U.S. Department of Commerce 1981c.

Boilers and Other Combustors

Tables 5.32, 5.33, 5.34, and 5.35 divide industrial boilers into categories, depending on their rate of combustion, and give the number and energy consumption requirements of these boilers. Note that Table 5.36 offers four different estimates taken from four different sources. Figure 5.12 displays the relative market share of boilers according to fuel type.

Table 5.36 presents the energy consumed by various types of combustors. This information should be used in conjunction with Table 5.37, which lists the size and useful life of the same representative process heaters. Useful life and depreciable life figures used in Tables 5.37 and 5.38 are only estimates and reflect relative, not absolute useful lives of different types of process heaters.

Table 5.39 lists projections of the future fuel requirements of boilers. These requirements could be compared to fuel consumption needs after conservation strategies are employed.

TABLE 5.32. Projected Boiler Stock: 1990

<u>Size (MMBtu)</u>	<u>Boilers Built Before 1982</u>	<u>Boilers Built from 1982 - 1990</u>	<u>Total</u>
10 - 100	1353	703	2056
100 - 250	1582	1379	2961
> 250	<u>1432</u>	<u>1353</u>	<u>2785</u>
Total	4367	3435	7802

Note: Unless otherwise cited, all industrial fuel use projections were estimated based on EEA's Industrial Fuel Choice Analysis Model runs, December 17, 1979.

Source: DOE 1980d.

TABLE 5.33. Industrial Boiler Capacity, 1974

<u>Boiler Size^(a) (MMBtu/hr)</u>	<u>Percent</u>			
	<u>MFBI^(b)</u>	<u>ABMA^(c)</u>	<u>NEDS^(d)</u>	<u>PEDCo^(e)</u>
10 - 50	33.5	11	12	32
50 - 100	33.5	21	19	17
100 - 250	33.2	39	41	23
> 250	33.3	29	28	28

(a) MFBI, ABMA, and NEDS data exclude capacity in small firetube boilers. PEDCo data include firetube boilers and therefore show more capacity in the small size range.

(b) These figures represent energy use. Data for boilers with heat input greater than 100 MMBtu/hr are from DOE's MFBI survey. The data for total energy consumption come from the ECDB.

(c) American Boiler Manufacturers Association, watertube boiler capacity sold 1965-1977.

(d) Environmental Protection Agency, National Emissions Data System.

(e) PEDCo Environmental, Inc., "The Population and Characteristics of Industrial/Commercial Boilers," prepared for EPA, May 1979.

Source: DOE 1980d.

TABLE 5.34. Capacity Distribution of Small Industrial Boilers by Size and Fuel Type (MMBtu/hr)

<u>Fuel Type</u>	<u>< 0.4</u>	<u>0.4-1.5</u>	<u>1.5-10</u>	<u>10-25</u>	<u>25-50</u>	<u>50-100</u>	<u>Total</u>	<u>%</u>
Coal	4,100	14,260	25,250	26,280	75,980	95,200	241,070	13.0
Residual	10,300	42,520	117,840	98,660	154,120	121,650	545,090	29.5
Distillate	6,400	22,740	63,180	47,170	35,010	14,660	189,160	10.2
Natural Gas	26,400	88,830	199,740	164,700	210,810	182,880	873,360	47.2
Total	47,200	168,350	406,010	336,810	475,920	414,390	1,848,680	99.9
Percent	2.6	9.1	22.0	18.2	25.7	22.4	100.0	

Source: DOE 1980.

TABLE 5.35. Distribution of Small Industrial Boilers by Size and Fuel Type

Boiler Type	Capacity Range (MMBtu/hr)						Total	%
	< 0.4	0.4-1.5	1.5-10	10-25	25-50	50-100		
Cast Iron								
# units	194,196	76,435	24,667	0	0	0	295,298	58.8
Capacity	47,200	60,700	71,500	0	0	0	179,400	9.7
Firetube								
# units	0	103,088	54,007	14,268	2,573	0	173,936	34.7
Capacity	0	103,100	298,800	250,100	96,500	0	748,500	40.5
Watertube								
# units	0	3,839	7,626	5,240	10,306	5,640	32,651	6.5
Capacity	0	4,550	35,710	86,710	379,420	414,390	920,780	49.8
Total								
# units	194,196	183,362	86,300	19,508	12,879	5,640	501,885	100.0
Capacity	47,200	168,350	406,010	336,810	475,920	414,390	1,848,680	100.0
% units	38.7	36.5	17.2	3.9	2.6	1.1	100.0	
% capacity	2.6	9.1	22.0	18.2	25.7	22.4	100.0	

Source: DOE 1980d.

TABLE 5.36. Oil and Gas Use in Major Process Heat Applications, 1974

<u>Equipment Type</u>	<u>1974 Oil and Gas Use (10¹² Btu)</u>
Low-risk fired heaters (used in atmospheric and vacuum distillation)	467
Regenerative glass melter	168
Rotary cement kiln	248
Face brick kiln	54
Blast furnace, hydrocarbon injection	100
Steel reheat furnace	266
Heat treating furnace	<u>67</u>
Subtotal	1370
Total process heat oil and gas use covered in analysis	2905

Source: DOE 1980d.

FIGURE 5.12. Boiler Sales by Fuel Type (DOE 1980d)

TABLE 5.37. Representative Process Heaters Used in Sample Cost Calculations

<u>Equipment Type</u>	<u>Capacity Size (MMBtu/hr)</u>	<u>Useful Utilization %</u>	<u>Useful Life</u>
1. Low risk (used in atmospheric and vacuum distillation)	99 and 364	90	25
2. Regenerative glass melter	200	90	5
3. Rotary cement kiln	333	90	25
4. Face brick kiln	42	90	25
5. Blast furnace - hydrocarbon injection	400	65	50
6. Steel reheat furnace	200	55	30
7. Heat treating furnace	10	55	30

TABLE 5.38. Depreciable Life of Boilers and Process Heaters

- Boilers:
 - Coal and alternative fuel 22 years
 - Oil- and gas-fired boilers 28 years
- Process heaters vary by industry and combustor^(a)
 - Food 12-18 years
 - Textiles 7.5-11 years
 - Paper 10-13 years
 - Chemicals 11 years
 - Petroleum 16 years
 - Stone, clay and glass 11-20 years
 - Primary metals 12-14 years

(a) Range reflects different depreciable lives for different subgroups within each industry group. The range does not include special tools that have much shorter lives.

Source: DOE 1980.

TABLE 5.39. Projected Boiler Fuel Requirements, by Industry
(10¹² Btu)

<u>Industry</u>	<u>Boiler Built Prior to 1982</u>	<u>Boiler Built Between 1982-1990</u>	<u>Total</u>
Food	735	656	1391
Textiles	40	16	56
Paper	760	525	1285
Chemicals	1617	1638	3255
Petroleum	439	214	653
Stone, Clay, and Glass	39	33	72
Steel	145	37	182
Aluminum	165	96	261
All Other	426	219	645
Total	4366	3434	7800

Source: DOE 1980d.

Electric Motors

Table 5.40 presents data on the existing capital stock of electric motors. These data are categorized by application:

- pumps
- compressors
- blowers/fans
- machine tools.

TABLE 5.40. Industrial Equipment Usage Profile (1971)
(integral HP motor drive only)

<u>Equipment Type</u>	<u>Estimated Population (000's)</u>	<u>Estimated Average Drive Size (kWh)</u>	<u>Average Usage (hr/yr)</u>	<u>Estimated Electricity Consumption (kWh x 10⁶)</u>
Centrifugal Pumps	6,310	11.42	3,000	216,000
Rotary Pumps	3,934	7.55	3,000	89,000
Reciprocating Pumps	383	7.5	3,000	8,600
Turbine and Other Pumps	<u>545.6</u>	<u>8.0</u>	<u>3,000</u>	<u>13,400</u>
	11,172.6	--	--	327,000
Air Compressors	705	13.94	3,000	29,400
Refrigeration Compressors	50.3	175	4,000	35,200
Vacuum Pumps	<u>1,256.0</u>	<u>3.75</u>	<u>4,000</u>	<u>18,900</u>
Subtotal Compressors				83,500
Centrifugal Blowers and Fans	1,808.0	20.0	2,500	90,400
Axial and Propeller Fans	<u>2,352.0</u>	<u>11.16</u>	<u>2,500</u>	<u>65,600</u>
Subtotal-Blowers and Fans	4,160.0	--	--	156,000
Metal-Cutting Machine Tools	2,362.0	9.0	1,000	21,300
Metal-Forming Machine Tools	<u>703.0</u>	<u>26.25</u>	<u>1,000</u>	<u>18,500</u>
Subtotal-Machine Tools	3,065.0	--	--	39,800
Subtotal	<u>20,408.9</u>			<u>606,300</u>
Adjustment for Usage in Other Sectors	--	--	--	<u>(267,300)</u>
				339,000
Other AC Integral HP				63,300
Fractional AC				20,000
DC Motors and Drives				<u>36,000</u>
Total				458,300

Source: Federal Energy Administration (no date), p. 23.

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SECTION 6.0

TRANSPORTATION ENERGY CONSUMPTION

SECTION 6.0

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TRANSPORTATION DATA QUALITY

<u>General Energy Consumption</u>		<u>Vehicle Efficiencies and Energy Losses</u>		<u>Vehicle Use, Ownership, and Stocks</u>	
1,1978	general consumption by mode	2,1974	power train losses	1,1978	vehicle stock by model
1,1978	fuel type by mode	2,1974	effects of drag, weight, and rolling resistance	1,1978	scrappage rates: • automobiles • small trucks • large trucks
	significant consumption by:	4,1976	effect of typical accessories	1,1979	new automobile registrations by fuel type
2,1976	• passenger travel energy intensity		expected impact of sample technology improvements	1,1978	ownership profiles
2,1976	• freight energy intensity	1,1979	• automobiles	1,1977	trip profiles
1,1978	• automobile fleet energy consumption	2,1976	• freight trucks	1, 1978	auto and truck sales
		1,1980	efficiencies of new automobiles by EPA class	1,1979	installed energy-related equipment

KEY:		Date Quality Code:	1. Information is recent and representative of current trends.
	1,1979		2. Information is dated yet is best available and/or representative of current trends.
Data Quality Code			3. Information is of questionable quality; better data will be available.
			4. Information is of questionable quality; better data are unavailable.
			5. Information is absent from this report; data are being sought.
			6. Information is absent from this report; data are currently unavailable.

6.0 TRANSPORTATION ENERGY CONSUMPTION

6.1 GENERAL CONSUMPTION

The transportation sector consumes about one fourth of the energy used in the U.S. (see Section 3 for aggregate energy consumption of major use sectors). However, although the transportation share of energy consumption is the smallest of the three main sectors, over one half of U.S. oil consumption occurs in transportation. Figure 6.1 and Table 6.1 display the relative gross energy consumption of the major modes of transportation in 1978.

FIGURE 6.1. 1978 Transportation Energy Consumption by Mode 10^{15} Btus and Percent of Total (Oak Ridge National Laboratory 1980)

TABLE 6.1. Civilian and Military Transportation Energy Use by Mode, 1978

	Total Consumption (military and civilian) Billion Btu (thousand bbl/day crude oil equivalent)	Military Consumption ^(a)	
		Billion Btu (thousand bbl/day crude oil equivalent)	Percentage of Total by Mode
Highway	15,721,730 (7,426.9)	12,302 (5.8)	0.08
Motorcycle and mopeds	69,576 (32.9)	NA	
Automobiles	10,350,527 (4,889.6)	2,625 ^(c) (1.2)	0.03
Recreational vehicles	89,789 (42.4)	NA	
Buses	136,287 (64.4)	754 (0.4)	0.55
Trucks	5,075,550 (2,397.7)	8,923 (4.2)	0.18
Nonhighway	4,800,274 (2,267.6)	548,867 (259.2)	10.14
Air	1,990,185 (940.2)	434,518 ^(d) (205.2)	21.83
Marine	1,459,191 (689.3)	61,446 ^(e) (29.0)	4.21
Pipeline	673,165 (318.0)	NA	
Rail	605,892 (286.2)	NA	
Snowmobiles	19,100 (9.0)	NA	
Other military operations	52,903 (25.0)	52,903 (25.0)	100.00
Total	20,522,004 (9,694.6)	561,169 (265.1)	2.73

(a) Military operations include the Army, Navy, Air Force, Marine Corps, and corresponding reserve units, as well as Defense Agencies, Army National Guard and the Air National Guard.

(b) Thousand bbl/day crude oil equivalent based on Btu content of a barrel of crude. Refinery loss is not taken into account.

(c) These data represent federal "large" fleets (2000 vehicles or more), which comprised 93.7% of the total federal fleet in 1978. Nonmilitary government fleets are included with civilian.

(d) Fuels used in the air mode include aviation gasoline, jet propulsion fuel-naptha type (JP-4), and jet propulsion-kerosene type (JP-5).

(e) Marine fuels include distillate fuel marine, navy distillate fuel, and navy special fuels; since states having ports show by far the largest consumption of residual fuel, the residual oil consumption reported by the Defense Fuel Supply Center has been ascribed to naval operations.

NA--Not applicable.

Source: Oak Ridge National Laboratory 1980.

Consumption by Fuel Type

Figure 6.2 displays the relative consumption of different fuels in the transportation sector. Table 6.2 presents the consumption of each major fuel type by mode of transport.

FIGURE 6.2. 1978 Transportation Energy Consumption by Fuel Type, 10¹⁵ Btus and Percent of Total (Oak Ridge National Laboratory 1980)

**TABLE 6.2. Transportation Fuel Consumption by Mode by Fuel Type, 1978
(civilian only)**

	Gasoline (thousand gal)	Distillate Fuel Oil(a) (thousand gal)	Liquefied Gases (thousand gal)	Jet Fuel (thousand gal)	Residual Fuel Oil (thousand gal)	Natural Gas (million cu ft)	Electricity (million kWh)
Highway	111,801,057	11,835,066	993,277				
Motorcycles and mopeds	556,611						
Automobiles	82,783,212						
Recreational vehicles	718,310						
Buses	416,261	602,017	13(b)				
Local	9,318	422,017	13(b)				
Intercity		180,000					
School	406,943						
Trucks	27,326,657	8,556,953	993,264(d)				
Personal light trucks(c)	13,886,761						
Other trucks	13,439,896	8,556,953	993,264(d)				
Nonhighway	2,054,140	5,710,177		11,096,651	6,614,790	530,451	15,407
Air	476,190(e)			11,096,651			
General aviation, air taxi, and commuter air carriers	476,190(e)			558,832(f)			
Domestic air carriers				8,831,512(f)			
Trunks and local service				8,446,117(f)			
Other carriers(g)				115,856(f)			
All cargo				164,060(f)			
Supplemental				105,479(f)			
International air carriers				1,057,953(f)			
Trunks and local service				870,959(f)			
All cargo				86,638(f)			
Supplemental				101,365(f)			
Foreign flag				648,354(h)			
Marine	1,425,000	1,653,822			6,614,790		
Freight		1,578,822			6,614,790		
Domestic trade		942,606			1,241,772		
Foreign trade		636,216			5,373,018		
Recreational	1,425,000	75,000					
Pipeline						530,451	11,662
Natural gas						530,451	2,424
Crude petroleum							4,510
Petroleum product							4,378
Coal slurry							350
Rail		4,056,355					3,805
Freight(i)		3,913,335					308
Passenger		143,020					3,499
Transit							2,233
Commuter rail		41,146					935
Intercity		101,874					341
Snowmobiles	159,950						
Total	113,855,197	16,943,226		11,096,651	6,614,790	530,451	15,467

(a) Includes diesel fuels.

(b) Propane.

(c) These figures do not include diesel fuel consumed by personal light trucks. Personal diesel light trucks represent less than 1% of all light trucks.

(d) Butane.

(e) Aviation gasoline.

(f) Kerosene-type.

(g) Includes Alaskan and Hawaiian carriers.

(h) 1977 figure.

(i) These figures do not include coal used by railroads in freight transport; the amount is less than 0.01% of total fuel used by freight.

Source: Oak Ridge National Laboratory 1980.

Significant Consumption Areas

The combined energy consumption of automobiles, trucks, and aircraft accounts for over 85% of the transportation energy consumption. Figures 6.3 and 6.4 present the average energy intensities of passenger and domestic freight transportation. These figures highlight the relative performance of the various transportation modes within main groups such as automobile, marine, air, and rail freight. Table 6.3 disaggregates intercity freight energy intensity and use, including natural gas, oil, and coal slurry pipelines.

Historically, automobile fleets have been effectively used for demonstration projects and rapid commercialization of new systems, partially because of the rapid depreciation schedules used by corporations. A rapid turnover of large fleets enables frequent implementation of new technologies. The use of electric vehicles in the postal service and phone company fleets is a good example. Also, centralization of the operation and maintenance records typically maintained for fleet vehicles enables more accurate evaluation of the demonstration programs. Table 6.4 outlines automobile fleet energy consumption by sector in 1978 and will be useful when estimating the market potential for demonstration programs of major technology improvements that meet the performance requirements of various fleets.

FIGURE 6.3. 1976 Estimates of Passenger Transportation Energy Intensity (DOE 1980b) Btu/passenger-mile

FIGURE 6.4. Domestic, Freight-Energy Intensity, 1976
(Btu/passenger-mile) (DOE 1980b)

(a) Excluding pipeline.

TABLE 6.3. Domestic Intercity Freight Movements and Energy Use
in the United States, 1977 and 1978

Mode	Energy Intensity (Btu/ton-mile)	Energy Use (trillion Btu)
TRUCK		
1977	2,727(a)	1,500(a)
1978	2,490(a)	1,500(a)
CERTIFICATED AIR CARRIER	(b)	
1977	--	25.2
1978	--	--
All cargo		
1977	26,859	13.9
1978	25,400	22.1
Lower hold		
1977	3,300(c)	11.3
1978		
MARINE		
1977	440	262.5
1978	--	316.6
Coastal		
1977	--	--
1978	--	--
Lakewise		
1977	--	--
1978	--	--
Internal		
1977	--	--
1978	--	--
PIPELINE		
1977	--	675.0
1978	--	673.1
Natural gas		
1977	--	569.9
1978	--	568.8
Crude and oil product		
1977	181	101.1
1978	172	101.1
Coal slurry		
1977	2,990	4.0
1978	2,990	4.0
RAIL		
1977	667	551.2
1978	637	546.3
TOTAL		
1977	1,186	3,013.9(d)
1978	--	3,058.1

(a) Gross estimate.

(b) "--" indicates areas where no data are available.

(c) Incremental fuel consumption. Assumes passenger aircraft would fly even if no belly freight were carried. Therefore, energy use by belly freights is defined as the incremental fuel used to carry its weight.

(d) Excludes lower hold energy use.

Source: Oak Ridge National Laboratory 1980.

TABLE 6.4. Fleet Automobile Energy Consumption by Sector, 1978
(fleets of 10 or more)

Sector	Gasoline Consumption (a) (million gal)	Energy Use	
		Billion Btu	Percentage
Police	719	89.8	6.3
Government(b)	816	102.0	7.2
Utilities	465	58.1	4.1
Taxi	775	96.8	6.8
Auto rental	597	74.7	5.3
Business 10-24	1,379	172.4	12.1
Business 25+	3,700	462.5	32.6
Other sectors	2,905	363.1	25.6
Total	11,356	1,419.4	100.0
Total (fleets of four or more)	17,662	2,207.7	

(a) Estimate based on 13.5 mpg for all fleet automobiles except taxis.
Mpg for taxis estimated to be 11.5.

(b) State and local nonpolice.

Source: Oak Ridge National Laboratory 1979.

6.2 EFFICIENCIES AND SOURCES OF SIGNIFICANT LOSSES

Losses in Automobile Engine-Power Transmission Systems

Automobiles and trucks account for over 75% of the total transportation energy consumption each year. The first-law efficiency of a typical modern automobile is only about 12%. Figure 6.5 displays the contributions to the inefficiency of a typical automobile engine-transmission system. Engines designed for full load (high acceleration at high speeds) typically convert about 25% of the fuel energy into rotational energy. However, normal driving requires less power and the engines are less efficient at these partial loads (see part-load losses arrow). Accessories and transmission inefficiencies further reduce the system efficiency to about 12%. Figure 6.6 is a more detailed display of the losses of a typical automobile.

FIGURE 6.5. Losses In Typical Automobile Engine and Transmission Systems (Ross and Williams 1981)

FIGURE 6.6. Passenger Car Energy Distribution During EPA Cycle (Grey et al. 1978)

Effects of Air Drag and Vehicle Weight

Reduction of air drag and weight can significantly reduce the fuel consumption of the truck and automobile fleets. Table 6.5 displays the drag coefficients for sample vehicles. Table 6.6 verifies the impact of air drag and rolling resistance by displaying their effects as vehicle speed increases. In these tables, air resistance or drag force is defined as:

$$F_d = \frac{C_d A_f v^2}{370}$$

where

F_d is the drag force in lb, A_f is the frontal area in ft^2 , and v is the speed in mph. C_d is a dimensionless drag coefficient. The rolling resistance of a new automobile tire is defined as:

$$F_r = \frac{M}{1000} \left[12 + 0.05 v + 0.004 (v-40)^2_{v \geq 40} \right]$$

where

F_r is in lbf, M is in lbm, and v is in mph.

Figure 6.7 graphically compares the relative importance of air drag and rolling resistance to vehicle weight. Figure 6.8 displays the linear relationship between vehicle weight and energy intensity.

TABLE 6.5. Sample Aerodynamic Drag Coefficients for Road Vehicles

<u>Vehicle</u>	<u>C_d</u>	<u>(Ref.)</u>	<u>Other Shapes</u>	<u>C_d</u>	<u>(Ref.)</u>
Ordinary truck	0.7	(a)	Teardrop (best)	0.03	(b)
Streamlined truck	0.55	(a)	Square flat plate (worst)	1.3	(b)
Jaguar XK-E	0.40	(b)	"Typical" auto shape	0.55	(b)
Porsche 904	0.35	(c)			
1972 Camaro	0.5	(d)			
1972 Dodge Polara Wagon	0.6	(d)			

(a) Smith (1970).

(b) TEP (1972).

(c) Campbell (1970).

(d) White and Korst (1972).

Source: American Institute of Physics 1975.

TABLE 6.6. Sample Effects of Drag and Rolling Resistance

COMPACT AUTOMOBILE^(a):

Velocity mph (m/sec)	Rolling Resistance		Air Resistance		Constant-Speed Power $P=v (F_r + F_d)$	
	F_r lb	(N)	F_d lb	(N)	hp	(kW)
20(8.9)	32.5	(145)	12	(53)	2.4	(1.8)
40(18)	35	(155)	48	(210)	8.9	(6.5)
60(27)	41.5	(185)	107	(475)	23.8	(17.6)
80(36)	56	(250)	190	(850)	52.5	(39.3)

Air drag and rolling resistance are equal at 34 mph (15 m/sec).

LUXURY CAR^(b):

Velocity mph (m/sec)	Rolling Resistance		Air Resistance		Constant-Speed Power $P=v (F_r + F_d)$	
	F_r lb	(N)	F_d lb	(N)	hp	(kW)
20(8.9)	65	(290)	17	(75)	4.4	(3.2)
40(18)	70	(310)	67	(300)	14.6	(10.8)
60(27)	93	(370)	150	(670)	38.9	(27.8)
80(36)	112	(500)	270	(1200)	81.5	(60.5)

Air drag and rolling resistance are equal at 41 mph (18 m/sec).

- (a) 2500-lb (1130-kg) compact (after Kummer, 1974): Estimated $C_d = 0.5$.
Estimated $A_f = 22 \text{ ft}^2 (2.0 \text{ m}^2)$.
(b) 5000-lb (2270-kg) "luxury" car: Estimated $C_d = 0.52$.
 $A_f = 30 \text{ ft}^2 (2.8 \text{ m}^2)$.

Source: American Institute of Physics 1975.

FIGURE 6.7. Effects of Air Drag, Rolling Resistance, and Weight Reduction of Compact Car, Urban Driving Cycle (DOE 1980b)

FIGURE 6.8. Energy Intensity Versus Vehicle Weight (Ross and Williams 1981)

Effect of Vehicle Accessories on Energy Consumption

Vehicle accessories are a common element of vehicle energy conservation discussions. Assessing the full impact of new technology advances such as air-conditioning systems requires a knowledge of the system's impact on vehicle efficiency, as well as inventory figures on the number of units being used in, or added to, the transportation fleet. Table 6.7 contains the estimated effects of common accessories. Stock information is in Section 6.3.

TABLE 6.7. Effect of Popular Options on Energy Use

	<u>Approximate Percentage Change in Fuel Economy</u>
Air conditioning	-13
Automatic transmission	-14 to 15.5
Power steering	-1
Radial tires	+2 to 2.5
V-8 engine	-18.5

Source: DOE 1980b.

Effect of Sample Technical Improvements

The automobile and truck fleets are the major targets for transportation energy conservation. Various studies have estimated the effects that certain hypothetical technical improvements would have on vehicle efficiency.

Table 6.8 presents some estimates for potential improvements in automobiles, using a typical 1975 model as the baseline. Table 6.9 presents similar estimates for truck fleets.

TABLE 6.8. Effect of Technical Changes on Automotive Fuel Consumption

<u>Area</u>	<u>Improvement</u>	<u>Specific Improvement</u>	<u>Reduction in Auto Fuel Consumption</u>
Aerodynamics	1. Low-Air-Drag Design	33% drag reduction	8%
Tribology (friction and lubrication)	2. Piston-Ring-Cylinder Friction reduction	25% reduction	2.4%
	3. Adiabatic diesel engine	60% efficiency increase	40%
	4. CVT--Conventional engine	Operation of engine at its most efficient range	20%
	5. CVT--Regenerative braking and energy storage	Operation of engine at its most efficient range	35%
	6. Improved engine and drive-line lubricants	25% reduction in engine friction	5%
Rolling Resistance	7. Low-Drag Tires	50% reduction in tire rolling resistance	13%
Traffic Management	8. Reducing idling operation in delays, reducing accelerations and decelerations	Up to 30% increase in urban gas mileage; 10% in highway	20%
Combustion Research	9. Diesel Engines, Stirling Cycle, Gas Turbine	30% efficiency improvement	30%
	10. Improved Otto Cycle	25% efficiency improvement	25%
Advanced System Research	11. Valve Resizing	60% reduction in pumping loss	13%
	12. Xylan Coating	Halves engine friction	15%
	13. Idle-off System	Cuts idle loss	12%

Source: Ross and Williams 1981.

TABLE 6.9. Estimated Truck Energy Efficiency Improvements Using Selected Options

<u>Option</u>	<u>% Efficiency Improvement</u>
Aerodynamic aids (wind deflector, fairings)	5% (mostly around 3%)
Demand-actuated fans	6%
Radial tires	10%
Fuel economy engines	20%
Multiple trailers	
Doubles	5%
Triples	28%

Source: DOE 1980b.

6.3 VEHICLE USE AND OWNERSHIP STATISTICS

Assessing the conservation potential of technology improvements in the transportation sector is difficult because of the multitude of travel modes commonly used in the U.S. Further difficulties arise because of the varied patterns of use typical of each mode. Some new technologies may apply only to a certain vehicle operating on a specified drive cycle; thus, aggregate consumption and use data for all must be supplemented by information on the characteristics of vehicle use, such as trip length, frequency, drive-cycles used, etc.

Information in this section was chosen to aid the identification of conservation potential for new technologies by providing statistics on consumption, vehicle inventories, and use patterns for various elements of the transportation sector.

Vehicle Stocks and Scrappage Rates

Assessing the conservation potential of new transportation technologies requires a knowledge of: 1) the total vehicle stock of each mode that may use the new technology, and 2) an estimate of the rate of sales and scrappage for the affected modes of transport. Table 6.10 includes statistics on vehicle stocks by mode for 1978. Figure 6.9 presents the vehicle survival probability curves. Survival probability is the chance that a vehicle of a certain age and type will be "in use" (registered) in a given year. This defines the age profiles and scrappage rates presented for automobiles in Table 6.11.

Table 6.12 presents scrappage rates for light trucks.

TABLE 6.10. Vehicle Stock by Mode, 1978

<u>Mode</u>	<u>Frequency (thousands)</u>
Automobiles registered	116,575
Automobiles in use	102,948
Two-seater	1.2%
Minicompact	6.9%
Subcompact	14.7%
Compact	15.5%
Midsize	23.9%
Large	37.8%
Trucks registered	31,703
Trucks in use	30,529
Personal light trucks	19,007
Recreational vehicles	6,000
Buses registered	500,362
Intercity	20,200
Local transit	52,866
School	398,804
Other	28,492
Motorcycles in use	7,305
Aircraft	187,195
General aviation aircraft	184,294
Air carrier aircraft	2,901
Marine vessels	34,688
Recreational boats	8,400
Rail	1,221,704
Locomotives	27,458
Rail cars	1,183,735
Transit vehicles	10,511
Snowmobiles	1,180
Total in use	152,971

Source: Oak Ridge National Laboratory 1980.

FIGURE 6.9. Survival Probability Curves for Automobiles and Light Trucks (Oak Ridge National Laboratory 1980)

TABLE 6.11. Automobiles in Operation, Scrappage Rates, and Vehicle-Miles-Traveled by Age of Vehicle, 1978

Age (in years) (a)	Number in Operation			Survival Probability (b)	Scrappage Rate (c)	Percent of Total VMT	
	Number (Thousands)	Percentage	Cumulative Percentage			Actual	Cumulative
Under 1	7,426.3	7.1%	7.1	99.9	0.1	7.5	7.5
1-2	10,381.7	10.1	17.2	99.6	0.3	13.1	20.6
2-3	9,483.1	9.2	26.4	99.1	0.5	11.8	32.4
3-4	7,290.6	7.1	33.5	98.1	1.1	7.1	39.5
4-5	9,431.3	9.2	42.7	96.0	2.1	11.6	51.1
5-6	9,431.3	9.2	42.7	96.0	2.1	11.6	51.1
6-7	9,140.5	8.9	61.9	85.4	7.3	9.1	69.9
7-8	7,325.6	7.1	69.0	75.3	11.8	6.7	76.6
8-9	6,784.0	6.6	75.6	62.6	17.0	5.7	82.3
9-10	6,087.0	5.9	81.5	49.1	21.5	5.2	87.5
10 and older	19,029.3	18.4	100.0	NA (d)	NA (d)	12.6	100.0
Total (e)	102,956.7	100.0				100.0	

(a) Each class interval includes lower but not higher age.

(b) The probability that a vehicle of a certain type in a given age class will be "in use" (registered) in a given year.

(c) Percentage of vehicles of a certain type in a given age class that are retired from use (lacking registration) in a given year.

(d) Not available.

(e) Includes 18,088 passenger cars for which year was not given.

Source: Oak Ridge National Laboratory 1980.

TABLE 6.12. Scrappage Rate for Light Trucks

Age in Years	Light Trucks	
	Scrappage Rate (a)	Survival Rate (b)
1	0.5	99.5
2	0.7	98.7
3	1.0	97.7
4	1.4	96.4
5	1.8	94.6
6	2.4	92.3
7	3.2	89.4
8	4.0	85.8
9	5.0	81.5
10	6.1	76.5
11	7.2	71.0
12	8.3	65.1
13	9.3	59.1
14	10.1	53.1
15	10.8	47.4
16	11.4	41.9
17	11.9	37.0
18	12.2	32.5
19	12.5	28.4
20	12.7	24.8
21	12.8	21.6
22	12.9	18.8
23	13.0	16.4
24	13.0	14.3
25	13.1	12.4
Median lifetime ^(c)	14.5 years	

(a) Percentage of vehicles that are of a certain type in a given age class and that are retired from use (lacking registration) in a given year.

(b) The probability that a vehicle of a certain type in a given age class will be "in use" (registered) in a given year.

(c) The age by which 50% of the model year total will have been scrapped.

Source: Oak Ridge National Laboratory 1980.

Automobile and Truck Sales

Some technology improvements, such as new engines, will only be used in new vehicles. Therefore, estimates of new vehicle sales by type are essential when estimating market penetration. Table 6.13 includes sales, market shares, and average efficiencies of automobiles for 1978 - 1980. Truck sales by weight and body type are displayed in Tables 6.14 and 6.15.

TABLE 6.13. Sales, Market Shares, and Sales-Weighted Efficiencies by EPA Class, 1978-1980

	Total Model ^(a) Year Sales	Market Share	MPG
Fleet			
78	8,069,695	99.9	20.5
79	10,898,416	99.9	20.5
80	4,749,590(b)	99.9(b)	23.3(b)
Minicompact			
78	1,027,487	12.8	27.6
79	536,799	5.0	26.2
80	195,218(b)	4.2(b)	29.9(b)
Subcompact			
78	1,600,258	19.9	24.3
79	3,599,447	33.1	24.6
80	1,705,802(b)	36.0(b)	27.0(b)
Compact			
78	1,128,642	14.0	19.6
79	1,013,400	9.3	18.7
80	305,060(b)	6.5(b)	22.6(b)
Midsize			
78	2,546,202	31.6	18.4
79	3,536,586	37.5	18.4
80	1,676,138(b)	35.3(b)	21.0(b)
Large			
78	1,678,318	20.8	16.3
79	2,117,548	19.5	16.7
80	813,314(b)	17.2(b)	19.4(b)
Two-seater			
78	90,788	1.2	18.5
79	94,636	0.9	17.3
80	55,058(b)	1.2(b)	19.9(b)

(a) These figures represent only those sales that could be matched to EPA gas mileage estimates.

(b) Half-year sales.

Source: Oak Ridge National Laboratory 1980.

TABLE 6.14. Domestic Factory Sales of Trucks by Gross Vehicle Weight, 1976-1979

	<u>6,000 and less</u>	<u>6,001- 10,000</u>	<u>10,001- 14,000</u>	<u>14,001- 16,000</u>	<u>16,001- 19,500</u>	<u>19,501- 26,000</u>	<u>26,001- 33,000</u>	<u>33,001 and over</u>	<u>Total</u>
Total factory truck sales									
1979(a)	850,910	1,247,663	16,358	2,355	2,855	99,304	37,308	145,822	2,402,575
1978	1,246,650	1,779,565	33,473	5,959	3,736	122,437	36,871	155,579	3,384,270
1977	1,253,409	1,580,533	20,015	1,221	4,831	122,423	26,699	140,045	3,149,176
1976	1,181,673	1,267,324	21,942	67	7,909	109,956	18,679	95,890	2,703,440
Total diesel sales									
1979(a)	25,196	570				12,751	21,554	139,819	199,890
1978	34,751	840				12,229	22,597	149,498	219,915
1977	2,386	975				11,142	15,695	135,361	165,559
1976		1,498				5,045	9,053	91,620	107,216
Diesel as a percentage of total factory truck sales									
1979(a)	3.0	b				12.8	57.8	95.9	8.3
1978	2.8	b				10.0	58.8	96.1	6.5
1977	0.2	0.1				9.1	58.8	96.7	5.2
1976		0.1				4.6	48.5	95.5	4.0

(a) Data are for first 10 months of 1979 only.

(b) Negligible.

Source: Oak Ridge National Laboratory 1980.

TABLE 6.15. U.S. New Truck Retail Deliveries by Body Type, 1978

	<u>1978</u>	<u>Distribution (%)</u>
Less than 10,000 lb	3,474,036	88.8
Utility	355,378	9.1
Car-type pickup	83,522	2.1
Compact import pickup	140,736	3.6
Van and cutaway chassis	673,683	17.2
Conventional pickup	2,075,259	53.0
Station wagon (truck chassis)	100,395	2.6
Passenger carrier	6,870	0.2
Multistop	38,193	1.0
10,001-14,000 lb	73,119	1.9
14,001-16,000 lb	5,792	0.1
16,001-19,500 lb	2,699	0.1
19,501-26,000 lb	155,616	4.0
26,001-33,000 lb	41,032	1.0
33,001 lb and over	161,608	4.1
Grand Total	3,913,902	100.0

Source: Oak Ridge National Laboratory 1980.

Installed Energy-Related Equipment in New Vehicles

Consumer buying trends dictate the demand for devices that affect vehicle efficiency. These consumer preferences are reflected in Table 6.16, which presents the percentage of new automobiles and light trucks that have certain devices such as air conditioning, radial tires, automatic transmissions, etc.

Sales of automobiles and light trucks that have diesel engines have risen rapidly since 1977. The high efficiency of the diesel cycle marks it as a prime research area in combustion research. Figure 6.10 displays the recent surge in diesel vehicle sales, whereas Table 6.17 lists estimated new car registrations by fuel type (including diesel) for 1975 through 1979.

TABLE 6.16. Factory Installation of Energy-Related Equipment on Domestic and Import Passenger Cars and Light Trucks, 1979

	Percentage of Units with Option					
	Automobiles			Light Trucks		
	Domestic	Import	Total	Domestic	Import	Total
4-speed transmission	9.7	34.3	14.5	16.3	54.7	21.0
5-speed transmission	0.3	38.6	7.8	0.0	32.4	3.9
Automatic transmission	89.7	27.0	77.5	74.3	12.9	66.8
4-cylinder engine	17.6	84.8	30.7	0.1	98.8	12.1
6-cylinder engine	23.8	6.8	20.5	16.8	1.21	14.9
V-8 engine	56.4	0.7	45.5	31.9	0.0	71.9
Diesel engine	2.2	4.1	2.6	1.2	0.0	1.1
Power steering	88.7	23.0	75.9	33.9	3.8	74.2
Power brakes	82.9	91.8	84.6	39.0	100.0	90.3
Air conditioning	79.8	26.8(a)	69.5	39.7	14.3(a)	36.6
Speed regulating device	37.2	NA	NA	19.5	NA	NA
Steel-belted radial plytires	76.0	89.3	78.6	15.2	23.3	16.2
Four-wheel drive	NA	NA	NA	29.4	NA	NA
Total units	9,500,893 ^(b)	2,304,439 ^(c)	11,805,332	3,394,360 ^(b)	470,115 ^(c)	3,864,475

(a) This figure may be misleading. Many imports have air conditioning installed at U.S. Ports of entry rather than in the factory.

(b) Production figures.

(c) Sales figures.

Source: Oak Ridge National Laboratory 1980.

FIGURE 6.10. U.S. Sales of Diesel Automobiles, 1965-1979
(Oak Ridge National Laboratory 1980)

TABLE 6.17. Estimated New Car Registrations by Fuel Type, 1975-1979^(a)

	<u>Domestic Cars</u> <u>(thousands)</u>	<u>Foreign Cars</u> ^(b) <u>(thousands)</u>	<u>Total</u> <u>(thousands)</u>
1975			
Regular	838	1,316	2,153
Unleaded	5,923	161	6,084
Diesel	0	25	25
1976			
Regular	274	1,266	1,539
Unleaded	8,031	156	8,187
Diesel	0	25	25
1977			
Regular	61	1,518	1,579
Unleaded	8,788	410	9,197
Diesel	2	39	41
1978			
Regular	0	930	930
Unleaded	8,939	941	9,880
Diesel	61	75	136
1979			
Regular	0	1,048	1,048
Unleaded	7,857	1,158	9,016
Diesel	139	132	271

(a) New car registrations are by calendar year.

(b) Foreign registrations are estimated from sales and total registration data.

Source: Oak Ridge National Laboratory 1980.

Vehicle Ownership and Trip Profiles

Technology improvements may apply only to specific segments of the population or only to the "second car" that is used for local, short distance trips. This section includes information that will help analysts disaggregate the travel consumption to levels commensurate with the level at which the technology will be applied. Table 6.18 through 6.20 present ownership and domestic passenger travel profiles by household size, age of head of household, income, trip purpose, trip length, and mode of transport.

TABLE 6.18. Household Vehicle Ownership and Use: Summary

Total number of households (thousands)	76,030
Number of licensed drivers per household	1.85
Number of cars per household	1.28
Number of trucks per household	0.25
Number of vehicles per household	1.53
Costs of operating an automobile, 1979 (¢/mile)	24.6
Duration of household vehicle ownership (yrs)	4.4
Average number of household vehicle trips per day	4.71
Average trip distance (miles)	7.4
Average load factor (PMT/VMT)	1.90
Average annual VMT per vehicle	10,000
Means of transportation to work (%)	
Drive alone	68.8
Carpool	19.2
Transit	6.8
Other	5.2

Source: Oak Ridge National Laboratory 1980.

TABLE 6.19. Domestic Passenger Travel, 1977

Mode	VMT		PMT		Energy Use ^(a)	
	(Millions)	Percentage	(Millions)	Percentage	Trillion Btu	Percentage
Motorcycles	27,812	2.1	30,593	1.1	75.4	0.6
Automobile	1,118,649	83.1	2,131,833	76.4	10,028.0	75.6
Personal light truck	186,265	13.8	318,875	11.4	1,724.7	13.0
Buses	5,675	0.4	119,180	4.3	132.4	1.0
Air	6,837	0.5	168,724	6.1	1,248.0	9.4
Rail	835	0.1	20,364	0.7	62.4	0.5
Total	1,346,073	100.0	2,789,569	100.0	13,270.9	100.0

Domestic Intercity Freight Movement, 1977

Mode	Tons-miles		Tons Shipped		Energy Use ^(a)	
	(Millions)	Percentage	(Millions)	Percentage	Trillion Btu	Percentage
Trucks	550,000	21.6	2,191	31.1	1,500	49.8
Air carriers	3,946	0.2	8	0.1	25	8.3
Marine vessels	599,000	23.6	969	13.8	263	8.7
Pipelines	561,338 ^(b)	22.1	1,502	21.3	675	22.4
Railroads	826,202	32.5	2,368	33.7	551	18.3
Total	2,540,486	100.0	7,038	100.0	3,014	100.0

(a) The energy-use numbers do not sum to total transportation energy use. Energy used by snowmobiles, recreational boats, international air carriers, marine vessels engaged in foreign trade, and local trucks is not included.

(b) Excludes natural gas pipelines for which no ton-mile data are available.

Source: Oak Ridge National Laboratory 1980.

TABLE 6.20. Vehicle Ownership and Average Annual Vehicle-Miles Traveled by Selected Household Characteristics, 1977

	Total Number of Households		Average number of Vehicles per Household			Average Number of Vehicle-Driver Trips ^(a) per Household per Day	Average Annual VMT per vehicle	Average Annual Household VMT ^(b)	Percentage of Total Household VMT
	(Millions)	Percentage	Cars	Trucks	Cars and Trucks				
All households	75.4	100.0	1.28	0.25	1.53	4.7	10,000	11,640	100.0
Size of household									
1	15.8	21.0	0.64	0.07	0.72	1.8	8,060	3,410	6.4
2	23.2	30.8	1.25	0.24	1.48	3.7	9,060	10,640	29.2
3	13.0	17.2	1.48	0.30	1.78	5.8	11,460	14,630	22.5
4	12.0	15.9	1.60	0.35	1.96	6.8	10,270	14,680	20.9
5	6.4	8.5	1.69	0.35	2.04	6.6	10,080	16,720	12.7
6 or more	4.9	6.5	1.68	0.36	2.03	6.7	10,890	14,390	8.4
Residence									
SMSA	51.4	68.2	1.29	0.18	1.47	4.5	9,800	11,560	67.7
Outside SMSA	24.0	31.8	1.27	0.40	1.67	5.3	10,390	11,790	32.3
Age of head									
Under 30 yr	14.8	19.6	1.21	0.22	1.40	4.6	10,220	9,960	16.8
30-39 yr	14.9	19.7	1.22	0.30	1.68	6.3	10,890	14,330	24.3
40-49 yr	12.3	16.3	1.61	0.34	1.96	6.2	10,430	16,000	22.4
50-59 yr	12.7	16.8	1.06	0.29	1.81	5.9	11,140	15,840	22.9
Over 60 yr	20.7	27.5	0.92	0.13	1.08	2.4	6,900	5,730	13.5
Income									
Under \$5,000	13.6	18.0	0.63	0.13	0.76	1.4	8,450	3,860	6.0
\$5,000-\$7,499	8.5	11.3	0.93	0.16	1.09	2.9	7,100	4,620	4.5
\$7,500-\$9,999	7.2	9.6	0.99	0.22	1.29	4.7	8,830	8,880	7.3
\$10,000-\$11,999	5.8	7.7	1.20	0.26	1.46	4.6	8,750	9,100	6.1
\$12,000-\$14,999	8.1	10.7	1.34	0.29	1.63	4.4	8,920	11,780	11.0
\$15,000-\$19,999	11.1	14.7	1.48	0.33	1.80	6.2	9,880	12,550	16.0
\$20,000-\$24,999	8.0	10.6	1.66	0.33	1.99	6.3	10,180	16,160	14.8
Over \$25,000	13.0	17.2	1.92	0.31	2.23	8.2	12,040	22,970	34.3

(a) A trip is defined as travel from one point to another. For example, if a person drove from home to work, from work to a shopping center, and from the shopping center to home, this would be defined as three separate trips.

(b) Includes households with no vehicles (that is, with an annual VMT of 0).

(c) Totals may not equal sum of components due to independent rounding.

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GLOSSARY

GLOSSARY

Air Exchange	The replacement of interior air with outside air. The air exchange rate refers to the rate at which this exchange of air occurs.(air changes per hour).
Air Infiltration	The entry of outside air into a building via soleplates, window frames and other structural areas where air ventilation was not intended.
Automotible Fleets	Groups of automobiles owned and operated by private or public institutions. Police departments, the military, telephone companies, etc., own and operate vehicle fleets.
Available Energy	That portion of the total energy that can be converted to useful work when the conversion is as efficient as is theoretically possible. Any process using heat energy suffers losses that are unavoidable.
British Thermal Unit	The amount of heat required to raise the temperature of 1 pound of water 1°F under stated conditions of pressure and temperature; equal to 252 calories.
Btu	See British Thermal Unit.
Coefficient of Performance	The dimensionless ratio of useful work produced by a device (heat for a heating device and heat extracted for a cooling device) to the total chemical and/or electrical energy input to the device.
Common Carriers	A category of those types of transport that provide regularly scheduled passenger service. Included are airlines, bus companies, and railroads.
Conservation Potential	A measure of the degree to which one or more of the goals of energy conservation are achievable for an activity that uses energy; the maximum potential for conservation being limited by technical, social, and economic constraints characteristic of that specific use.
COP	See Coefficient of Performance.

End Use	An activity that consumes energy; cooking is an example of an end use in the residential/commercial sector.
Energy Conservation	Reducing the quantity of energy used to perform a given service and/or converting to an energy source that is more compatible with national energy policy (produced domestically, less expensive, etc.).
Energy Factor Intensity	The ratio of the cost-of-energy inputs to the cost-of-all inputs.
Energy Intensity	The gross energy consumption of a device per unit of service provided. For example, Btus per passenger mile is a measure of the energy intensity of transporting passengers.
Energy Quality	Measured by the amount of work that a given unit of energy can accomplish. For instance, 1 Btu of water at 80°F can perform less work than 1 Btu of electrical energy; therefore, the electrical energy has a higher quality.
First Law of Thermodynamics	<p>Energy can neither be created nor destroyed in a process; it is converted from one form to another. The first-law efficiency of a process is:</p> $\frac{\text{Energy in the desired outputs}}{\text{Energy applied to do the task.}}$ <p>Thus, the first-law efficiency of an electric heater would be:</p> $\frac{\text{Btus of heat produced}}{\text{Btus of electricity consumed.}}$
Fuel Type	The specific kind of fuel consumed during a process or activity. Coal, oil, gas, etc. are examples of fuel types.
Gross Energy Consumption	The total number of Btus used in a process, end-use sector, etc., regardless of the type or quality of energy.

Heat Pump	A year-round space-conditioning system that uses refrigeration equipment. Heat is extracted from outside air, water, or ground and released inside when the unit is heating a building. When cooling, the cycle is reversed and indoor heat is absorbed and released outside.
Industrial Sector	One of the three energy sectors that use energy. It typically includes manufacturing, construction, agriculture, and mining activities.
Leakiness	Refers to the amount of unwanted air that "leaks" into a building.
Market Penetration	For a given product market, the fraction of that market that will be captured by a specific product (such as a conservation technology). For example, the market penetration of small diesel engines would be the percentage of all cars and small trucks that are powered by diesel engines in a given year.
Passenger Miles Traveled	A measure of transport use. The unit is one passenger traveling one mile. It is commonly used to record the number of miles traveled per passenger, summed over all passengers during a given time period.
Personal Passenger Vehicles	This category of vehicles includes automobiles, motorcycles, vans, and small trucks.
PMT	See Passenger Miles Traveled.
Quad	One quad is equal to one quadrillion Btus (10^{15} Btus).
Residential/Commercial Sector	One of the three main energy-use sectors. It includes energy consumption in homes, commercial buildings, and public structures such as schools, hospitals, etc.
Scrappage Rates	The distribution of the probability that a vehicle of a certain age will be scrapped. This information reflects the expected life of certain vehicles.

Second Law of Thermodynamics	Describes the effectiveness with which the quality of the energy is used. In a general sense, the second law compares the least work theoretically required to accomplish a task to the maximum work that could be derived (available work) from the actual fuel used to accomplish that task.
Space Heating	The provision of heat to the interior of a building, regardless of the type of system or fuel.
Transportation Sector	One of the main energy consumption sectors. It includes all energy uses that perform transportation tasks. Personal vehicles, commercial vehicles, pipelines, and marine freight are included.
Useful Life (of capital stock)	The length of time a piece of equipment or machinery is expected to operate productively; it defines the length of time that equipment will be used.
Vehicle Miles Traveled	A measure of transport use. The unit is one vehicle traveling one mile. It is used to measure the number of miles traveled per vehicle type, summed over all vehicles of that type during a given period. Total vehicle miles would be the total number of miles traveled by all vehicles.
VMT	See Vehicle Miles Traveled.

CONVERSION FACTORS

CONVERSION FACTORS

Energy Equivalence Factors

1 quad = 10^{15} Btu
1.055 x 10^{18} Joules
44.4 million short tons of anthracite coal
43.7 million short tons of bituminous coal
980.4 billion ft³ of natural gas (dry)
172.4 million bbl of crude oil
293 billion kWh of electricity
286 billion acre ft² of hydro
24 million m² year (6000 acre year) of extraterrestrial solar
260.7 million bbl of propane
190.4 million bbl of motor gasoline
1 acre ft² hydro = 1 kWh (@ 100% efficiency)
1 million bbl of oil per day = 2 quads per year

Consumption of a 1000 MWe Power Plant at 60% Capacity Factor

2.4 million tons of coal per year, or
9 million bbl of residual oil per year, or
0.9 metric tons of uranium-235 (consumed per year)

Heat Content of Various Fuels

Crude oil	$5.8(10^6)$ Btu/bbl
Residual Fuel Oil	$6.3(10^6)$ Btu/bbl
Distillate Fuel Oil	$5.8(10^6)$ Btu/bbl
Gasoline	$5.3(10^6)$ Btu/bbl
Jet Fuel	
Kerosene	$5.7(10^6)$ Btu/bbl
Naptha	$5.4(10^6)$ Btu/bbl
Natural Gas Liquids	
Liquid propane	$4.0(10^6)$ Btu/bbl
Ethane	$3.1(10^6)$ Btu/bbl

Natural Gas

Dry	1021 Btu/ft ³
Wet	1095 Btu/ft ³

Coal

Anthracite	22.5(10 ⁶) Btu/short ton
Bituminous and lignite	22.9(10 ⁶) Btu/short ton
Uranium-235	76(10 ⁶) Btu/gram fissioned

Energy

1 eV	= 1.602 x 10 ⁻¹⁹ J
1 erg	= 10 ⁻⁷ J
1 ft lb	= 1.356 J
1 cal	= 4.184 J
1 Btu	= 1054.4 J
1 kcal(= 1 food calorie)	= 4184 J
1 hphr	= 2.686x10 ⁶ J
1 kWhr(kWh)	= 3.60x10 ⁶ J
1 therm(10 ⁵ Btu)	= 1.054x10 ⁶ J
1 kiloton(explosive energy)	= 4.20x10 ¹² J
1 quad(10 ¹⁵ Btu)	= 1.054x10 ¹⁸ J

Power

1 Btu/yr	= 3.341x10 ⁻⁵ W
1 kWhr/yr	= 0.114 W
1 Btu/hr	= 0.293 W
1 ft lb/sec	= 1.356 W
1 hp	= 746 W
1 Btu/sec	= 1054 W
1 ton (cooling)	= 3500 W
1 kcal/sec	= 4184 W
1 quad/yr	= 3.341x10 ¹⁰ W

Energy Per Unit Mass

1 Btu/lb	= 2324 J/kg
1 kcal/kg(1 cal/gm)	= 4184 J/kg
1 eV/amu	= 9.649×10^7 J/kg

Molar Specific Heat, Entropy

1 cal/mole °C	= 4.184 J/mole K
1 Btu/lb-mole °F	= 4.184 J/mole K

Energy Flux

1 Btu/ft ² hr	= 3.152 W/m ²
--------------------------	--------------------------

U Value

1 Btu/ft ² hr °F	= 5.674 W/m ² °C
-----------------------------	-----------------------------

Fuel Economy

1 lbm/hphr	= 0.6080 kg/kWhr
1 mile/gal(mpg)	= 0.425 km/liter

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