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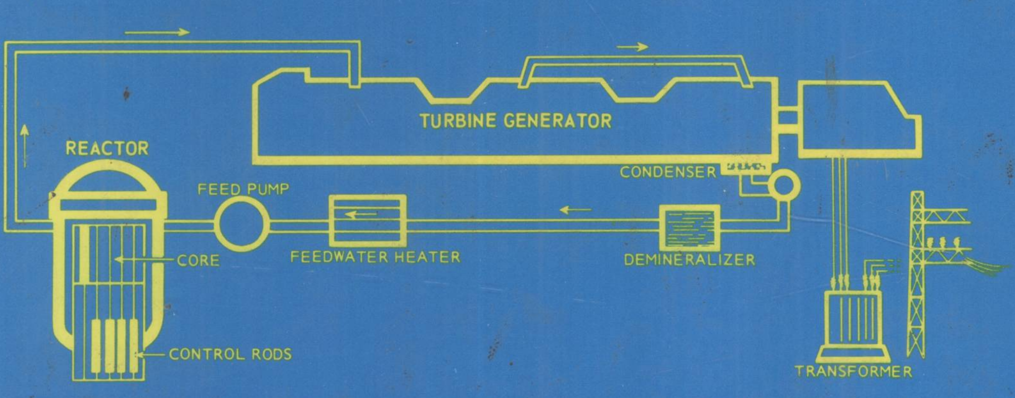

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PREFACE

The role of energy in the United States is second to none. Energy is used to exploit our natural resources to maintain our way of life, and industry consumes it in gigantic portions to fuel our economy and maintain our well-being. The importance of energy has become more and more magnified with its increasing cost, its limited availability, and our dependence upon sources outside the United States.

An energy system brings the basic energy resource (such as coal, oil, gas, hydro power, solar, nuclear, or geothermal) from its natural form to a given state and place in which it can be utilized. Energy systems may involve extraction, processing, transportation, and delivery to the ultimate user. The United States consumes over 70 quadrillion Btu of energy each year. Over 74% of the energy consumed in the United States is derived from petroleum or natural gas. The domestic supply of both these fuels is dwindling rapidly and may be scarce and costly if not prohibitive economically early in the next century (less than twenty years away). Foreign sources are becoming exponentially more expensive.

It is with these facts in mind that the authors have set out to analyze the various energy options and systems available to us in the last quarter of the twentieth century. As this book was being written it was apparent that we are experiencing the end of an era—an era of cheap, abundant energy.

This book is intended to serve as a data reference, to supplement other sources used in evaluating energy data and resources.

The intent is to provide one composite source to aid in quantitative evaluation of energy resources, as well as to provide summary data and analysis. This book, by its content and structure, addresses all the energy options, and its chapters represent the major energy resources available to us. This allows the user to turn quickly to one source rather than many to find needed information. The figures and tables provided for reference have been drawn from primary sources wherever possible or specifically prepared for this book.

The authors are all involved professionally in energy resources and systems evaluation and have attempted to present most of the useful data for ready reference. It is hoped that this book will enable the reader to shorten both time and shelf space with the data provided.

Asad T. Amr
Jack Golden
Robert P. Ouellette
Paul N. Cheremisinoff

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1 ENERGY SYSTEMS IN THE UNITED STATES

1.1 BACKGROUND

Energy plays an exceptionally important role in the United States economy. It recycles natural resources into food, clothing, light, and shelter. Industry consumes energy mainly in the form of process steam. Commercial establishments and private households consume it mainly in the form of space heat and light; transportation vehicles and electric utilities consume fuels mainly by burning them directly. Figure 1.1 illustrates the distribution of energy consumption in the United States in 1975 [1,2].

1.2 ENERGY SYSTEMS AND THEIR CHARACTERISTICS

An energy system consists of all the components necessary for bringing a basic energy resource--coal, oil, natural gas, uranium, hydropower, geothermal and solar energy*--from its natural position and state to a given place in the form in which it is to be used.

Most energy systems involve recovery and extraction of an energy resource, processing, transportation of the resource among various operations, conversion into a useful, or more useful, form, delivery or transmission to the ultimate user, and, finally, consump-

*Also addressed are lead acid batteries and flywheel and hydrogen storage.

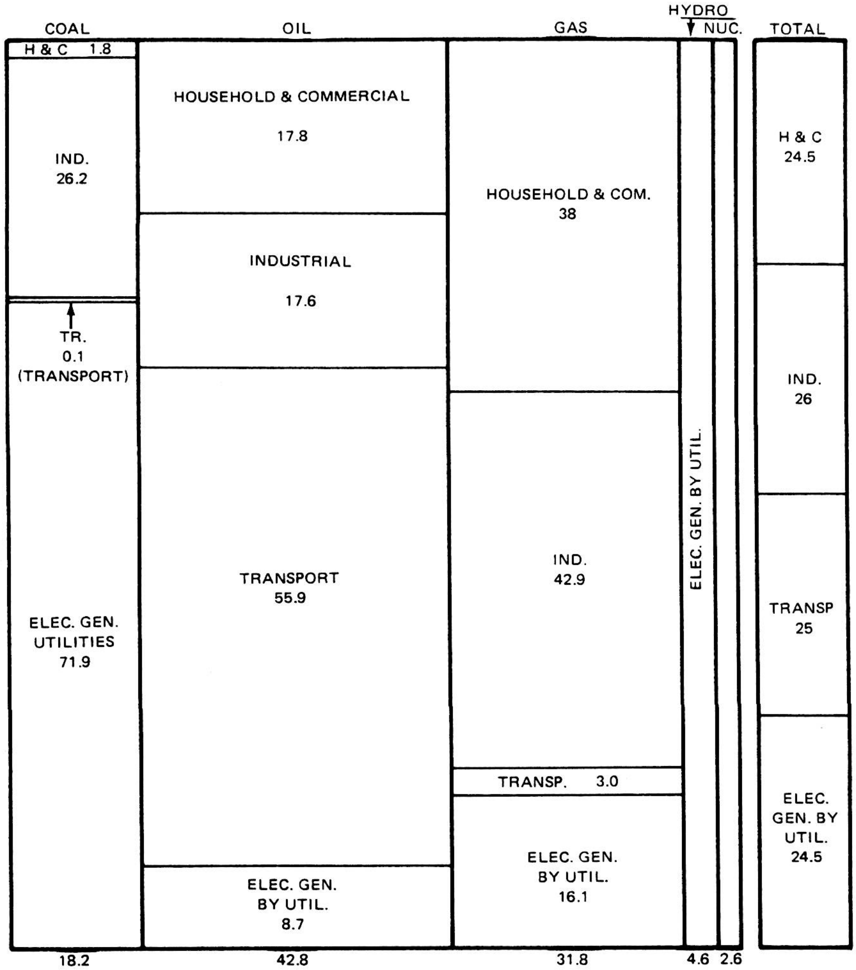

Figure 1.1 Distribution of U.S. energy consumption, 1975. (Adapted from Refs. 1 and 2.)

tion of the energy produced. Figure 1.2 shows the flow stages of an electric energy system.

As can be seen from Tables 1.1 and 1.2, most of the energy consumed in the United States is supplied by petroleum and natural gas (over 74% total energy consumed) [3,4]. The domestic supply of both of these fuels is dwindling, and may be exhausted early in the twenty-first century.

The United States consumes over 70 quadrillion (70×10^{15}) Btu or 70 quads of energy a year. Total U.S. energy consumption in

Table 1.1. U.S. Energy Consumption, 1975

Source	Demand Percent	Trillion Btu	Units
Oil and liquified natural gas	46.4	32,719	5.64 billion bbl
Gas	28.3	19,948	18.1 trillion SCF
Coal	18.2	12,828	493.4 million tons
Hydro power	4.5	3.229	322.9 billion kWh
Nuclear	2.6	1,833	183.3 billion kWh
Total	100.0	70,557	-3.0% from 1974

Source: Adapted from Refs. 3 and 4.

1975 is shown in Table 1.2. The United States, however, relies on its least plentiful resources--oil and gas [5] (see Fig. 1.3). The United States consumes its least plentiful resources, oil and gas (70% consumption), while these resources make up only 7% of the nation's proved reserves. Only 18% of U.S. energy consumption is supplied by coal, which constitutes 90% of proved reserves.

Energy Resources

It is obvious that discovery of any resource must precede production. As technical ability to use the resources develops, the demand for it expands. Increased demand accelerates exploration and discovery, as well as production. Eventually, however, the resource becomes more difficult to extract.

As efforts to acquire ultimate recovery of the energy resource is approached, discovery and production--as well as the remaining amount of the resource--taper off.

Thus the total discoveries of a given energy resource are *produced resources* and *proved reserves,* a basic relationship which can be written as $Q_d = Q_p + Q_r$ (discoveries = production + proved reserves). Correspondingly, the rate of discovery equals the rate of production plus the rate of change of proved reserves ($dQ_d/dt = dQ_p/dt + dQ_r/dt$).

Another way of looking at resources is that potential resources are equal to conditional resources plus hypothetical resources plus speculative resources, a basic relationship which can be written as:

$$A_{pt} = Q_c + Q_h = Q_s$$

Correspondingly, the rate of change in potential resources is equal to the rate of change in conditional and hypothetical and speculative resources:

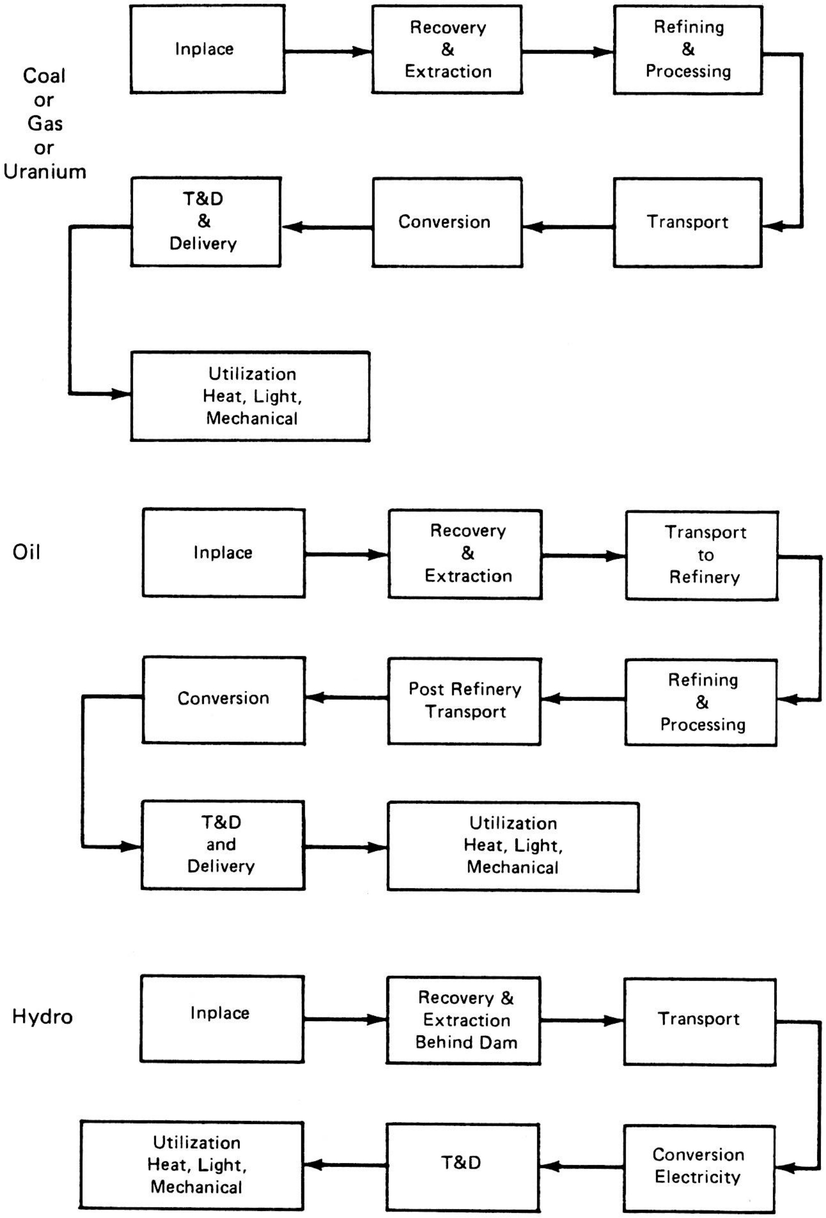

Figure 1.2. Flow of an electric energy system.

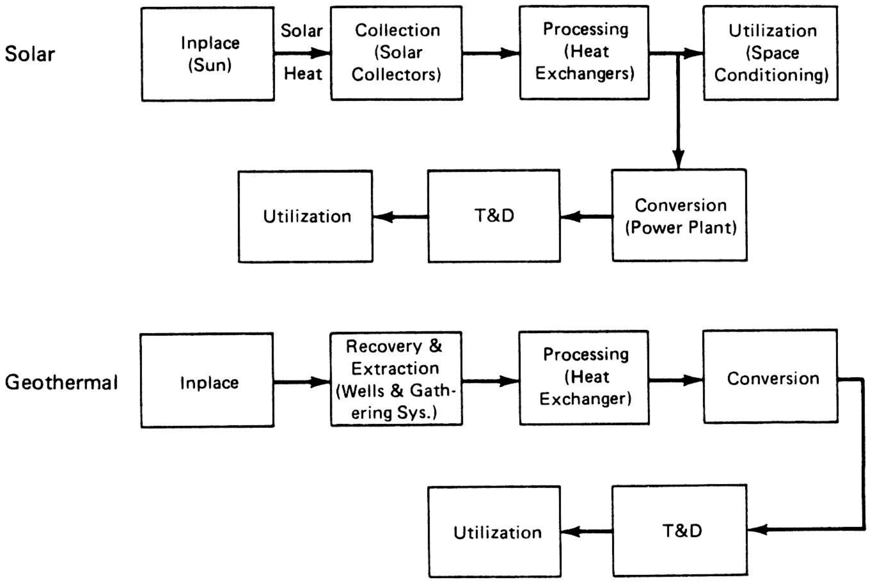

Figure 1.2. (Continued)

$$\frac{dQ_{pt}}{dt} = \frac{dQ_c}{dt} + \frac{dQh}{dt} + \frac{dQs}{dt}$$

Figure 1.4 is a pictorial view of a number of the resource terms identified in the "glossary of coal resource terms." Also shown is the distribution of fuel reserves and energy sources in Figs. 1.5 to 1.10.

For example, Figure 1.5 shows that most anthracite coal occurs in Pennsylvania. Medium- and high-volatile bituminous coals are mostly mined in the Appalachian and Illinois basins. Lower-quality subbituminous coals occur in the Powder River, Big Horn, Denver, and San Juan basins in the West. Low-grade lignite resources are in southeastern Texas, North Dakota, and Montana and extend into Canada.

Also, Fig. 1.8 shows existing conventional and pumped storage capacity by National Power Survey regions. Over the years, hydroelectric plants have provided a substantial but declining proportion of the nation's electric power supply. At the end of 1975, conventional hydroelectric capacity totaled 58,945 MW (megawatts) compared to only 9091 MW of pumped storage capacity. Most of the conventional capacity is in the WSCC region while most of the pumped storage capacity is in the NPCC and ECAR regions.

Table 1.2. Estimated U.S. Energy Consumption by Major Sectors, 1975 (Trillion Btu)

	Coal	Petroleum and liquefied natural gas[a]	Natural Gas	Hydro power	Nuclear	Total	Percent
Household and Commercial	246	5,752	7,589	--	--	13,587	19.3
Industrial	3,821	5,517	8,551	35	--	17,924	25.4
Transportation	1	17,933	595	--	--	18,529	28.2
Electricity generation by utilities	8,760	3,213	3,213	3,194	1,833	20,239	28.7
Miscellaneous and losses	--	278	--	--	--	278	0.4
Total	12,828	32,719	19,948	3,229	1,833	70,557	100.0

[a]Includes natural gas liquids, liquefied refinery gas, and still gas.
Source: Ref. 4.