HANDBOOK OF ENERGY SYSTEMS ENGINEERING

PRODUCTION AND UTILIZATION

Edited by
LESLIE C. WILBUR, M.S., P.E., Fellow, ASME

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WILEY SERIES IN MECHANICAL ENGINEERING PRACTICE

CONSULTING EDITOR

Marvin D. Martin
President, Marvin D. Martin, Inc., Consulting Engineers, Tucson, Arizona

A Wiley-Interscience Publication
JOHN WILEY & SONS
New York • Chichester • Brisbane • Toronto • Singapore

Library of Congress Cataloging in Publication Data:

Main entry under title:

Handbook of energy systems engineering
(Wiley series in mechanical engineering practice)
"A Wiley-Interscience publication."
Bibliography: p.
Includes index.
1. Power (Mechanics)—Handbooks, manuals, etc.

I. Wilbur, Leslie C. II. Series.
TJ163.9.H35 1985 621.042 84-20830
ISBN 0-471-86633-4

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

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SERIES PREFACE

The Wiley Series in Mechanical Engineering Practice is written for the practicing engineer. Students and academicians may find it useful, but its primary thrust is for the working engineer who needs a convenient and comprehensive reference on hand.

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1. Numerical information such as strengths of materials, thermodynamic properties of fluids, standard pipe sizes, thread systems, and so on.
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The profession has expanded to cover such a broad range of engineering activities that no one can be knowledgeable in more than a fraction of the whole field. Yet, in day-to-day work, practicing engineers frequently have to use, or at least interface with, specialty areas outside their normal sphere of competence. This book is written to provide readers with the state of the art information and standard practices in these other areas.

The task of covering such a vast amount of material has dictated the decision to split the series into five separate volumes:

Design and Manufacturing
Fluids and Fluid Machinery
Mechanics, Materials, and Structures
Power and Energy Systems
Instrumentation and Control

Each volume is designed to stand alone but the five complement each other in providing the broad coverage mentioned above. Within each volume chapter and section headings are designed to help the user in finding the material being sought.

A serious attempt was made to provide state of the art material at the time of writing. Since many of the areas are in a state of rapid change, there will be some obsolescence by the time printing is complete. It is planned to revise and update at reasonable intervals so that users may purchase newer editions and keep their references up to date.

The many editors and contributors who have made this series possible join me in the hope that the several volumes will turn out to be really useful tools for the practicing engineer.

MARVIN D. MARTIN

Tucson, Arizona
January 1985

PREFACE

The intent of this volume is to provide professionally trained persons with concentrated store of user-oriented information on a broad spectrum of ener applications. The contributing authors were instructed to select the optimu material in their respective areas, taking into consideration severe space co straints. Each section is written as a miniprimer adequate to enable the reader grasp vital concepts at a decision-making level and to give the nonexpert in given discipline a reasonable degree of literacy.

Carefully selected bibliographies have been provided to expedite a follow where more detailed information is needed. Chapters of mathematical relatio ships and fundamental data are included. Contributors were permitted to use t system of units they considered most convenient for current practitioners in th own fields. Extensive conversion factors are provided in Chapter 18.

As Editor-in-Chief I wish to state my gratitude to the contributors for th professional, dedicated efforts, and to the numerous workers who contributed the preparation of this material. In particular, Nancy Stanhope and Catheri Marinelli provided outstanding and tireless support. Special recognition is d Professor Donald N. Zwiep, past president of ASME, and Chairman, Departme of Mechanical Engineering, Worcester Polytechnic Institute, for his vigoro assistance and encouragement. Most of all I wish to express my appreciation my wife Gertrude for her unfailing inspiration and support.

LESLIE C. WILBUR

Berlin, Massachusetts
May 1985

CONTENTS

CHAPTER 1

DEMOGRAPHICS

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The energy demographics chapter of the handbook presents statistics on energy demand, production, and resources. Section 1.1 examines energy consumption trends in the United States and the rest of the world. Sections 1.2–1.5 present data on reserves, resources, and production of four major conventional fuels: coal, oil, natural gas, and uranium. In general, these sections present reserve estimates for the United States and the world as a whole covering a number of past years, current reserve figures distributed by country, and current estimates of total U.S. and world resources of each fuel. The quality of the deposits and accuracy of the resource estimates are examined. Total reserves and potential resources are compared with current production levels and trends to evaluate the adequacy of U.S. and world supplies of conventional fossil fuels. Section 1.6 discusses the potential of renewable energy resources (such as solar, wind, wave, and hydroelectric) to contribute to meeting the world's energy needs. Section 1.7 describes the world's resources of alternative nonconventional fossil fuels: shale oil, tar sands, and peat.

1.1 ENERGY DEMAND

This section presents data on world and U.S. energy consumption trends over the last several decades. The growing world demand for energy is illustrated graphically in Fig. 1.1-1. The levels of total world primary energy consumption and the consumption of oil, coal, natural gas, hydroelectric energy, and nuclear energy in millions of tons of oil equivalent are graphed by decade from 1928 to 1965 and annually thereafter to 1981. Primary energy consumption and the consumption of the major fuels in 1981 are listed in Table 1.1-1 for the major countries of the world.

Data on U.S. energy demand is presented in two tables. Tables 1.1-2 and 1.1-3 give energy consumption by type of energy and energy end use, respectively, for each year from 1951 to 1981. Table 1.1-3 lists the U.S. domestic price of each type of energy for the years 1951–1981.

H. K. Acharya is the author of Section 1.6-9.

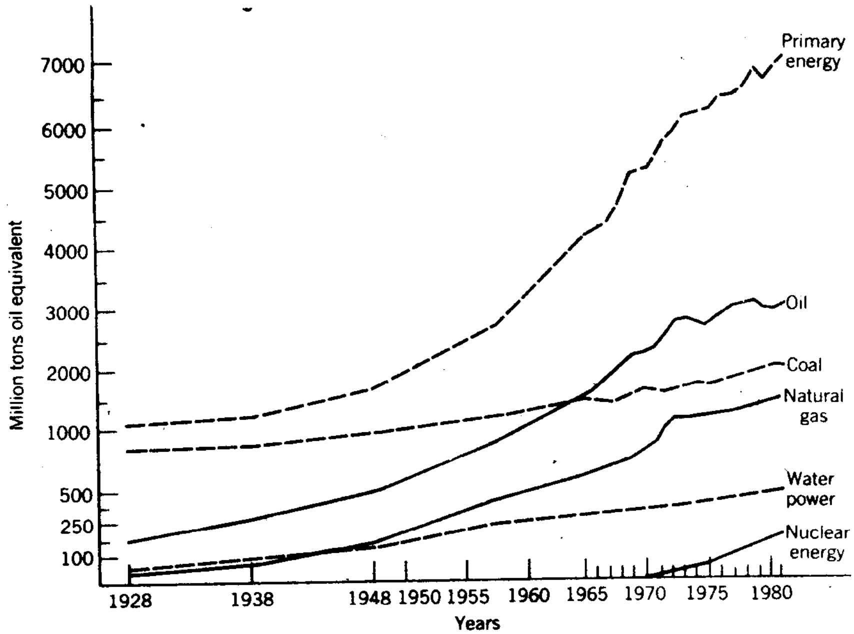

Fig. 1.1-1 World energy consumption. (Source: The British Petroleum Co. Ltd., *BP Statistical Review of the World Oil Industry*, Various Issues. London: The British Petroleum Co. Ltd., 1981.)

Since 1928 total world primary energy consumption has grown from 1.166 billion† tons of oil equivalent to nearly 6 times that amount, 6.849 billion in 1981. The annual compound rate of growth has been 3.4%, about the same as the rate of growth in industrial production. Growth in energy consumption was particularly rapid during the first three decades of the postwar period. From 1948 to 1973 energy consumption grew from 1.739 billion tons of oil equivalent to 5.92 billion tons—an annual compound rate of growth of 5%. Since 1973 the growth rate in world primary energy consumption has slowed considerably, dropping to 1.8% per annum. In the non-Communist world the growth rate since 1973 has been even lower, averaging only 1% per annum according to figures presented in the British Petroleum Company *BP Statistical Review of the World Oil Industry* (1982).

The reason for the sharp drop in the rate of growth in energy consumption since 1973 has, of course, been the energy crisis—the large increase in the cost of petroleum and most other sources of energy that has occurred since 1973. Table 1.1-4 shows that U.S. crude oil prices, for example, increased by a factor of 8 from 1973 to 1981 and that the combined price index for all fuels increased from $0.394 per million Btu to $2.70 over this period.

Although all forms of energy have become more costly since 1973, the price of oil has increased at a much faster rate than that of other types of energy. For example, the price of oil was approximately double that of coal in 1973 and is currently about 5 times the price of coal.

The increase in the relative costliness of oil compared with other forms of energy has resulted in a substantial shift in energy shares away from oil to coal and natural gas. From 1928 to 1973 the share of world primary energy consumption accounted for by oil increased steadily at the expense of coal. Since 1973 this pattern has changed dramatically, with oil consumption actually declining in the non-Communist world and growing at a rate of only a 0.4% per annum in the world as a whole. In contrast, world coal consumption has grown at 2.3% per annum since 1973—greater than the *average* growth rate in demand for primary energy.

In the United States the pattern has been very similar. Since 1973 coal consumption has resumed growing after a 50-year hiatus. Petroleum consumption, on the other hand, declined from 6.3 billion barrels in 1973 to 5.8 billion in 1981. Hydro and nuclear power have grown substantially since 1973, particularly the latter. Natural gas consumption, on the other hand, has declined slightly, primarily due to price regulation, which has kept gas limited in supply. In the United States total energy consumption declined slightly, from 74.6 quadrillion‡ Btu in 1973 to 73.9 quatrillion Btu in 1981.

† Billion is here defined as 10^9.
‡ Quadrillion is here defined as 10^{15}.

TABLE 1.1-1 ENERGY CONSUMPTION, 1981[a]

Country/Area	Primary Energy	Coal	Oil	Natural Gas	Water Power	Nuclear Energy
U.S.A.	1 806.2	406.3	743.2	509.4	74.0	73.3
Canada	221.5	22.9	81.6	48.1	59.2	9.7
Total North America	2 027.7	429.2	824.8	557.5	133.2	83.0
Latin America	348.5	16.9	227.8	54.4	48.6	0.8
Total Western Hemisphere	2 376.2	446.1	1 052.6	611.9	181.8	83.8
Western Europe						
Austria	24.8	3.1	10.9	4.0	6.8	—
Belgium & Luxembourg	48.3	10.3	25.6	9.5	0.1	2.8
Denmark	17.1	5.4	11.7	—	—	—
Finland	21.3	1.8	12.0	0.6	3.4	3.5
France	188.1	26.2	99.3	24.7	15.8	22.1
Greece	16.7	3.9	11.9	—	0.9	—
Iceland	1.8	—	0.5	—	1.3	—
Republic of Ireland	8.2	1.7	5.4	0.9	0.2	—
Italy	143.8	13.5	95.5	22.8	10.7	1.3
Netherlands	69.3	4.3	35.2	28.8	—	1.0
Norway	28.6	0.5	7.5	—	20.6	—
Portugal	11.6	0.4	8.9	—	2.3	—
Spain	74.3	16.4	48.0	1.9	6.2	1.8
Sweden	39.4	1.4	21.8	—	9.9	6.3
Switzerland	26.4	0.7	11.9	0.8	9.3	3.7
Turkey	25.4	7.8	15.4	—	2.2	—
United Kingdom	195.7	69.7	74.6	42.0	1.3	8.1
West Germany	259.2	82.7	117.6	41.2	5.8	11.9
Yugoslavia	40.0	14.6	14.4	3.7	7.3	—
Cyprus/Gibraltar/Malta	1.4	*b*	1.4	—	—	—
Total Western Europe	1 241.4	264.4	629.5	180.9	104.1	62.5
Middle East	121.0	*b*	84.7	35.3	1.0	—
Africa	175.1	67.1	75.9	18.4	13.7	—
South Asia	154.7	88.7	43.4	8.9	12.8	0.9
South East Asia	200.3	57.2	123.7	7.3	8.6	3.5
Japan	353.6	63.2	224.3	24.2	20.7	21.2
Australasia	89.0	31.5	36.3	11.6	9.6	—
USSR	1 198.1	336.8	444.1	353.7	48.5	15.0
Eastern Europe	439.8	258.0	102.4	69.4	5.8	4.2
China	499.6	394.2	84.8	10.4	10.2	—
Total Eastern Hemisphere	4 472.6	1 561.1	1 849.1	720.1	235.0	107.3
World (excl. USSR, E. Europe & China)	4 711.3	1 018.2	2 270.4	898.5	352.3	171.9
World	6 848.8	2 007.2	2 901.7	1 332.0	416.8	191.1

Source. The British Petroleum Co. Ltd., *BP Statistical Review of the World Oil Industry 1982*, The British Petroleum Co. Ltd., London, 1983.

[a] In million tonnes oil equivalent.
[b] Less than 0.05 million tonnes oil equivalent.

TABLE 1.1-2 CONSUMPTION OF ENERGY BY TYPE, 1951–1981

	Coal[a]		Natural Gas		Petroleum[b]		Hydropower[c]		Nuclear Power	
Year	Quadrillion Btu	Million Short Tons	Quadrillion Btu	Trillion Cubic Feet	Quadrillion Btu	Million Barrels	Quadrillion Btu	Billion kW · h[d]	Quadrillion Btu	Billion kW · h[d]
1951	13.20	505.9	7.05	6.81	14.43	2,561	1.45	106.6	0	0
1952	11.84	454.1	7.55	7.29	14.96	2,661	1.50	112.0	0	0
1953	11.87	454.8	7.91	7.64	15.56	2,774	1.44	111.6	0	0
1954	10.17	389.9	8.33	8.05	15.84	2,831	1.39	114.0	0	0
1955	11.52	447.0	9.00	8.69	17.25	3,086	1.41	120.3	0	0
1956	11.72	456.9	9.61	9.29	17.94	3,212	1.49	129.8	0	0
1957	11.14	434.5	10.19	9.85	17.93	3,215	1.56	137.0	0	0
1958	9.83	385.7	10.66	10.30	18.53	3,328	1.63	146.9	([g])	0.2
1959	9.79	385.1	11.72	11.32	19.32	3,477	1.59	144.7	([g])	0.2
1960	10.12	398.0	12.39	11.97	19.92	3,586	1.65	153.7	0.01	0.5
1961	9.89	390.3	12.93	12.49	20.22	3,641	1.68	157.5	0.02	1.7
1962	10.17	402.2	13.73	13.27	21.05	3,796	1.82	172.2	0.03	2.3
1963	10.69	423.5	14.40	13.97	21.70	3,921	1.77	169.1	0.04	3.2
1964	11.25	445.7	15.29	14.81	22.30	4,034	1.91	182.3	0.04	3.3
1965	11.89	472.0	15.77	15.28	23.25	4,202	2.06	196.8	0.04	3.7
1966	12.48	497.7	17.00	16.45	24.40	4,411	2.07	199.0	0.06	5.5
1967	12.24	491.4	17.94	17.39	25.28	4,585	2.34	224.6	0.09	7.7
1968	12.66	509.8	19.21	18.63	26.98	4,902	2.34	225.2	0.14	12.5
1969	12.72	516.4	20.68	20.06	28.34	5,160	2.66	254.5	0.15	13.9
1970	12.66	523.2	21.79	21.14	29.52	5,364	2.65	252.9	0.24	21.8
1971	12.01	501.6	22.47	21.79	30.56	5,553	2.86	273.1	0.41	38.1
1972	12.45	524.3	22.70	22.10	32.95	5,990	2.94	283.6	0.58	54.1
1973	13.30	562.6	22.51	22.05	34.84	6,317	3.01	289.7	0.91	83.5
1974	12.88	558.4	21.73	21.22	33.45	6,078	3.31	316.9	1.27	114.0
1975	12.82	562.6	19.95	19.54	32.73	5,958	3.22	309.3	1.90	172.5
1976	13.73	603.8	20.35	19.95	35.17	6,391	3.07	295.5	2.11	191.1
1977	13.96	625.3	19.93	19.52	37.12	6,727	2.51	241.0	2.70	250.9
1978	13.85	625.2	20.00	19.63	37.97	6,879	3.14	303.2	3.02	276.4
1979	15.11	680.5	20.67	20.24	37.12	6,757	3.14	303.4	2.71	255.2
1980	15.46	702.7	20.39	19.88	34.20	6,242	3.11	300.1	2.67	251.1
1981[f]	16.01	727.7	19.93	19.42	32.00	5,840	2.97	287.0	2.90	272.3

Source. U.S. Dept. of Energy, *1981 Annual Report to Congress Vol. 2: Energy Statistics*, U.S. Dept. of Energy, Washington, D.C., 1982 (Table 3, p. 7).

[a] Bituminous coal, lignite, and anthracite.
[b] Refined petroleum products supplied including natural gas plant liquids and crude oil burned as fuel.
[c] Electric utility and industrial generation of hydropower and net electricity imports.
[d] Consumed by electric utilities.
[e] Wood, refuse, and other vegetal fuels consumed by electric utilities. Converted to Btu by applying national average heat rates for fossil fuel steam electric plants. Data do not include the consumption of wood-derived fuel (other than that consumed by the

TABLE 1.1-2 (*Continued*)

	Geothermal[d]		Wood and Waste[e]		Net Imports of Coal Coke		Total Energy Consumption	Change from Previous Year
Year	Quadrillion Btu	Billion kW · h[c]	Quadrillion Btu	Billion kW · h[c]	Quadrillion Btu	Thousand Short Tons	Quadrillion Btu	Percent[f]
1951	0	0	0	0	−0.02	−865	36.11	7.4
1952	0	0	0	0	−0.01	−479	35.83	−0.8
1953	0	0	0	0	−0.01	−363	36.76	2.6
1954	0	0	0	0	−0.01	−272	35.73	−2.8
1955	0	0	0	0	−0.01	−405	39.17	9.6
1956	0	0	0	0	−0.01	−525	40.75	4.0
1957	0	0	0	0	−0.02	−704	40.80	0.1
1958	0	0	0	0	−0.01	−271	40.65	−0.4
1959	0	0	0	0	−0.01	−337	42.41	4.3
1960	([g])	0	([g])	0.1	−0.01	−227	44.08	3.9
1961	([g])	0.1	([g])	0.1	−0.01	−318	44.72	1.5
1962	([g])	0.1	([g])	0.1	−0.01	−222	46.80	4.6
1963	([g])	0.2	([g])	0.1	−0.01	−298	48.61	3.9
1964	([g])	0.2	([g])	0.1	−0.01	−421	50.78	4.5
1965	([g])	0.2	([g])	0.3	−0.02	−744	52.99	4.4
1966	([g])	0.2	([g])	0.3	−0.03	−1,006	55.99	5.7
1967	0.01	0.3	([g])	0.3	−0.02	−618	57.89	3.4
1968	0.01	0.4	([g])	0.4	−0.02	−698	61.32	5.9
1969	0.01	0.6	([g])	0.3	−0.04	−1,456	64.53	5.2
1970	0.01	0.5	([g])	0.4	−0.06	−2,325	66.83	3.6
1971	0.01	0.5	([g])	0.3	−0.03	−1,335	68.30	2.2
1972	0.03	1.5	([g])	0.3	−0.03	−1,047	71.63	4.9
1973	0.04	2.0	([g])	0.3	−0.01	−317	74.61	4.2
1974	0.05	2.5	([g])	0.3	0.06	2,262	72.76	−2.5
1975	0.07	3.2	([g])	0.2	0.01	546	70.71	−2.8
1976	0.08	3.6	([g])	0.3	([g])	−4	74.51	5.4
1977	0.08	3.6	0.01	0.5	0.02	588	76.33	2.4
1978	0.06	3.0	([g])	0.3	0.13	5,029	78.18	2.4
1979	0.08	3.9	0.01	0.5	0.07	2,534	78.91	0.9
1980	0.11	5.1	([g])	0.4	−0.04	−1,412	75.91	−3.8
1981[h]	0.12	5.7	([g])	0.4	−0.02	−643	73.91	−2.6

electric utility industry) which amounted to an estimated 2.2 quadrillion Btu (1981). This table excludes small quantities of energy forms for which consistent historical data are not available, such as solar energy obtained by the use of thermal and photovoltaic collectors; wind energy; and geothermal, biomass, and waste energy other than that consumed at electric utilities.

[f] Percent change calculated from data prior to rounding.

[g] Less than 0.005 quadrillion Btu.

[h] Preliminary.

Note: Sum of components may not equal total due to independent rounding.

TABLE 1.1-3 CONSUMPTION OF ENERGY BY END-USE SECTOR, 1951–1981[a]

	Residential and Commercial		Industrial		Transportation			
Year	Without Electricity Distributed	With Electricity Distributed[b]	Without Electricity Distributed	With Electricity Distributed[b]	Without Electricity Distributed	With Electricity Distributed[b]	Electric Utilities	Total Energy Consumption
1951	7.00	9.60	14.66	17.41	8.99	9.11	5.45	36.11
1952	7.04	9.80	14.18	16.99	8.94	9.04	5.67	35.83
1953	6.83	9.75	14.83	17.86	9.05	9.15	6.06	36.76
1954	7.02	10.04	13.76	16.77	8.83	8.91	6.12	35.73
1955	7.47	10.62	15.44	18.99	9.47	9.55	6.79	39.17
1956	7.78	11.19	15.88	19.70	9.79	9.86	7.30	40.75
1957	7.54	11.17	15.61	19.46	9.84	9.90	7.55	40.80
1958	8.04	11.83	15.16	18.82	9.97	10.02	7.51	40.65
1959	8.23	12.33	15.80	19.74	10.30	10.35	8.08	42.41
1960	8.91	13.22	16.46	20.34	10.48	10.52	8.23	44.08
1961	9.13	13.63	16.47	20.44	10.62	10.66	8.51	44.72
1962	9.60	14.43	17.04	21.23	11.10	11.14	9.06	46.80
1963	9.62	14.86	17.79	22.17	11.54	11.58	9.66	48.61
1964	9.72	15.35	18.82	23.50	11.89	11.92	10.34	50.78
1965	10.13	16.19	19.50	24.47	12.30	12.33	11.07	52.99
1966	10.53	17.13	20.39	25.78	13.04	13.08	12.03	55.99
1967	11.09	18.17	20.38	26.00	13.69	13.72	12.73	57.89
1968	11.44	19.30	21.16	27.20	14.80	14.83	13.92	61.32
1969	11.94	20.66	21.91	28.40	15.43	15.46	15.25	64.53
1970	12.18	21.76	22.32	29.00	16.03	16.06	16.29	66.83
1971	12.38	22.67	22.05	28.96	16.65	16.68	17.22	68.30
1972	12.64	23.73	22.77	30.24	17.63	17.66	18.58	71.63
1973	12.24	24.20	23.86	31.88	18.49	18.52	20.01	74.61
1974	11.74	23.77	22.85	30.94	18.00	18.03	20.16	72.76
1975	11.58	23.92	20.57	28.60	18.14	18.18	20.42	70.71
1976	12.25	25.01	21.68	30.44	19.03	19.07	21.55	74.51
1977	11.83	25.41	21.97	31.18	19.70	19.74	22.82	76.33
1978	11.93	26.00	22.12	31.56	20.58	20.61	23.55	78.18
1979	11.79	26.08	22.58	32.39	20.40	20.43	24.14	78.91
1980	10.98	25.87	20.85	30.36	19.65	19.68	24.44	75.91
1981[c]	10.69	25.64	19.39	29.02	19.18	19.22	24.63	73.91

Source. U.S. Dept. of Energy, *1981 Annual Report to Congress, Vol. 2: Energy Statistics*, U.S. Dept. of Energy, Washington, D.C., 1982 (Table 4, p. 9).

[a] Data do not include consumption of wood-derived fuel (other than that consumed by the electric utility industry), which amounted to an estimated 2.2 quadrillion Btu in 1981. Also, small quantities of other energy forms for which consistent historical data are not available, such as solar energy obtained by the use of thermal and photovoltaic collectors; wind energy; and geothermal, biomass, and waste energy other than that consumed at electric utilities, are not included. In quadrillion Btu.

[b] Energy consumption by electric utilities is allocated to the three major end-use sectors in proportion to electricity sales.

[c] Preliminary.

Note: Sum of components may not equal total due to independent rounding.

Table 1.1-3 shows that the fastest growing energy end-use sector in the United States was residential and commercial, which grew from 24.2 quadrillion Btu in 1973 to 25.64 in 1981. Energy consumption also grew in transportation, from 18.5 quatrillion Btu to 19.2. In the industrial sector energy consumption declined slightly over the 1973–1981 period. From 1951 to 1981 total energy consumption in the United States grew from 36.1 to 73.9 quadrillion Btu, a growth rate of nearly 3%. The most rapidly growing sector was residential and commercial, which increased practically threefold, from 9.6 to 25.64 quadrillion Btu.

1.2 COAL RESOURCES AND PRODUCTION

1.2-1 Introduction

Coal is a dark brown or black combustible substance consisting of carbonized vegetable matter. It was created during past geologic ages when plant material in swamps was compacted under successive layers of vegetation and transformed first into peat and later, as marine or continental deposits covered the coal swamps, into coal. This transformation was marked by a progressive decrease in the amount of volatile matter and moisture resulting from the increased compression and temperature associated with greater depth of burial.[1] The geologic origin of coal is discussed in greater detail in Chapter 6.

The chief constituents of coal are fixed carbon, moisture, ash, volatile material, and sulfur. The ash and volatile material contain hydrocarbons, nitrogen, and polyacyclic organic matter as well as inorganic trace elements and radio nuclites.[2] The composition of coal is of great economic importance. The higher the carbon and heat content and the lower the percentage of ash, volatile material, and sulfur, the more valuable coal is to consumers.

1.2-2 U.S. Coal Resources

Coal is a very abundant fuel both in the United States and in the world as a whole. The total resources of coal in the United States have been estimated at approximately 4 trillion tons (see Table 1.2-1). In 1980 U.S. coal production was 835 million short tons or less than $\frac{1}{4500}$ of total resources.[3] A recent U.S. Geological Survey estimate[4] put the world total of identified plus hypothetical coal resources at 17 trillion short tons. In 1980 world production of coal was approximately 4 billion short tons or less than $\frac{1}{4000}$ of total resources.

Tables 1.2-1 and 1.2-2 present the U.S. Geological Survey estimates of the total remaining coal resources and the coal reserve base of the United States as of January 1, 1974.[5] The resource figures in Table 1.2-1 are divided into three categories—identified, hypothetical, and additional hypothetical—according to the methods of estimation and expected accuracy.

The estimates of identified resources shown in Table 1.2-2 are based on detailed information accumulated by mapping outcrops of coal beds and drilling holes to test coal bed thickness. They are subject to increase in the future as mapping, prospecting, and development are continued.[6] The resources included in the identified category satisfy certain constraints with respect to the minimum thickness of coal seams (14 in. for anthracite and bituminous coal and $2\frac{1}{2}$ ft for subbituminous coal and lignite) and the maximum depth of overburden (3000 ft in most states). In addition, the maximum ash and sulfur content is limited to 32.6 and 7.7%, respectively. It should be noted that the bulk of identified coal resources fall well within these limits.[7]

The percentage distribution of total identified resources by depth of overburden, thickness of beds, and rank are presented in Fig. 1.2-1. Overburden and seam thickness are major determinants of the cost of mining coal. Fig. 1.2-1 shows that the bulk, over 91% of resources, lies within 1000 ft of the surface and 58% is contained in seams of 5 ft or thicker for subbituminous coal and lignite and 28 in. or thicker for anthracite and bituminous coal. Conservative procedures were employed in estimating average seam thickness between points of measurement and in estimating the areal extent of coal beds around isolated points of information.

The hypothetical resources shown in Table 1.2-1 are estimates of coal in areas of known coal fields that are unmapped and unexplored. Hypothetical resources contain coal located in areas of coal-bearing rock that were excluded from consideration in the identified category because of lack of specific information about the occurrence and thickness of coal. Most exploration and mining of coal in the United States is concentrated along outcrops. As a result, only general information is available about coal in the centers of large coal basins. Moreover, many coal-bearing areas are so remote that they have been examined only by reconnaissance. The estimated hypothetical resources include an allowance for coal, which should be discovered when detailed geological mapping is extended into such areas.[8]

The estimates of coal in the hypothetical category are subject to the same constraints with respect to seam thickness and overburden applied to identified resources. The bulk of hypothetical resources lies in the range of 1000–2000 ft deep. Estimated hypothetical resources located below the 3000 ft