Fundamentals of Energy Engineering

Albert Thumann, P.E., C.E.M.

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Fundamentals of Energy Engineering

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Energy Situation

INTRODUCTION

Energy engineering is a profession which applies scientific knowledge for the improvement of the overall use of energy. It combines the skills of engineering with the knowledge of energy problems. The energy engineer must be able to identify problems in the use of energy, creatively design solutions, and implement the process.

In order to develop economic and socially acceptable ways to use available resources for the benefit of mankind, the energy engineer searches for a better way to combine a broad base of knowledge with experience.

Energy engineering requires a "system approach" and is multidisciplinary in nature. Thus an energy engineer must have both engineering skills in, for example, electrical, mechanical and process engineering, as well as good management knowledge.

Problems, such as the high cost of energy, the depletion of resources, and the degradation of the environment are not transitory, but will plague mankind for decades to come. The energy engineering profession is addressing these and other problems in a systematic and cost-effective manner.

ENERGY CONVERSION FACTORS

In order to communicate energy engineering goals and to analyze the literature in the field, it is important to understand the conversion factors used in energy engineering and how they are applied.

Each fuel has a heating value, expressed in terms of the British thermal unit, Btu. The Btu is the heat required to raise the temperature of one pound of water 1°F. Table 1-1 illustrates the heating values of various fuels. To compare efficiencies of various fuels, it is best to convert fuel usage in terms of Btu's. Table 1-2 illustrates conversions used in energy engineering calculations.

When comparing cost of fuels, the term "cents or dollars per therm" (100,000 Btu) is commonly used.

The chemical energy stored in fuel is sometimes expressed as Higher Heating Value (HHV) or Lower Heating Value (LHV).

Table 1-1. Heating Values for Various Fuels

Fuel	*Average Heating Value*
Fuel Oil	
Kerosene	134,000 Btu/gal.
No. 2 Burner Fuel Oil	140,000 Btu/gal.
No. 4 Heavy Fuel Oil	144,000 Btu/gal.
No. 5 Heavy Fuel Oil	150,000 Btu/gal.
No. 6 Heavy Fuel Oil 2.7% sulfur	152,000 Btu/gal.
No. 6 Heavy Fuel Oil 0.3% sulfur	143,800 Btu/gal.
Coal	
Anthracite	13,900 Btu/lb
Bituminous	14,000 Btu/lb
Sub-bituminous	12,600 Btu/lb
Lignite	11,000 Btu/lb
Gas	
Natural	1,000 Btu/cu ft
Liquefied butane	103,300 Btu/gal.
Liquefied propane	91,600 Btu/gal.

Source: Brick & Clay Record, October 1972.

Table 1-2. List of Conversion Factors

1 U.S. barrel	=	42 U.S. gallons
1 atmosphere	=	14.7 pounds per square inch absolute (psia)
1 atmosphere	=	760 mm (29.92 in.) mercury with density of 13.6 grams per cubic centimeter
1 pound per square inch	=	2.04 inches head of mercury
	=	2.31 feet head of water
1 inch head of water	=	5.20 pounds per square foot
1 foot head of water	=	0.433 pound per square inch
1 British thermal unit (Btu)	=	heat required to raise the temperatrure of 1 pound of water by 1°F
1 therm	=	100,000 Btu
1 kilowatt (Kw)	=	1.341 horsepower (hp)
1 kilowatt-hour (Kwh)	=	1.34 horsepower-hour
1 horsepower (hp)	=	0.746 kilowatt (Kw)
1 horsepower-hour	=	0.746 kilowatt hour (Kwh)
1 horsepower-hour	=	2545 Btu
1 kilowatt-hour (Kwh)	=	3412 Btu
To generate 1 kilowatt-hour (Kwh) requires 10,000 Btu of fuel burned by average utility		
1 ton of refrigeration	=	12,000 Btu per hr
1 ton of refrigeration requires about 1 Kw (or 1.341 hp) in commercial air conditioning		
1 standard cubic foot is at standard conditions of 60°F and 14.7 psia		
1 degree day	=	65°F minus mean temperature of the day, °F
1 year	=	8760 hours
1 year	=	365 days
1 MBtu	=	1 million Btu
1 Kw	=	1000 watts
1 trillion barrels	=	1 X 10^{12} barrels
1 KSCF	=	1000 standard cubic feet
1 Quad	=	one quadrillion (10^{15}) Btu's

Note: In these conversions, inches and feet of water are measured at 62°F (16.7°C), and inches and millimeters of mercury at 32°F (0°C).

The higher heating value is obtained by burning a small sample of fuel in an oxygen environment and recording the heat transferred to the water sample surrounding it. This test includes the latent heat of vaporization of the condensed vapor.

The lower heating value subtracts the latent heat of vaporization since this energy is usually unavailable in practice.

European countries usually use lower heating values for fuels while in the United States higher heating values are used. Thus a heating device tested in Europe will be approximately 10% more efficient than if tested in the United States due to the standard in heating values assumed.

Example Problem 1-1

The supply of fuel oil is projected at 11.5 million barrels per day. What is the supply in Btu per year, assuming an average fuel oil value of 140,000 Btu/gallon?

Answer

Fuel supply = 140,000 Btu/gallon $\times$ 11.5 $\times$ 10^6 barrels/day $\times$ 42 gallons/barrel $\times$ 365 days/year = 24.7 $\times$ 10^{15} Btu/year.

Example Problem 1-2

The warehouse of the plant is required to be minimally heated at night. Two methods of heating are being considered. One method is electric heaters. The second is to operate the oil-fired boiler (using No. 2 fuel oil) which keeps the radiators warm all night. Electricity costs, excluding demand charges, is 10 cents per kilowatt hour; No. 2 fuel oil costs $1.00 per gallon. Assume the boiler is 70% efficient and exclude the costs of running pumps and fans to distribute heat. What is the relative cost to heat the building using electricity or the oil-fired boiler?

Answer

To compare fuel costs, a common base of $ per therm will be used.

Electricity Cost

$$1 \text{ Kwh} = 3412 \text{ Btu}$$

$$\text{Cost} = \frac{100{,}000}{3412} \times .10 = \$2.93/\text{therm}$$

No. 2 Fuel Oil

$$\text{No. 2 fuel oil} = 140{,}000 \text{ Btu/gallon}$$

$$\text{Cost} = \frac{100{,}000}{140{,}000} \times \$1.00 = 71 \text{ cents/therm}$$

Taking into account an efficiency of combustion of 0.7, the relative cost becomes:

$$\text{Cost} = \frac{71}{0.7} = \$1.02/\text{therm}$$

ENERGY CONSUMPTION WORLDWIDE

Industrial nations are competing in a world-wide market place. Energy consumption of the industrial sectors in each country gives a good comparative indicator of how each nation uses energy.

In order to compare energy consumption, energy per Gross Domestic Product (GDP) is used instead of Gross National Product (GNP) due to the fact that income originating in overseas investments which do not use domestic energy, is excluded.

Figure 1-1 illustrates how various nations compare in energy use. From this figure it is apparent that the United States uses more energy for a given output than the United Kingdom, West Germany, Sweden, Netherlands, France or Italy.

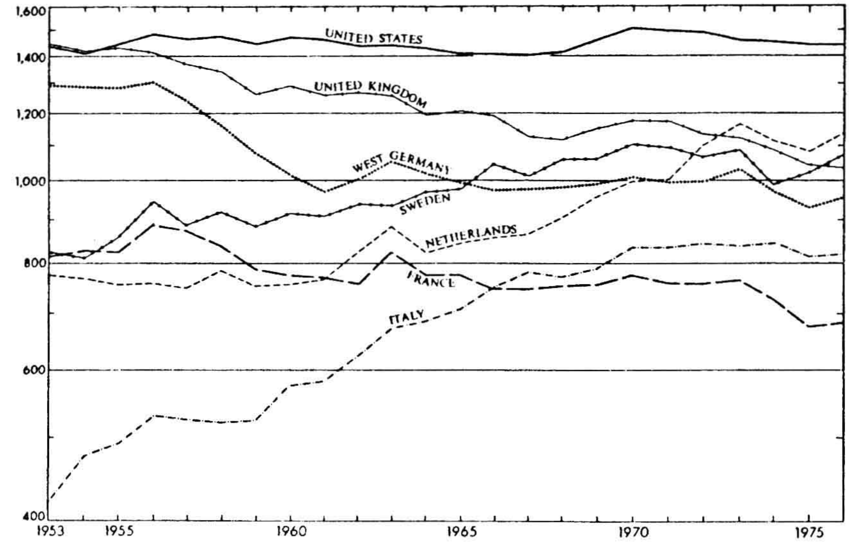
WORLD ENERGY OUTLOOK

The Organization for Economic Co-operation and Development (OECD) was established under a Convention signed in Paris on December 14, 1960. Members of OECD are Australia, Belgium, Canada, Finland, France, Federal Republic of Germany, Greece, Iceland, Ireland, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States.

In the 1982 World Energy Outlook published by OECD* several trends were discussed. Several conclusions to be drawn are:

**Source:* World Energy Outlook, OECD 1982, International Energy Agency, 2 Rue André-Pascal, 75775 Paris Cedex 16, France.

Energy consumption (tons oil equivalent) per million U.S. dollars of gross domestic product



Source: EPRI EA 1471, Aug. 1980

Figure 1-1. Energy Intensity Among Industrial Societies

1. Energy and oil markets will remain stable in mid-1980's but will become increasingly tight thereafter.
2. Energy demand will accelerate between .6 to .8% per year in the first half of the 1980's to as much as 1.7 to 2.6% per year during the 1990's.
3. Electric consumption will grow at a faster rate of 2–3% up to the 1990's and 3–4% thereafter.
4. OECD countries are expected to remain highly dependent on imported oil.
5. Natural gas is unlikely to grow beyond 20% of its present share of total OECD energy use. To maintain the present share of gas use imports of natural gas will have to increase five to sixfold.

6. Coal is expected to grow in use over oil due to its price advantage.
7. Nuclear by the year 2000 is expected to grow 10–11% for OECD total energy.

In the Executive Summary of the World Energy Outlook the finding concluded:

> In sum, while some structural change away from oil can be expected in the energy economy as a result of the price mechanism, the basic vulnerability of the world economy to oil supply disruptions is far from being eliminated. On the contrary, with energy demand pressures growing, there is a continuing risk that a closely balanced demand and supply equilibrium could once again be precipitated by political events in the Middle East.

ENERGY CONSUMPTION DATA SOURCE

The U.S. Department of Energy, Energy Information Administration, Office of Energy Data Operations, publishes the "Monthly Energy Review" based on data from DOE, other government agencies and private establishments. The data which follows is from this source unless otherwise referenced.

U.S. Energy Production

Energy production for 1980 totaled 64.8 quadrillion Btu, a 1.4% increase compared to production for 1979. This increase amounted to 1.2% when measured as a daily rate (a measure which removes the influence of leap year). Increases in production occurred for petroleum and coal. Petroleum production was up 0.3% and coal 6.7% (all measured as daily rates). Natural gas production decreased by 2.1%. All other forms of energy production combined were down by 1.3%, primarily due to a decline in electricity production by nuclear plants.

U.S. Energy production, classified by energy type is presented in Figure 1-2.

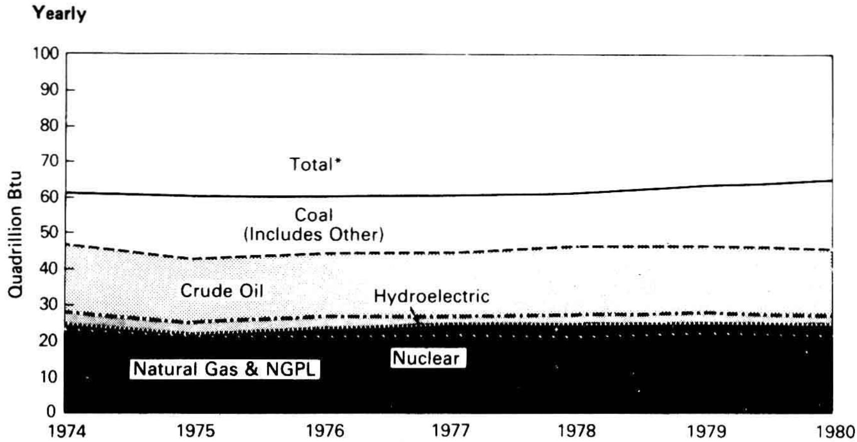


Figure 1-2. U.S. Production of Energy by Type[1]

U.S. Energy Consumption

Total U.S. energy consumption in 1980 dropped to 76.3 quadrillion Btu, 3.4% below 1979 and a 2.4% decrease from the 1978 consumption level. The consumption by energy type is presented in Figure 1-3. Figure 1-4 shows the U.S. energy consumption by end-use sector. Energy consumption per GNP dollar is presented in Figure 1-5.

The Residential and Commercial sector consumption was 27.3 quadrillion Btu in 1980, a 0.5% decrease from the amount consumed the previous year and a 2.9% decrease from the amount consumed in 1978. The Residential and Commercial sector consumed 35.8% of the total consumption for 1980, up from the sector's 34.8% share in 1979. The consumption of energy by the Commercial and Residential sector is presented in Table 1-3.

The Industrial sector consumption was 30.3 quadrillion Btu in 1980, down 4.0% from 1979, but up 3.2% from the consumption

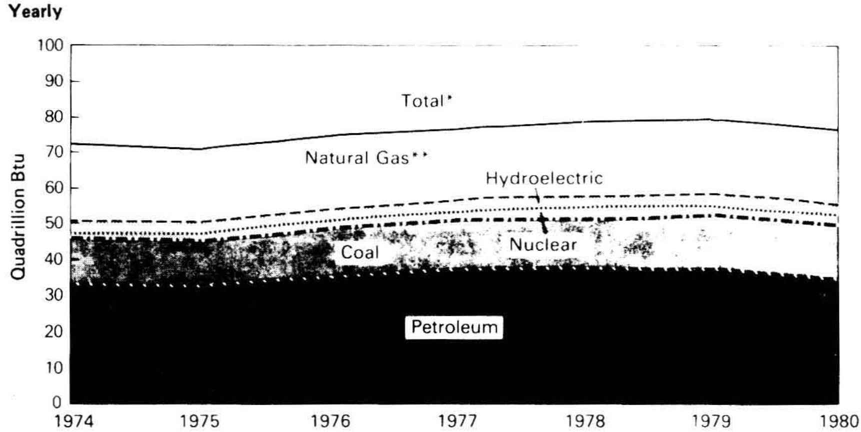


Figure 1-3. U.S. Consumption of Energy by Type[1]

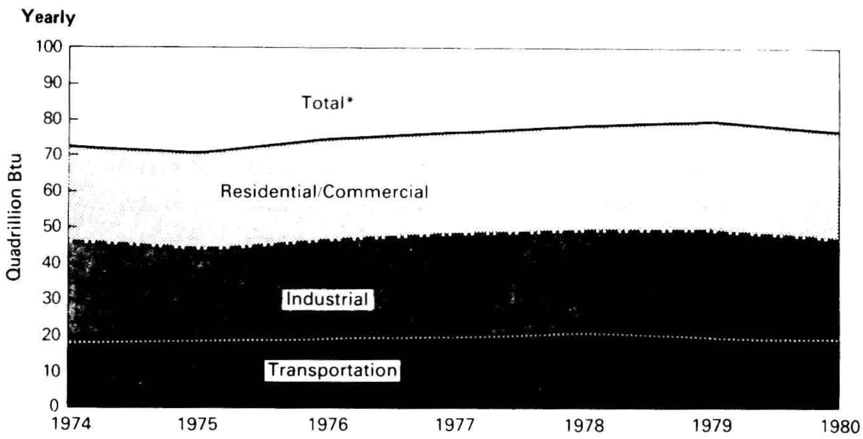


Figure 1-4. U.S. Consumption of Energy by End-Use Sector[1]

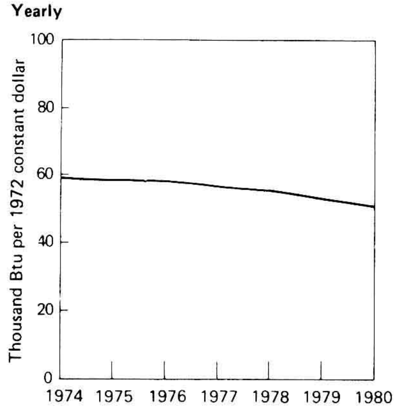


Figure 1-5. Energy Consumption per GNP Dollar[1]

Table 1-3. Consumption of Energy by the Residential and Commercial Sector*[1]

	Coal	Natural Gas (Dry)	Petroleum	Electricity Sales	Electrical Energy Losses†	Total Energy Consumed
			Quadrillion (10^{15}) Btu			
1973	0.291	7.626	6.741	3.495	8.460	26.613
1974	0.293	7.518	6.141	3.475	8.548	25.974
1975	0.239	7.581	5.792	3.588	8.814	26.014
1976	0.227	7.866	6.302	3.729	9.089	27.213
1977	0.225	7.461	6.245	3.936	9.702	27.569
1978	0.250	7.624	6.268	4.100	9.918	28.159
1979	0.210	7.891	5.027	4.184	10.150	27.462
1980	0.194	7.637	4.389	4.354	10.762	27.337

Notes:

*The Residential and Commercial Sector consists of housing units, nonmanufacturing business establishments (e.g., wholesale and retail businesses), health and educational institutions, and government office buildings. Notes on the methodology used for sector calculations are provided in the Notes and Sources of Reference 1.

†Proportion of total electrical energy losses incurred in the generation and transmission of electricity plus plant use and unaccounted for that are attributed to this sector.

level in 1978. The Industrial sector consumed 39.7% of the 1980 total, as compared to the 40.0% share in 1979. The consumption of energy by the Industrial sector is presented in Table 1-4.

The Transportation sector consumption was 18.6 quadrillion Btu in 1980, down 6.6% from 1979 and down 9.6% from the consumption level in 1978. This sector consumed 24.4% of the 1980 total, as compared to a 25.3% share in 1979. Petroleum energy consumption of the Transportation sector is presented in Table 1-5.

The Electric Utilities consumption was an estimated 24.8 quadrillion Btu of energy in 1980, 2.5% higher than in the previous year, and 6.0% higher than the energy consumed in 1978. Coal contributed 48.8% of the energy consumed by Electric Utilities in 1980, while natural gas contributed 15.3%, hydroelectric power 12.5%, petroleum 12.1%, nuclear power 10.9%, and geothermal, wood and waste 0.5%. The consumption of energy by the Electric Utilities is presented in Table 1-6.

Imports and Exports

Net imports of energy for 1980 totaled 12.0 quadrillion Btu, 28.3% below the 1979 level. This decrease amounted to 28.5% when measured as a daily rate. By energy source, the decreases in net imports were petroleum, 21.8%; natural gas 21.7%; and electricity and coal coke combined, 37.1% (daily rates). Net exports of coal for 1980 were 41.0% higher than the level for 1979.

The annual value of U.S. energy imports between 1974 and 1980 is presented in Figure 1-6. The annual production and consumption data is also presented for comparison.

The total annual U.S. energy imports and exports for 7 years is presented in Figures 1-7 and 1-8. This data indicates both a decrease in imports and increase in exports in 1980.

The U.S. dependence on petroleum imports is shown in Figure 1-9.

Table 1-4. Consumption of Energy by the Industrial Sector*[1]

	Coal	Natural Gas (Dry)	Petroleum	Hydroelectric	Net Coke Imports†	Electricity Sales	Electrical Energy Losses**	Total Energy Consumed
				Quadrillion (10^{15}) Btu				
1973	4.350	10.397	6.683	0.035	(0.008)	2.341	5.676	29.474
1974	4.057	10.012	6.506	0.033	0.059	2.337	5.751	28.755
1975	3.801	8.531	6.160	0.032	0.014	2.304	5.669	26.512
1976	3.792	8.768	6.951	0.033	0.000	2.525	6.162	28.230
1977	3.494	8.642	7.692	0.033	0.015	2.635	6.513	29.024
1978	3.462	8.540	7.840	0.032	0.131	2.732	6.637	29.373
1979	3.641	8.554	9.401	0.034	0.066	2.873	6.983	31.551
1980	3.354	8.407	8.876	0.033	(0.037)	2.781	6.886	30.300

Notes:

*The Industrial Sector is made up of construction, manufacturing, agriculture, and mining establishments. Notes on the methodology used for sector calculations are provided in the Notes and Sources of Reference 1.

†Net Imports=imports minus exports. Parentheses indicate exports are greater than imports.

**Proportion of total electrical energy losses incurred in the generation and transmission of electricity plus plant use and unaccounted for that are attributed to this sector.