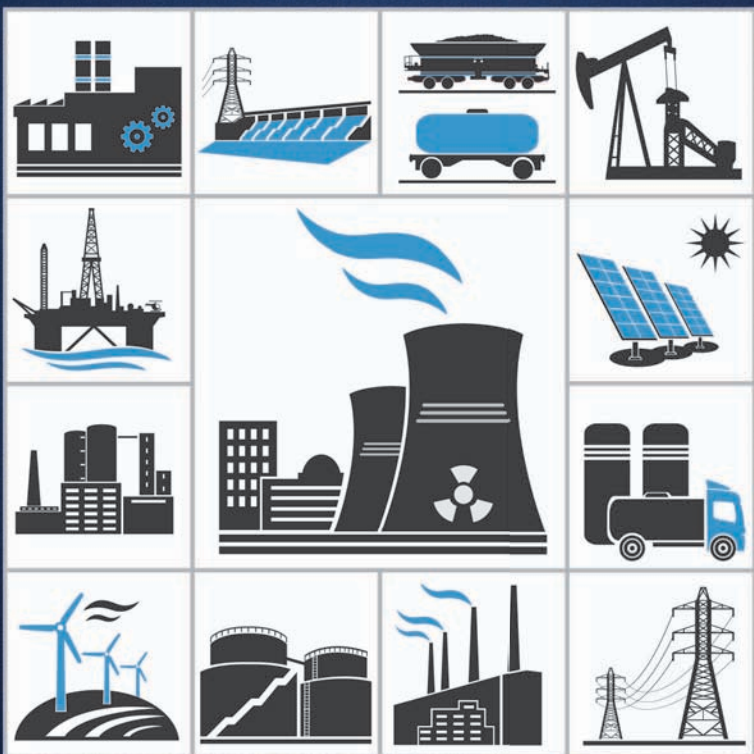
ENERGY AND THE ENVIRONMENT

Abbas Ghassemi, Series Editor

ENERGY RESOURCES

AVAILABILITY, MANAGEMENT, *and* ENVIRONMENTAL IMPACTS



Kenneth J. Skipka • Louis Theodore

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SERIES EDITOR

Abbas Ghassemi

New Mexico State University

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To those who seek a true and complete understanding of the world's energy problems and continually strive to select the best available resources to meet energy demands considering all attendant impacts. Our collective existence and prosperity are in their hands.

Kenneth J. Skipka

and

Governor Mike Huckabee—who thankfully continues to confront the negative impacts of a biased media, and whose commitment to traditional values and the American Dream has never wavered.

Lou Theodore

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Series Preface

By 2050, the demand for energy could double or even triple as the global population rises and developing countries expand their economies. According to data from the United Nations, it is projected that world population will increase from 7.2 billion to more than 9 billion in 2050. This increase, coupled with continued demand for the same, limited natural resources, will cause significant increase in consumption of energy. All life on Earth depends on energy and the cycling of carbon. Affordable energy resources are essential for economic and social development as well as food production, water supply availability, and sustainable, healthy living. In order to avoid long-term adverse and potentially irreversible impact of harvesting energy resources, we must explore all aspects of energy production and consumption, including energy efficiency, clean energy, global carbon cycle, carbon sources and sinks, and biomass as well as their relationship to climate and natural resource issues. Knowledge of energy has allowed humans to flourish in numbers unimaginable to our ancestors. The world's dependence on fossil fuels began approximately 200 years ago. Are we running out of oil? No, but we are certainly running out of the affordable oil that has powered the world economy since the 1950s. We know how to recover fossil fuels and harvest their energy for operating power plants, planes, trains, and automobiles, which results in modifying the carbon cycle and additional greenhouse gas emissions. This has resulted in the debate on availability of fossil energy resources, peak oil era, and timing for the anticipated end of fossil fuel era, and price and environmental impact versus various renewable resources and use, carbon footprint, emission, and control, including cap and trade, and the emergence of "green power."

Our current consumption has largely relied on oil for mobile applications and coal, natural gas, nuclear, or water power for stationary applications. In order to address the energy issues in a comprehensive manner, it is vital to consider the complexity of energy. Any energy resource including oil, gas, coal, wind, biomass, etc., is an element of a complex supply chain and must be considered in the entirety as a system from production through consumption. All of the elements of the system are interrelated and interdependent. Oil, for example, requires consideration for interlinking of all of the elements, including exploration, drilling, production, transportation, water usage and production, refining, refinery products and by-products, waste, environmental impact, distribution, consumption/application, and finally emissions. Inefficiency in any part of the system has impact on the overall system and disruption if one of these elements causes major interruption and a significant cost impact. As we have experienced in the past, interrupted exploration will result in disruption in production, restricted refining and distribution, and consumption shortages; therefore, any proposed energy solution requires careful evaluation and, as such, may be one of the key barriers to implementing the proposed use of hydrogen as a mobile fuel.

Even though an admirable level of effort has gone into improving the efficiency of fuel sources for delivery and use of energy, we are faced with severe challenges on many fronts. These include population growth, emerging economies, new and expanded usage, and limited natural resources. All energy solutions include some level of risk, including technology SNAFUs, changes in market demand, economic drivers, and others. This is particularly true when proposing energy solutions involving implementation of untested alternative energy technologies.

There are concerns that emissions from fossil fuels lead to changing climate with possibly disastrous consequences. Over the past five decades, the world's collective greenhouse gas emissions have increased significantly, even as efficiency has increased, resulting in extending energy benefits to more of the population. Many propose that we improve the efficiency of energy use and conserve resources to lessen greenhouse gas emissions and avoid a climate catastrophe. Using fossil fuels more efficiently has not reduced overall greenhouse gas emissions due to various reasons and it is unlikely that such initiatives will have a perceptible effect on atmospheric greenhouse gas content. While there is a debatable correlation between energy use and greenhouse gas emissions, there are effective means to produce energy, even from fossil fuels, while controlling emissions. There are also emerging technologies and engineered alternatives that will actually manage the makeup of the atmosphere, but will require significant understanding and careful use of energy.

We need to step back and reconsider our role and the knowledge of energy use. The traditional approach of micromanagement of greenhouse gas emissions is not feasible or functional over a long period of time. More assertive methods to influence the carbon cycle are needed and will be emerging in the coming years. Modifications to the carbon cycle mean that we must look at all options in managing atmospheric greenhouse gases, including various ways to produce, consume, and deal with energy. We need to be willing to face reality and search in earnest for alternative energy solutions. There appear to be technologies that could assist; however, they may not all be viable. The proposed solutions must not be in terms of a "quick approach"; but a more comprehensive, long-term (10, 25, and 50+ years) approach that is science based and utilizes aggressive research and development. The proposed solutions must be capable of being retrofitted into our existing energy chain. In the meantime, we must continually seek to increase the efficiency of converting energy into heat and power.

One of the best ways to define sustainable development is through long-term, affordable availability of limited resources including energy. There are many potential constraints to sustainable development. Foremost of these is the competition for water use in energy production, manufacturing, farming, and others versus a shortage of fresh water for consumption and development. Sustainable development is also dependent on the Earth's limited amount of productive soil. In the not too distant future, it is anticipated that we will have to restore and build soil as a part of sustainable development. We need to focus our discussions on the motives, economics, and benefits of natural resource conservation, as well as the limitation of technology improvement in impacting sustainability (i.e., we are limited catching fish from the ocean due to the number of fish available—not bigger boats or better nets). Hence, possible sustainable solutions must not be solely based on technology enhancement and improvement, specifically in obtaining the fossil resources, but rather be comprehensive and based on integrating our energy use with nature's management of carbon, water, and life on Earth as represented by the carbon and hydrogeological cycles. The challenges presented by the need to control atmospheric greenhouse gases are enormous and require "out of the box" thinking, innovative approaches, imagination, and bold engineering initiatives in order to achieve sustainable development. We will need to exploit ingeniously even more energy and integrate its use with control of atmospheric greenhouse gases.

The continued development and application of energy are essential to the sustainable advancement of society. Therefore, we must consider all aspects of the energy options, including performance against known criteria, basic economics and benefits, efficiency, processing and utilization requirements, infrastructure requirements, subsidies and credits, and waste and ecosystems, as well as unintended consequences such as impacts to natural resources and the environment. Additionally, we must include the overall changes and the emerging energy picture based on current and future efforts in renewable alternatives and modified and enhanced fossil fuels and evaluate the energy return for the investment of funds and other natural resources such as water. Water is a precious commodity in the West in general and the Southwest in particular and has a significant impact on energy production, including alternative sources, due to the nexus between energy and water and the major correlation with the environment and sustainability-related issues.

A significant driver in creating this book series focused on alternative energy and the environment and was provoked as a consequence of lecturing around the country and in the classroom on the subject of energy, environment, and natural resources such as water. While the correlation between these elements, how they relate to each other, and the impact of one on the other is understood, it is not significantly debated when it comes to integration and utilization of alternative energy resources into the energy matrix. Additionally, as renewable technology implementation grows by various states, nationally and internationally, the need for informed and trained human resources continues to be a significant driver in future employment resulting in universities, community colleges, and trade schools offering minors, certificate programs, and even, in some cases, majors in renewable energy and sustainability. As the field grows, the demand for trained operators, engineers, designers, and architects who would be able to incorporate these technologies into their daily activity is increasing. We receive a daily deluge of flyers, e-mails, and texts on various short courses available for parties interested in solar, wind, geothermal, biomass, etc., under the umbrella of retooling an individual's career and providing trained resources needed to interact with financial, governmental, and industrial organizations.

In all my interactions throughout the years in this field, I have conducted significant searches in locating integrated textbooks that explain alternative energy resources in a suitable manner and that would complement a syllabus for a potential course to be taught at the university while providing good reference material for interested parties getting involved in this field. I have been able to locate a number of books on the subject matter related to energy, energy systems, and resources such as fossil nuclear, renewable, and energy conversion, as well as specific books in the subjects of natural resource availability, use, and impact as related to energy and the environment. However, specific books that are correlated and present the various subjects in detail are few and far between. We have therefore started a series of texts, each addressing specific technology fields in the renewable energy arena. As part of this series, there are textbooks in wind, solar, geothermal, biomass, and hydro energy, and others yet to be developed. Our texts are intended for upper level undergraduate students and graduate students and for informed readers who have a solid fundamental understanding of science and mathematics, as well as individuals/organizations that are involved with design development of the renewable energy field entities that are interested in having reference material available to their scientists and engineers, consulting organizations, and reference libraries. Each book presents fundamentals as well as a series of numerical and conceptual problems designed to stimulate creative thinking and problem solving.

I wish to express my deep gratitude to my wife, Maryam, who has served as a motivator and intellectual companion and too often has been a victim of this effort. Her support, encouragement, patience, and involvement have been essential to the completion of this series.

Abbas Ghassemi, PhD
Las Cruces, New Mexico

Series Editor

Dr. Abbas Ghassemi is the director of the Institute for Energy and Environment (IEE) and professor of chemical engineering at New Mexico State University. As the director of IEE, he is the chief operating officer for programs in education, research, and outreach in energy resources including renewable energy, water quality and quantity, and environmental issues. He is responsible for the budget and operation of the program. Dr. Ghassemi has authored and edited several textbooks and has many publications and papers in the areas of energy, water, carbon cycle, including carbon generation and management, process control, thermodynamics, transport phenomena, education management, and innovative teaching methods. His research areas of interest include risk-based decision making, renewable energy and water, carbon management and sequestration, energy efficiency, pollution prevention, multiphase flow, and process control. Dr. Ghassemi serves on a number of public and private boards, editorial boards, and peer-review panels. He holds MS and PhD degrees in chemical engineering, with minors in statistics and mathematics, from New Mexico State University and a BS in chemical engineering, with a minor in mathematics, from the University of Oklahoma.

Preface

Over the past several decades, there has arisen among informed leaders of industry, government, and the environmental movement, an acute awareness of energy as a problem of impending critical magnitude on the national and international scene. The energy crisis or problem, as it has been called, was created by historical increases in demand for energy and the continuing lack of a viable management policy. This situation has resulted in two issues that are fast becoming pervasive concerns. One is the adequate, reliable supply of all forms of energy both in developed and underdeveloped countries, and the other is the growing public concern with the environmental and social consequences of producing and distributing usable energy.

The solution to the energy problem amazingly may simply be conservation and the development of new, less destructive/consumptive energy forms. Energy conservation may sharply reduce the historic and current waste of resources that has been at the very heart of many of the problems resulting from the exploitation of energy resources. An extensive conservation program could be implemented in a very short period of time. Such an effort could play a major role in slowing the growth in the demand for energy and in causing energy to be used much more efficiently. At this same time, new sources of energy must be developed to take the place of extinguishable resources and to ensure the availability of adequate, long-term energy supplies. The feasibility of developing solar power, wind, tidal, geothermal, fusion, etc., and other so-called unconventional sources of energy must continue to be investigated in this never-ending process until a truly viable renewable or unlimited source of energy is discovered.

In the final analysis, grim projections for the future are obtained by extending the consumption patterns and trends of the past to define future "energy demand." Once it has been determined that the demand exists, the choice among the various means of energy conversion systems, either available at present or in some stage of development, will be made. This should involve an evaluation of each means of power generation from the available fuel resources, including the environmental implications, and their relation to relevant economic, political, and social issues. However, these projections are themselves influenced by assumptions regarding future demands for power that must also be reexamined. For example, various alternatives can be devised to maximize long-term social return per unit of energy consumed by analyzing the various components that presently constitute energy demand, resources, and transmission options. In turn, such alternatives may have important implications for the economic systems, social processes, and lifestyles.

Topics such as resource quantity, resource availability, economics, energy quality, conservation requirements, transportation requirements, delivery requirements, operation and manufacturing, regulatory issues, political issues, environmental concerns, cost consequences, advantages, disadvantages, and public acceptance will be reviewed throughout the analyses presented in this text. The work begins with a cursory review of the various principles involved in the analysis of energy resource options. This is followed by a synopsis of the primary and secondary energy resources available both historically and today. Chapters also provide insight into the problems facing energy managers nationally and internationally, and they examine or propose solutions to potential paths forward. Another feature of the work includes a chapter that provides a ranked quantitative detailed review and practical evaluation of all viable energy options, categories, and corresponding weighting factors that are contained in the analysis. These considerations define the energy issues and provide a means of solving and managing energy problems that exist today and defining the optimal course for future generations. Finally, the book concludes with the authors' approach to solving the energy problem and developing a viable, manageable energy policy for the future.

The authors are particulary indebted to four individuals. Thanks are due to Rita D'Aquino for effectively serving as the authors' personal technical and editorial consultant on the project. Thanks are also due to Vinnie DelGatto for his contribution to the manuscript. A special thank you to Monica Dahl for typing the original manuscript and to Ronnie Zaglin for doing a superb job in "beautifying" it, and for the extra pair of eyes when it came time for proofreading.

Kenneth J. Skipka
Lou Theodore

The Authors

Kenneth Skipka received a BA degree in natural sciences from Long Island University and an MS in meteorology from Cornell University. Over the past 45 years, Mr. Skipka has held a variety of academic, government, and private industry positions. He worked as a research scientist at Brookhaven National Laboratories in New York and at the White Sands Missile Range in New Mexico. He taught at Queens College as an assistant professor and worked as a research assistant at Cornell University. He has held staff scientist positions at the Tri-State Regional Planning Commission in New York and with several environmental consulting firms, including Smith-Singer Associates, Equitable Environmental Health (vice president), and Camp Dresser and McKee (senior scientist, regional manager). In 1986, Mr. Skipka, along with three other partners, founded RTP Environmental Associates, Inc. (RTP), an environmental consulting firm specializing in air, water, and solid waste issues for a variety of industries, particularly the power industry. RTP has become a nationally recognized firm and its success is attributed to the exceptional staff and their superior work products. Mr. Skipka's background includes extensive research while preparing various studies involving evaluating energy alternatives for the Pacific Northwest, preparing environmental analyses for permitting coal, gas, and nuclear power plants; wind power projects; mining activities; biofuels projects; waste-to-energy plants; geothermal facilities; landfill projects; landfill gas energy plants; and pumped storage facilities, in addition to projects in the electric power, pulp and paper, steel, petrochemical, cement, mining, manufacturing, transportation, industrial, commercial, and residential sectors. Mr. Skipka is currently a principal with RTP Environmental Associates, Inc., owner of the IT Leasing Company, and a long-standing member of the Air & Waste Management Association (AWMA). He is also a certified consulting meteorologist (CCM) with the American Meteorological Society (AMS). He has authored, collaborated on, and/or published numerous books, technical reports, and papers concerned with environmental and energy issues. One of his primary interests concerns the development of a sound energy policy for future generations.

Louis Theodore received the degrees of MChE and EngScD from New York University and a BChE from The Cooper Union. Over the past 50 years, Dr. Theodore was a successful educator at Manhattan College (holding the rank of full professor of chemical engineering), graduate program director (raising extensive financial support from local industries), researcher, professional innovator, and communicator in the engineering field. During this period, he was primarily responsible for his program achieving a no. 2 ranking by the *US News & World Report* and was particularly successful in placing students in internships, jobs, and graduate schools. He has authored 98 text/reference books and over 100 technical papers, and is the author of the recent CRC Press/Taylor & Francis Group risk assessment text entitled *Environmental Health and Hazard Risk Assessment: Principles and Calculations* and the John Wiley & Sons text *Heat Transfer for the Practicing Engineer.* He currently serves as a part-time consultant to the US EPA and Theodore Tutorials. Dr. Theodore is a member of Phi Lambda Upsilon, Sigma Xi, Tau Beta Pi, American Chemical Society, American Society of Engineering Education, Royal Hellenic Society, and a fellow of the International Air & Waste Management Association (AWMA). Dr. Theodore is the recipient of the AWMA's prestigious Ripperton award that is "presented to an outstanding educator who, through example, dedication, and innovation has so inspired students to achieve excellence in their professional endeavors." He was also the recipient of the American Society of Engineering Education (ASEE) AT&T Foundation award for "excellence in the instruction of engineering students."

Section I

Basic Principles

Section I provides as an overview on energy management. The subject matter varies from a broad introduction to energy, to energy-related engineering principles, regulations, to energy conservation (including entropy calculations), and to sustainability/green engineering. Chapter titles include:

1. Introduction to the Issues
2. Thermodynamic Principles: Entropy Analysis
3. Energy Demand
4. Sustainability and Green Science/Engineering
5. Energy Regulations
6. The Modern Energy Matrix: An Overview

1

Introduction to the Issues

Introduction

Energy is the keystone of life and prosperity. Adequate energy supplies and a satisfactory living environment are goals of overriding importance to every individual. There is no question that as energy is made available, the quality of life improves. At the same time, however, economic and national stability must also be maintained. Recent developments provide evidence that the discourse on all of these aspects will continue and be the prime determinants of domestic and foreign policy for many years to come.

Over the past 40+ years there has arisen among informed leaders of industry, governments, and the environmental movement an acute awareness of energy as an issue of critical importance to everyone's well-being and survival. An energy crisis—or problem, or shortage, or dilemma, as it has been called—is created by the continually increasing demand for energy. This demand has resulted in three issues becoming critical concerns of the entire international community. First is the adequate, reliable supply of all forms of energy. Second is the growing public concern with the environmental consequences of producing energy. Finally—and equally important—are the social ramifications associated with the accompanying financial expenditures required to meet the energy demand.

The solutions to the problems that arise from energy demand may simply be conservation and the development of new, less expensive energy forms. Energy conservation can sharply reduce the waste of resources that has been at the very heart of many environmental problems. Moreover, an extensive conservation program can be implemented in a very short period of time. Such an effort can play a major role in slowing the growth in the demand for energy and in causing energy to be used more efficiently. At the same time, new sources of energy must be developed to ensure the availability of adequate, inexpensive, long-term energy supplies. The feasibility of solar power, wind, tidal, geothermal, fusion, and other less traditional sources of energy must continue to be investigated and developed further.

Because energy has been relatively cheap and plentiful in the past, many energy-wasting practices were allowed to develop and continue in all areas of energy use. Industries have wasted energy by discharging hot process water instead of recovering its sensible heat and by wasting the energy discharged in flue gases from power plant stacks. Waste hydrocarbons have been discharged to the environment or combusted with little consideration for recovering their energy value. There are many more examples, too numerous to mention. Elimination of these practices can, at least temporarily and partially, reduce the rate of increase in energy demand. Thus, the most dramatic short-term improvements can be developed by energy conservation in the industrial sector of the economy since industrial users account for approximately 40 percent of the energy consumed in the United States. Also, industry might be considered more dynamic, progressive, and strongly motivated by the economic incentives offered by conservation than the other energy-use sectors (residential, commercial, and transportation).

Before discussing energy management, however, there are several terms that require definition, because they are critical to understanding the laws that govern energy resources and their use. These definitions are addressed in the following section.

Energy Terms [1–3]

All forms of energy must be included in an energy balance. In many processes, certain energy forms remain constant and changes in them may be neglected. However, these forms should be recognized and understood before their magnitude and constancy can be determined. Some forms of energy are easily recognized in everyday life: the energy of a moving object, the liberated energy given off by a fire, and the energy content of a container of hot water. Other forms of energy are less easily recognized.

Five key energy terms—kinetic, potential, internal, heat, and work—are commonly used as energy descriptors. These are briefly described next.

1. *Kinetic energy.* The energy of a moving object is called *kinetic energy.* A baseball thrown by a pitcher possesses kinetic energy as it travels toward the catcher. The mass of flowing fluid possesses kinetic energy as it travels through a duct.
2. *Potential energy.* The energy possessed by a mass by virtue of its position in the Earth's gravitational field is referred to as *potential energy.* A boulder lying at the top of a cliff possesses potential energy with reference to the bottom of the cliff. If the boulder is pushed off the cliff, its potential energy is transformed into kinetic energy as it falls. Similarly, a mass of fluid in a flowing system possesses a potential energy because of its height above an arbitrary reference level (e.g., Niagara Falls).

3. *Internal energy.* The component molecules of a substance are constantly moving within the substance. This motion imparts *internal energy* to a mass. The molecules may rotate, vibrate, or migrate within the substance. The addition of heat to a material increases its molecular activity and thus its internal energy. The temperature of a material is a direct measure of its internal energy.
4. *Heat.* When energy is transferred between a system and its surroundings, it is transferred either as *work* or as *heat.* Thus, heat is energy in transit. This type of energy transfer occurs whenever a hot body is brought into contact with a cold body. Energy flows as heat from the hot body to the cold body until the temperature difference is dissipated (i.e., until thermal equilibrium is established). For this reason, heat may be considered as energy being transferred due to a temperature difference.
5. *Work.* Work is also energy in transit. Work is experienced whenever a force acts through a distance.

Other less recognizable forms of energy include light, sound, electrical, magnetic, etc. Included in this category is mass. This form of energy was first realized at the beginning of the last century. It can be thought of as the "energy of existence," possessing energy simply by virtue of its presence. Any mass is nothing more than a highly concentrated source of energy. The amount of this energy (if motionless) is proportional to its mass. If the mass is moving, it has still more energy because of its kinetic energy. A massless substance, such as a photon, has only energy of motion and no energy of being (mass). The relation between the mass and its energy is given by Einstein's equation, to be discussed shortly. Electricity is actually another form of energy (others refer to it as a secondary source of energy). It serves as a useful carrier of energy since it is readily and safely transported at high efficiencies.

Power is defined as the time rate of doing work, or

$$\text{Power, } P = \frac{Work}{Time} \tag{1.1}$$

The most common unit for power is horsepower (hp), defined as work being done at the rate of 550 ft·lb$_f$/s. Most continuously operating equipment, such as electrical motors or internal combustion engines, are rated in terms of horsepower and the "efficiency" of energy conversion of such units is defined as

$$Efficiency = \frac{Power\ \ output}{Power\ \ input} \tag{1.2}$$

For most engineering work, the following approximate conversion factors are used:

$$1\ (\text{Btu}) = 1055\ (\text{J}) = 252\ (\text{cal}) = 778\ (\text{ft}\cdot\text{lb}_f)$$

Another useful conversion factor is given by

$$1(\text{cal})/(\text{g}) = 1.8\ (\text{Btu})/(\text{lb})$$

Extensive sets of conversion factors are available on the Internet as well as in several references in this chapter. These terms will be used throughout this section and the remaining sections of this book.

Conservation Law for Energy

The concept of energy developed slowly over a period of several hundred years and culminated in the establishment of the general principle of conservation of energy around 1850 [1–3]. This energy principle, as it applies to mechanics, was presented earlier in the work of Galileo (1564–1642) and Isaac Newton (1642–1726).

James Joule's experiments cleared the way for the enunciation of the first law of thermodynamics: When a closed system goes through a cyclic process, the work done on the surroundings equals the heat absorbed from the surroundings. Mathematically, this statement, in a very broad sense, introduced the conservation law of energy.

A presentation of the conservation law for energy would be incomplete without a brief review of some introductory thermodynamic principles. *Thermodynamics* is defined as that science that deals with the relationships among the various forms of energy. As noted earlier, a system may possess energy due to certain qualities, including:

1. Temperature
2. Velocity
3. Position
4. Molecular structure
5. Surface properties

The energies corresponding to the five states listed are

1. Internal
2. Kinetic

3. Potential
4. Chemical
5. Surface

Empirical observations, during these early times, led to the conclusion that although energy can be transformed, it cannot be created or destroyed. This concept, known as the first law of thermodynamics, constitutes one of the basic principles of classical mechanics. This principle, along with the parallel principle of conservation of mass, holds true only for phenomena involving velocities that are small compared to the velocity of light. At higher velocities (close to that of light), as in nuclear reactions, energy and mass are interconvertible. Thus, the two concepts—the conservation of energy and of mass—are interedepent.

The first law of thermodynamics specifies that energy is conserved. Thus, the change in energy of a system is exactly equal to the opposite change in the energy of its surroundings. For a system of constant mass (a closed system), a system and its surroundings may only interchange energy by the aforementioned heat and work, where heat and work were defined as energy in transit. They are not properties and cannot be stored in a system. Two common forms of work are expansion and electrical. As also noted, heat is energy in transit because of a temperature difference; this heat transfer may take place by conduction, convection, or radiation [4].

The energy balance makes use of the conservation law to account for all the energy in a chemical process, or in any other process for that matter. After a system is defined, the energy balance considers the energy entering the system across the boundary, the energy leaving the system across the boundary, and the accumulation of energy within the system. This may be written in a simplified equation form as:

$$\text{Energy in} - \text{energy out} = \text{energy accumulated} \tag{1.3}$$

This expression has the same form as the general law of conservation of mass as well as the conservation law for momentum. It may also be written on a time rate basis. This law, in steady-state equation form for batch and flow processes, is presented here.

For batch processes:

$$\Delta E = Q + W \tag{1.4}$$

For flow processes:

$$\Delta H = Q + W_s \tag{1.5}$$

where potential, kinetic, and other energy effects have been neglected and

Q = the energy in the form of heat transferred across the boundaries of the system
W = the energy in the form of work transferred across the boundaries of the system
W_s = the energy in the form of mechanical work transferred across the boundaries of the system
E = the internal energy of the system
H = the enthalpy of the system, as defined in Equation (1.6) (see next section)
ΔE, ΔH = the change in the internal energy and enthalpy, respectively, during the process.

The changes in internal energy and enthalpy as defined in Equations (1.4) and (1.5), respectively, may be on a *mass* basis (i.e., for 1 kg or 1 lb of material), on a *mole* basis (i.e., for 1 gmol or 1 lbmol of material), or represent the total internal energy and enthalpy of the entire system. It makes no difference as long as these equations are dimensionally consistent.

Enthalpy

One of the more important thermodynamic functions engineers work with is the aforementioned enthalpy. The enthalpy is defined by

$$H = E + PV \tag{1.6}$$

where
P = the pressure of the system
V = the volume of the system

The terms E and H are *state* or *point* functions. By fixing a certain number of variables on which the function depends, the numerical value of the function is automatically fixed (i.e., it is single valued). For example, fixing the temperature and pressure of a one-component, single-phase system immediately specifies the enthalpy and internal energy.

The change in enthalpy as it undergoes a change in state from T_1, P_1 (initial) to T_2, P_2 (final) is given by:

$$\Delta H = H_2 - H_1 = C_p(T_2 - T_1) \tag{1.7}$$

where
C_p = the heat capacity of the substance; Btu/lb·°F, cal/g·°C

Note that H and ΔH are independent of the path. This is a characteristic of all state or point functions (i.e., the state of the system is independent of the path by which the state is reached). The terms Q, W, and W_s in Equations (1.4) and (1.5) are "path" functions; their values depend on the path used between the two states. Unless a process or change of state is occurring, path functions have no value.

There are many different types of enthalpy effects; these include:

Sensible (temperature)

Latent (phase)

Dilution (with water)—for example, HCl with H_2O

Solution (nonaqueous)—for example, HCl with a solvent other than H_2O

Reaction (chemical)

To summarize, a *sensible* enthalpy change is associated with temperature changes. The *latent* enthalpy change finds application in thermodynamic calculations for determining the heat (enthalpy) of condensation or vaporization, often for water. Steam tables (or the equivalent) are usually employed for this determination. The *dilution* and *solution* enthalpy effects are often significant in some industrial absorber calculations but may safely be neglected in most energy conservation calculations. The *enthalpy of reaction* is defined as the enthalpy change of a fuel/source undergoing chemical reaction; this effect normally cannot be neglected.

The equivalence of mass and energy was qualitatively addressed earlier. This relationship is only important in nuclear reactions involving the rearrangement of electrons outside the nucleus of the atom. In a nuclear reaction, it is the nucleus of the atom that undergoes rearrangement, releasing a significant quantity of energy; this process occurs with a miniscule loss of mass. The classic Einstein equation relates energy to mass, as provided in Equation (1.8).

$$\Delta E = (\Delta m)c^2 \tag{1.8}$$

where

Δm = decrease in mass

c = velocity of light

Two simple examples involving the conservation law for energy are Niagara Falls and a pendulum. At Niagara Falls, the potential energy of the water at an elevated height is converted to kinetic energy as it falls to a lower height. The action of a swinging pendulum provides a second example. Here, both the height and velocity vary due to the swinging action of the pendulum. The velocity is zero at its maximum height where the direction of motion changes. At its lowest point, the velocity has its maximum value.

Although both the height and velocity are changing during the swinging action, the combination of both energy quantities does not change with time, but instead maintains a constant value (i.e., kinetic energy is transferred into potential energy and then potential energy is transferred into kinetic energy). Thus, the sum of both contributions is a conserved quantity.

Heat Transfer

As noted earlier, the most important thermodynamic term practicing engineers and scientists work with is enthalpy. The subject of heat transfer and heat exchangers plays an important role in many energy conservation studies. Most energy conservation measures in industry involving energy recovery in the form of heat utilize any one of a variety of heat exchangers [4]. This issue is discussed next in terms of heat transfer.

A review of the literature suggests that the concept of heat transfer was first introduced by the English scientist Sir Isaac Newton in his 1701 paper entitled "Scala Graduum Caloris" [5]. The specific ideas of heat convection and Newton's law of cooling were developed from that paper.

Before the development of kinetic theory in the middle of the nineteenth century, the transfer of heat was explained by the *caloric* theory. This theory was introduced by the French chemist Antoine Lavoisier (1743–1794) in 1789. In his paper, Lavoisier proposed that caloric was a tasteless, odorless, massless, and colorless substance that could be transferred from one body to another and that the transfer of caloric to a body increased its temperature, and the loss of calorics correspondingly decreased its temperature. Lavoisier also stated that if a body cannot absorb/accept any additional caloric, then it should be considered saturated and, hence, the idea of a saturated liquid and vapor was developed [6].

Lavoisier's caloric theory was never fully accepted because the theory essentially stated that heat could not be created or destroyed, even though it was well known that heat could be generated by the simple act of rubbing hands together. In 1798, an American physicist, Benjamin Thompson, reported in his paper that heat was generated by friction, a form of motion, and not by caloric flow. Although his idea was also not readily accepted, it did help establish the law of conservation of energy in the nineteenth century [7].

In 1843, the caloric theory was proven wrong by the English physicist James P. Joule. His experiments provided the relationship between mechanical work and the nature of heat, and led to the development of the first law of thermodynamics (i.e., the conservation of energy) [8].

The development of kinetic theory in the nineteenth century put to rest all other theories. Kinetic theory states that energy or heat is created by the random motion of atoms and molecules. The introduction of kinetic theory helped to develop the concept of the conduction of heat [9].

The earlier developments in heat transfer helped set the stage for the French mathematician and physicist Joseph Fourier (1768–1830) to reconcile Newton's law of cooling, which in turn led to the development of Fourier's law of conduction. Newton's law of cooling suggested that there was a relationship between the temperature difference and the amount of heat transferred. Fourier took Newton's law of cooling and arrived at a convection heat equation [10]. Fourier also developed the concepts of heat flux and temperature gradient. Using the same process that he used to develop the equation of heat convection, Fourier subsequently developed the classic equation for heat conduction that has come to be known as Fourier's law [11].

Heat transfer, as an engineering practice, grew out of thermodynamics at around the turn of the twentieth century. This arose because of the need to deal with the design of heat transfer equipment required by emerging and growing industries. Early applications included steam generators for locomotives and ships, and condensers for power generation plants. Later, the rapidly developing petroleum and petrochemical industries began to require rugged, large-scale heat exchangers for a variety of processes. Between 1920 and 1950, the basic forms of many heat exchangers used today were developed and refined, as documented by Kern [12]. These heat exchangers still remain the choice for most process applications.

Starting in the late 1950s, at least three unrelated developments rapidly changed the heat exchanger industry:

1. With respect to heat exchanger design and sizing, the general availability of computers permitted the use of complex calculation procedures that were not possible before.
2. The development of nuclear energy introduced the need for precise design methods, especially in heat transfer calculations.
3. The energy crisis of the 1970s significantly increased the cost of energy, triggering a demand for more efficient heat utilization [13].

As a result, heat-transfer technology suddenly became a prime recipient of large research funds, especially during the 1960s and 1980s. This elevated the knowledge of heat exchanger design principles to where it is today [14].

The application of heat transfer thermodynamic principles receives treatment in the next chapter. In particular, it addresses energy conservation measures utilizing heat exchangers [4].

Net Energy Analysis [15]

How much energy does it take to produce useable energy or materials? The term *energy analysis* represents a broad field of study dealing with the development and use of all aspects of energy in human society and the environment. *Net energy analysis,* a more limited field of study, deals with the analysis of the energy made available to society by energy production processes *after* accounting for energy lost to society/environment as a result of the processes. This subject can also include the energy analysis of materials production (i.e., how much energy must be invested in the total system needed for the production of a unit of material). Net energy analysis is a topic that will be addressed several times in this book.

Net energy analysis differs significantly from traditional engineering efficiency studies. First, net energy analysis is concerned with the total system of production, starting with resources in the ground. Second, it is concerned with the total quantity of energy throughout society that must be input into construction and operation of an energy or material production system up to the point where the produced energy is actually utilized.

The objectives of a net energy analysis are the following:

1. Provide reliable, objective, credible information to government and industry on the net energy inputs and outputs of energy systems.
2. Provide a workable methodology that could be used in subsequent expanded net energy studies.
3. Provide the best possible documentation of data related to net energy.
4. Discuss and describe the usefulness and limitation of net energy studies and their potential values in decision making.
5. Discuss philosophy and issues pertaining to net energy studies.

Three major concerns or issues to which the general title of net energy analysis might apply include the following:

1. How much energy is required from the industrial component of society to *drive* or establish and operate an energy production process, relative to the energy yield of the process?
2. In extracting, processing, and moving a resource (if applicable) to provide energy to end users, what final yields are obtained relative to losses of the total energy of the recovered (fuel) resources and of the industrial energy needed to establish and operate the energy production systems?
3. For a given output of energy for end use, what total amounts of the gross (fuel) resources and industrial energies are necessary to establish and operate the system?

The issues of the finiteness of (fuel) resources and the rate of depletion are also of concern to society.

Energy must be expended when a material is extracted from its source, is processed, or is transported. As a material moves *downstream* through a series of processing steps, it represents (or has necessitated) an accumulation of energy expenditures. This energy embodied in the material as a result of processing is called *sequestered* energy. A petroleum-derived chemical usually has such an energy value. Thus, the energy requirements of finished products include fuel values in some cases, and expended processing energy in all cases, to represent the total sequestered energy.

Net energy analysis should not be used as the primary decision factor. Other factors may generally carry more weight; they include the following:

1. Economics
2. Environment
3. National security
4. Energy mix
5. Lead times
6. Transportation capacities
7. Institutional restraints, such as governmental regulations and incentives
8. Availability of needed materials
9. Local attitudes
10. Socioeconomic impacts
11. Employment needs
12. Needs for energy
13. Safety concerns

Net energy analysis is not a panacea for energy planning, but is worth utilizing as a framework for energy analyses in examining a variety of issues. This is addressed in more detail in the last chapter of Section I.

Developing a National Energy Policy

The facts on present-day energy consumption are universally accepted. Even the projections for raw material reserves of oil, coal, gas, and uranium cause little argument. But, consensus on all other aspects of energy policy is nonexistent. In the broadest sense, many cannot agree whether there is presently a crisis or a problem. In any event, a number of measures must be taken to assure that where energy problems exist, they will not worsen. To better appraise the magnitude of these measures, one must set short-term and long-term goals, both of which are discussed next [16].

Short Term

Because of the long lead times required to improve a nation's energy position substantially, the only answer to the present energy shortage is to allow the continued importation of crude oil, distillate, and residuals. Because of the serious strain that such imports are placing on the balance of payments, it is critical that conservation steps be initiated.

Long Term

In the United States, a comprehensive coordinated national energy policy *must* be formulated. This policy should be subject to continuing review and adjustment to address such needs as depleting resources, new technological breakthroughs, conservation measures, etc. In short, the policy should cover the following (baker's dozen) categories:

1. Set up a comprehensive cabinet-level agency dealing with all forms of energy.
2. Systematize and refine air and water pollution guidelines and establish land utilization policies to ease the siting of refineries, power plants, and petrochemical operations.
3. Stimulate increases in domestic oil and gas production by deregulating gas prices or regulating them with realistic price guidelines.
4. Stimulate increases in domestic oil and gas production by increasing the size of offshore leases as well as the frequency of lease sales.
5. Change Internal Revenue guidelines to favor exploration in the United States rather than favoring international exploration, and production abroad by allowing royalties paid to foreign governments to be written off against federal tax owed the U.S. government.
6. Foster research on improved coal mining and new reclamation techniques.
7. Sponsor, fund, and encourage coal gasification projects to a degree that would lead to possible commercialization of the process within this and the next decade.
8. Foster additional research on alternative energy sources (solar, nuclear, tidal, wind, biofuel, and geothermal energy).
9. Provide regulations and/or incentives to allow the use of coal as a petroleum substitute in certain industrial operations.
10. Accelerate and systematize the environmental review process of proposed energy projects.
11. Coordinate all energy research to take advantage of breakthrough technologies with the end goal being energy independence.

12. Foster additional research on the environmental problems involved in the production of nuclear energy.
13. Analyze and implement energy conservation measures whenever such a need arises.

Similar options can be considered in other developed or developing nations.

In a very real sense, one of the objectives of the above list is to develop and propose an energy policy. This introductory chapter is the beginning of that attempt. The goal is that it will culminate with presentation of that policy in the last chapter.

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2

Thermodynamic Principles: Entropy Analysis

Introduction

Energy conservation can be achieved by a variety of means, but the recovery of useful energy in the form of heat ranks high on the list. Heat is most efficiently recovered via the use of heat exchangers. However, heat recovery in a cost-effective manner has not been addressed by many practicing engineers. This chapter details various aspects of this specific energy conservation/recovery process.

The law of conservation of energy is defined by many as the first law of thermodynamics. Its application allows calculations of energy relationships associated with various processes. The second law of thermodynamics is referred to as the *limiting law.* Historically, the basis of the second law was developed by individuals such as Carnot, Clausius, and Kelvin in the middle of the nineteenth century. This development was made purely on a macroscopic scale and is referred to as the "classical approach" to the second law.

The terms *energy conservation* and *energy efficiency* have come to mean different things to different people. In particular, definitions are many and varied when applied to measuring heat. This mainly happens because of the many approaches to describing, defining, and measuring the energy efficiency of energy-related processes. This chapter attempts to provide the reader with information on what it really means to conserve energy. This includes a new term—*entropy*—that is employed in many thermodynamic second-law applications.

Environmental concerns involving conservation of energy issues gained increasing prominence during and immediately after the OPEC oil embargo of 1973. In addition, global population growth led to an increasing demand for energy. Although the use of energy has resulted in great benefits, the environmental and human health impacts of this energy use have become a concern. One of the keys to reducing and/or eliminating this problem will be achieved through what has come to be referred to as *meaningful* energy conservation.

The aforementioned first law of thermodynamics is a conservation law concerned with energy transformations. Regardless of the types of energy involved in processes—thermal, mechanical, electrical, elastic, magnetic, etc.—the change in the energy of a system is equal to the difference between energy input and energy output. The first law also allows free convertibility from one form of energy to another, as long as the overall quantity is conserved. Thus, this law places no restriction on the conversion of work into heat or on its counterpart—the conversion of heat into work. However, the second law of thermodynamics is another matter.

The material to follow introduces the reader to the second law and the accompanying definition of entropy; heat exchanger applications complement the presentation.

Qualitative Review of the Second Law

The preceding brief discussion of energy conversion leads to an important second-law consideration—energy has *quality* as well as quantity. Because work is 100 percent convertible to heat, but the reverse situation is not true, work is a more valuable form of energy than heat. Although it is not as obvious, it can also be shown through second-law arguments that heat also has quality in terms of the temperature at which it is discharged from a system. The higher the temperature, the greater is the potential for the transformation of energy into work. Thus, thermal energy stored at high temperatures is generally more useful to society than that available at lower temperatures. While there is an immense quantity of energy stored in the oceans, for example, its present availability to society for performing useful tasks is quite low. This implies, as noted earlier, that thermal energy loses some of its quality, or is degraded, when it is transferred by means of heat transfer from one temperature to a lower one. Other forms of energy degradation include energy transformations due to frictional effects and electrical resistance. Such effects are highly undesirable if the use of energy for practical purposes is to be maximized [1–3].

The second law provides some means of measuring this energy degradation through a thermodynamic term referred to as *entropy,* and it is the second law (of thermodynamics) that serves to define this important property. Entropy is normally designated as S with units of energy per absolute temperature (e.g., Btu/°R or cal/K). Furthermore, entropy calculations can provide quantitative information on the "quality" of energy and energy degradation [2,3].

In line with the above discussion regarding the quality of energy, individuals at home and in the workplace are often instructed to "conserve energy." However, this comment, if taken literally, is a misnomer because energy is automatically conserved by the provisions of the first law. In reality, the comment "conserve energy" addresses only the concern associated with the quality of energy. If the light in a room is not turned off, energy is degraded, although energy is still conserved; that is, the electrical energy is converted to internal energy (which heats up the room). Note, however, that this energy transformation will produce a token rise in temperature of the room from which little, if any, quality energy can be recovered and used again (for lighting or other useful purposes) [1].

There are a number of other phenomena that cannot be explained by the law of conservation of energy. It is the second law of thermodynamics that provides an understanding and analysis of these diverse effects. However, among these considerations, it is the second law that can allow the measuring of the aforementioned quality of the energy, including its effect on the design and performance of heat exchangers.

Describing Equations

Key equations pertinent to entropy calculations and energy recovery/conservation via heat exchanger design receive treatment in this section.

If ΔS_{syst} and ΔS_{surr} represent the entropy change of a system and surroundings, respectively, it can be shown [1–3] that, for a particular process (and as a consequence of the second law), the total entropy change ΔS_{tot} is given by:

$$\Delta S_{tot} = \Delta S_{syst} + \Delta S_{surr} \geq 0 \tag{2.1}$$

In effect, the second law requires that for any real processes, the total entropy change is positive; the only exception is if the process is reversible (the driving force for heat transfer is at all times zero) and then

$$(\Delta S_{tot})_{rev} = 0 \tag{2.2}$$

Thus, no real process can occur for which the total entropy change is zero or negative. The fundamental facts relative to the entropy concept are that the entropy change of a system may be positive (+), negative (–), or zero; the entropy change of the surroundings during this process may likewise be positive, negative, or zero.

To reexamine the concept of "quality" energy, consider the insulated space pictured in Figure 2.1(a, b). Space (a) contains air and steam that are separated; space (b) contains the resulting mixture when both components are mixed. Both spaces are insulated ($Q = 0$) in this closed system with no work term ($W = 0$), so that one can conclude from the first law ($Q + W = \Delta U$) that