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and
Renewable Energy**

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Edited by

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“With the exception of preventing war, this (the energy crisis) is the greatest challenge our country will face during our lifetime.”

—*President Jimmy Carter, April 18, 1977*

Preface

Purpose

The goal of this handbook is to provide information necessary for engineers, energy professionals, and policy makers to plan a secure energy future. The time horizon of the handbook is limited to approximately 25 years because environmental conditions vary, new technologies emerge, and priorities of society continuously change. It is therefore not possible to make reliable projections beyond that period. Given this time horizon, the book deals only with technologies that are currently available or are expected to be ready for implementation in the near future.

Overview

Energy is a mainstay of an industrial society. As the population of the world increases and people strive for a higher standard of living, the amount of energy necessary to sustain our society is ever increasing. At the same time, the availability of nonrenewable sources, particularly liquid fuels, is rapidly shrinking. Therefore, there is general agreement that to avoid an energy crisis, the amount of energy needed to sustain society will have to be contained and, to the extent possible, renewable sources will have to be used. As a consequence, conservation and renewable energy technologies are going to increase in importance and reliable, up-to-date information about their availability, efficiency, and cost is necessary for planning a secure energy future.

The timing of this handbook also coincides with a new impetus for the use of renewable energy. This impetus comes from the emergence of renewable portfolio standards [RPS] in many states of the U.S. and renewable energy policies in Europe, Japan, Israel, China, Brazil, and India. An RPS requires that a certain percentage of energy used be derived from renewable resources. RPSs and other incentives for renewable energy are currently in place in 20 of the 50 states of the U.S. and more states are expected to soon follow. The details of the RPS for renewable energy and conservation instituted by state governments vary, but all of them essentially offer an opportunity for industry to compete for the new markets. Thus, to be successful, renewable technologies will have to become more efficient and cost-effective. Although RPSs are a relatively new development, it has already been demonstrated that they can reduce market barriers and stimulate the development of renewable energy. Use of conservation and renewable energy can help meet critical national goals for fuel diversity, price stability, economic development, environmental protection, and energy security, and thereby play a vital role in national energy policy.

The expected growth rate of renewable energy from portfolio standards and other stimulants in the U.S. is impressive. If current policies continue to be implemented, by the year 2017 almost 26,000 megawatts of new renewable energy will be in place in the U.S. alone. In 2005, photovoltaic production in the world has already topped 1000 MW per year and is increasing at a rate of over 30%. In Germany, the electricity feed-in laws that value electricity produced from renewable energy resources much higher than that from conventional resources, have created demand for photovoltaic and wind power. As a result, over the last three years the photovoltaic power has grown at a rate of more than 51% per year and wind power has grown at a rate of more than 37% in Germany. Recently, a number of other European countries have

adopted feed-in laws similar to Germany. In fact, growth of both photovoltaic and wind power has averaged in the range of 35% in European countries. Similar policy initiatives in Japan indicate that renewable energy technologies will play an increasingly important role in fulfilling future energy needs.

Organization and Layout

The book is essentially divided into three parts:

- General overviews and economics
- Energy conservation
- Energy generation technologies

The first chapter is a survey of current and future worldwide energy issues. The current status of energy policies and stimulants for conservation and renewable energy is treated in [Chapter 2](#) for the U.S. as well as several other countries. Economic assessment methods for conservation and generation technologies are covered in [Chapter 3](#), and the environmental costs of various energy generation technologies are discussed in [Chapter 4](#). Use of renewables and conservation will initiate a paradigm shift towards distributed generation and demand-side management procedures that are covered in [Chapter 5](#).

Although renewables, once in place, produce energy from natural resources and cause very little environmental damage, energy is required in their initial construction. One measure of the energy effectiveness of a renewable technology is the length of time required, after the system begins operation, to repay the energy used in its construction, called the energy payback period. Another measure is the energy return on energy investment ratio. The larger the amount of energy a renewable technology delivers during its lifetime compared to the amount of energy necessary for its construction, the more favorable its economic return on the investment will be and the less its adverse environmental impact. But during the transition to renewable sources a robust energy production and transmission system from fossil and nuclear technologies is required to build the systems. Moreover, because there is a limit to how much of our total energy needs can be met economically in the near future, renewables will have to coexist with fossil and nuclear fuels for some time. Furthermore, the supply of all fossil and nuclear fuel sources is finite and their efficient use in meeting our energy needs should be a part of an energy and CO₂ reduction strategy. Therefore, [Chapter 6](#) gives a perspective on the efficiencies, economics, and environmental costs of the key fossil and nuclear technologies. Finally, [Chapter 7](#) provides projections for energy supply, demand, and prices of energy through the year 2025.

The U.S. transportation system relies 97% on oil and more than 60% of it is imported. Petroleum engineers predict that worldwide oil production will reach its peak within the next 10 years and then begin to decline. At the same time, demand for liquid fuel by an ever-increasing number of vehicles, particularly in China and India, is expected to increase significantly. As a result, gasoline prices will increase precipitously unless we reduce gasoline consumption by increasing the mileage of the vehicle fleet, reducing the number of vehicles on the road by using mass transport, and producing synthetic fuels from biomass and coal. The options to prevent an energy crisis in transportation include: plug-in hybrid vehicles, biofuels, diesel engines, city planning, and mass-transport systems. These are treated in [Chapter 8](#); biofuels and fuel cells are treated in [Chapter 24](#) and [Chapter 27](#), respectively.

It is an unfortunate fact of life that the security of the energy supply and transmission system has recently been placed in jeopardy from various sources, including natural disasters and worldwide terrorism. Consequently, energy infrastructure security and risk analysis are an important aspect of planning future energy transmission and storage systems, and these topics are covered in [Chapter 9](#).

Energy efficiency is defined as the ratio of energy required to perform a specific task or service to the amount of energy used for the process. Improving energy efficiency increases the productivity of basic energy resources by providing the needs of society with less energy. Improving the efficiency across all sectors of the economy is therefore an important objective. The least expensive and most efficient means in this endeavor is energy conservation, rather than more energy production. Moreover, energy conservation is also the best way to protect the environment and reduce global warming.

Recognizing that energy conservation in its various forms is the cornerstone of a successful national energy strategy, eight chapters (10 through 17) are devoted to conservation. The topics covered include energy management strategies for industry and buildings, HVAC controls, cogeneration, and advances in specific technologies, such as motors, lighting, appliances, and heat pumps.

In addition to the energy conservation topics covered in this handbook, there is another area for reducing energy consumption: waste management. As materials are mined, manufactured, and used to produce consumer goods, energy is required and wastes are generated. The utilization of the raw materials and the disposal of waste is a complicated process that offers opportunities for energy conservation. The U.S. Environmental Protection Agency (EPA) has identified four basic waste management options: (1) source reduction, (2) recycling and composting, (3) combustion (waste to energy incineration) and (4) landfilling. These four options are interactive—not hierarchical—because measures taken in one sector can influence another. For example, removing metals in the recycling step will increase the efficiency of combustion and facilitate landfilling.

In the course of waste management, many opportunities exist for conservation and reduction in energy consumption. The most obvious one is source reduction. Energy is saved if consumers buy less or use products more efficiently. Recycling and composting will also reduce energy requirements and preserve natural resources. From our perspective, however, combustion of waste and extraction of energy from the municipal waste stream are technologies that generate energy without requiring new primary sources and therefore fall within the purview of this handbook. The reader interested in energy-efficient integrated waste management of municipal wastes is referred to an extensive treatment in *The Handbook of Solid Waste Management*, 2nd ed., edited by G. Tchobanoglous and F. Kreith (2002), and for management of industrial solid wastes to *The Handbook of Industrial and Hazardous Waste Treatment*, 2nd ed., edited by L. K. Wang et al. (2004).

The third part of the book deals with energy storage and energy generation from renewable sources. One of the most challenging tasks, especially for renewable energy systems that cannot operate continuously, is energy storage. The main reason why fossil fuels, such as petroleum and coal, are such convenient energy sources is probably their easy storage. But there are new and relatively undeveloped storage technologies available that are discussed and evaluated in Chapter 18, which also includes the design of a robust and intelligent electric energy transmission system. Chapter 19 presents the availability of renewable sources: solar, wind, municipal waste, and biomass. The renewable generation technologies for solar thermal, wind power, photovoltaics, biomass, and geothermal are then covered in Chapters 20 through 25.

At this time, it is not clear whether hydrogen will play a major role in the national energy structure within the next 25 years, but there is ongoing discussion about the feasibility and cost of what is called “the hydrogen economy.” Energy experts recognize that the generation and use of hydrogen have a critical inefficiency problem that is rooted in basic thermodynamics. This inefficiency renders hydrogen impractical and uneconomical as an energy carrier compared to electricity. There are also ground transportation options that are less expensive than using hydrogen vehicles powered by fuel cells. But there is substantial support for continuing research to eventually develop a viable place for hydrogen in a future energy structure. Therefore, the topics of hydrogen energy and fuel cells are included in Chapters 26 and 27, respectively. This information should be useful background for comparing competing options for energy generation, storage, and distribution.

We hope that this handbook will serve as a useful reference to all engineers in the energy field and pave the way for a paradigm shift from fossil fuels to a sustainable energy systems based on conservation and renewable technologies. But we also recognize the complexity of this task, and we invite readers to comment on the scope and the topics covered. A handbook such as this needs to be updated every 5 to 10 years and we will respond to readers’ comments and suggestions in the next edition.

Frank Kreith
D. Yogi Goswami
Editors-in-Chief

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