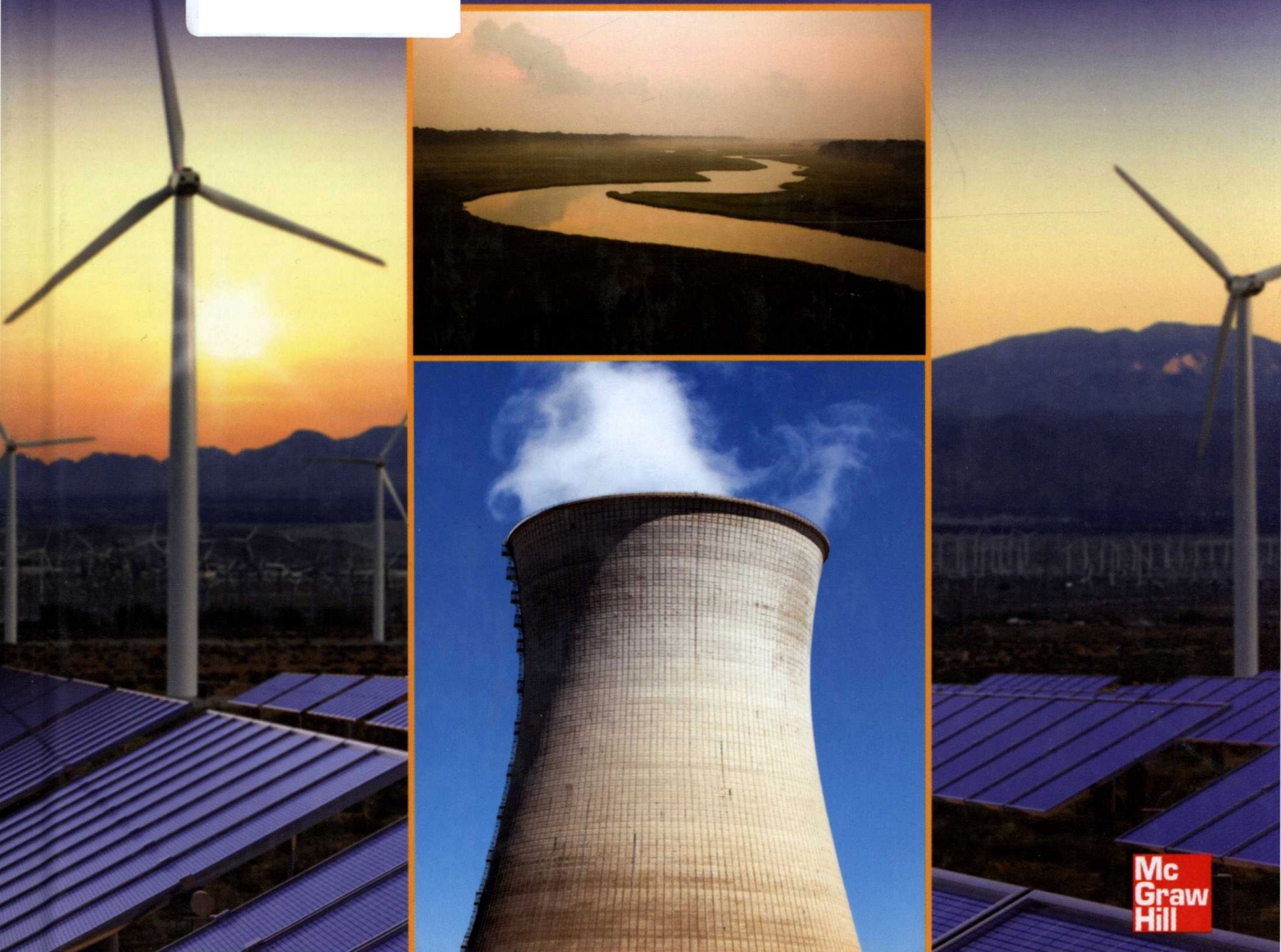


SECOND EDITION

Energy Systems ENGINEERING

Evaluation and Implementation



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Hill

FRANCIS M. VANEK | LOUIS D. ALBRIGHT | LARGUS T. ANGENENT

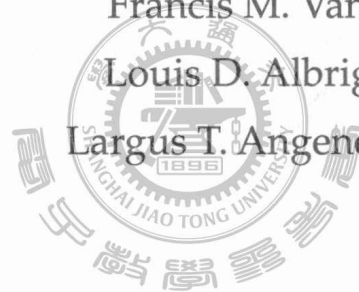
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Louis D. Albright

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To my wife, Catherine Johnson, to my parents,
Jaroslav and Wilda Vanek, and to my children,
Raymond and Mira Vanek-Johnson

—Francis M. Vanek

To my wife and partner in life, Marilyn Albright

—Louis D. Albright

To my wife and son, Ruth Ley and Miles Ley Angenent

—Largus T. Angenent

Preface

The goal of this book is to provide both professional engineers and engineering students interested in energy systems with essential knowledge of major energy technologies, including how they work, how they are quantitatively evaluated, what they cost, and what is their benefit or impact on the natural environment. A second goal is to provide the reader with an overview of the context within which these systems are being implemented and updated today and into the future. Perhaps at no time in recent history has society faced such challenges in the energy field: the yearning to provide a better quality of life to all people, especially those in the more impoverished countries, coupled with the twin challenges of a changing energy resource base and the effects of climate change due to increased concentration of CO_2 in the atmosphere. Energy systems engineers from many disciplines, as well as nonengineers in related fields, will serve at the forefront of meeting these challenges.

As we updated the book from the first edition (edited in 2007 and published in 2008) into the second, the routine process of updating figures on CO_2 emissions and on the installation of renewable energy capacity highlighted both the challenge and the opportunity for the energy field around the world. Figure 4-3 in Chap. 4 gives world emissions of carbon from fossil fuel use, which in 2004 stood at 7.6 gigatonnes of carbon equivalent. Figure 4-3 in the current version of the book gives emissions for 2008 (the most recent year available from the U.S. Carbon Dioxide Information and Analysis Center) at 8.8 gigatonnes—an increase of 1.2 gigatonnes in the annual emissions rate in just four years. Not only does this increase represent the growing challenge of meeting energy needs without increasing atmospheric CO_2 , but the increased emissions also symbolize newly added energy consuming devices, ranging from large power plants to small individual private vehicles, for which populations will expect continued access to energy supplies in the years going forward. On a more positive note, we have documented the many-fold increase in the installed capacity of solar and wind photovoltaic capacity around the world in Chaps. 10 and 13—637% for solar and 231% for wind from 2005 to 2010, measured in total installed gigawatts—suggesting that individuals, businesses, and governments are beginning to embrace this challenge.

Turning from motivation to content, chapter topics are chosen in the first part of the book to provide key background for the analysis of energy systems, and in the second part to give a representative view of the energy field across a broad spectrum of possible approaches to meeting energy needs. In Chaps. 1 to 3, we present tools for understanding energy systems, including a discussion of sustainable development, a systems approach to energy, and economic tools for evaluating energy systems as investments. In

Chaps. 4 and 5, we consider climate change and fossil fuel availability, two key factors that will shape the direction of energy systems in the twenty-first century. Chapters 6 through 14 present a range of technologies for generating energy for stationary applications, including fossil fuel combustion, carbon sequestration, nuclear energy, solar energy, wind energy, and biological energy (the last of these being newly added in the second edition). Chapters 15 and 16 turn to energy conversion for use in transportation systems, and Chap. 17 provides a brief overview of some emerging technologies not previously covered, as well as the conclusions for the book.

The contents of the book assume a standard undergraduate engineering background, or equivalent, in physics, chemistry, mathematics, and thermodynamics, as well as a basic introduction to statistics, fluid mechanics, and heat transfer. Each technology area is introduced from first principles, and no previous knowledge of the specific technologies is assumed.

This book originated in two courses taught at Cornell University, one in the School of Mechanical and Aerospace Engineering entitled "Future Energy Systems," and the other in the Department of Biological and Environmental Engineering entitled "Renewable Energy Systems." In addition, a third course, "Civil Infrastructure Systems" taught in the School of Civil & Environmental Engineering, influenced the writing of passages on sustainable development and systems engineering. Energy system concepts, example problems, and end-of-chapter exercises have been developed through introduction in the classroom. In both courses, we have focused on solar and wind energy systems, so we have also placed a special emphasis on these two fields in this book. Interest in solar and wind energy is growing rapidly at the present time, but information about these fields may not be as accessible to some engineers, so we aim to provide a useful service by giving them extensive treatment in Chaps. 9 through 13.

Presentation of technical content in the book adheres to several premises for energy systems engineering that are independent of the technologies themselves. The first is that *energy systems choices should be technology-neutral*. No energy system is perfect, and every system has a range of advantages and disadvantages. Therefore, to the extent possible, the choice of any system should be based on choosing criteria first and then finding a system, or mixture of systems, that best meets those criteria, rather than preordaining that one type of system or another be chosen.

A second premise is that *there is value to a portfolio approach to energy options*. All the energy pathways described in this book are, to varying degrees, subject to uncertainty over both the short and long term, in terms of cost, availability, and reliability. There is therefore value in developing diversity in energy options so that in the future we are not vulnerable to the disadvantages of any one technology. Also, given the global demand for energy that is anticipated in the twenty-first century, having multiple sources of energy will allow us to add capacity more quickly when it is needed while still striving to meet our environmental obligations to present and future generations.

A third premise is that *where long-term technologies will take time to develop fully, there is value to developing "bridge" technologies for the short- to medium term*. Some of the technologies presented in this book eliminate harmful emissions or use only renewable resources, but are not yet reliable or cost-competitive enough to enter the market in a large-scale way. In this situation, there is value to bridge technologies that are cost-effective now and also reduce nonrenewable resource consumption or CO₂ emissions, even if they do not eliminate them entirely. Typically, these technologies consume fossil

fuels but are more efficient or have higher utilization, so that they deliver more energy service per unit of resource consumed or CO₂ emitted.

Although the book is written by American authors in the context of the U.S. energy system, we maintain an international focus. This is important because of the increasingly global nature of the energy industry, in terms of both the resource base and also the transfer of technology between countries. We hope that non-U.S. readers of the book will find the material accessible, and that U.S. readers can apply the content to energy projects in other countries, and also to understanding the energy situation around the world. For simplicity, all costs are given in dollars; however, other world currencies can of course be substituted into equations dealing with financial management.

Both a systems approach and an engineering economics approach to designing and costing projects are emphasized. The use of good systems engineering techniques, such as the systematic consideration of the project scope, evaluation of tradeoffs between competing criteria, and consideration of project life-cycle cost and energy consumption, can deliver more successful projects. Consideration of cost and revenues from a project, as well as technical efficiency, helps us to better understand the profitability of a project.

For the purposes of cost analysis, approximate prices for the cost of energy resources and the purchase of energy conversion equipment have been introduced in places at their appropriate value. These values are intended to give the reader a general sense of the financial dimensions of a technology, for example, approximately what proportion of an energy technology's life-cycle cost is spent on fuel versus capital or nonfuel operating costs. Note, however, that these values should not be used as a basis for detailed decision making about the viability of a project, since up-to-date costs for specific regions are the required source. It is especially important to find up-to-date numbers for one's particular project of interest because of the volatility in both energy and raw material prices that has developed since 2004 or 2005. With rapid economic growth in the two largest countries by population in the world, namely China and India, there is burgeoning demand not only for energy commodities but also for materials such as steel or copper that are essential for fabricating energy conversion technologies. This affects not only operating costs of fossil-fuel-driven energy systems but also capital cost of both renewable and nonrenewable energy systems. As a result, the cost of virtually all energy system options has risen markedly in the past few years.

Earlier books on energy systems have placed an emphasis on equipment to prevent release of air pollutants such as scrubbers or catalytic converters. As presented in the body of the book, emerging technologies that use new energy resources and eliminate CO₂ emissions also tend to eliminate emissions of harmful air pollutants, so air quality as a separate objective is deemphasized in this book. In some cases, it appears instead as a constraint on energy systems development: where air quality problems may be aggravated by emerging technologies that are beneficial for other objectives but increase emissions of air pollutants, regulations or targets related to air quality may restrict our ability to use that technology.

In conclusion, we offer a word of "truth in advertising" about the contents of the book: it provides some answers, and also many unanswered questions. It is humbling to write a book about energy systems, just as it is to teach a course or give a presentation about them: one ends up realizing that it is a very challenging area, and that many aspects of future solutions remain hidden from us at present. We hope that in publishing this book we have helped to answer some of the questions about energy systems where possible, and, where not, posed them in such a way that the act of exploring them will

move the field forward. The extent and complexity of the challenge may seem daunting at times, yet there are and will be great opportunities for energy professionals, both now and in the future. We wish each of you success in your part of this great endeavor.

Note to Instructors

If you are an instructor of an energy systems course using this book as a textbook, please be aware that the end-of-chapter exercises included in the book are a subset of a larger collection of homework and exam problems, instructor's manual, spreadsheet solutions, PowerPoint slides, and computer scripts. Please visit www.mhprofessional.com/energysystemsengineering for information about how you can download these materials to assist your teaching.

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There were many, many people whose support made such a difference in the writing of this book. I would first like to thank my family, including my wife Catherine Johnson, my parents Jaroslav and Wilda Vanek, and my children Ray and Mira, for their patience as I spent so many hours on the book, for their encouragement, and for their curiosity about the topic, which affects both young and old alike.

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—FRANCIS M. VANEK

No book such as this should be attempted without the benefit of first teaching the material to interested and interactive students. The students over the years who questioned, contributed, and succeeded (yes, especially those in the earlier days of my renewable energy systems course when it met, for a decade, three times a week at 8 a.m.) have helped me immeasurably in understanding the material of this book and how it can be presented. Without you, my part of this book would never have been possible and life would have been much less enjoyable.

—LOUIS D. ALBRIGHT

Contents at a Glance

1	Introduction	1
2	Systems Tools for Energy Systems	29
3	Economic Tools for Energy Systems	75
4	Climate Change and Climate Modeling	101
5	Fossil Fuel Resources	133
6	Stationary Combustion Systems	157
7	Carbon Sequestration	205
8	Nuclear Energy Systems	231
9	The Solar Resource	269
10	Solar Photovoltaic Technologies	293
11	Active Solar Thermal Applications	337
12	Passive Solar Thermal Applications	371
13	Wind Energy Systems	399
14	Bioenergy Resources and Systems	449
15	Transportation Energy Technologies	477
16	Systems Perspective on Transportation Energy	523
17	Conclusion: Creating the Twenty-First Century Energy System ...	573
A	Perpetual Julian Date Calendar	599
B	LCR Table	601
C	CF Table	607
D	Numerical Answers to Select Problems	613
E	Common Conversions	615
F	Information about Thermodynamic Constants	617
	Index	619

Contents

Preface	xxi
Acknowledgments	xxv
1 Introduction	1
1-1 Overview	1
1-2 Introduction	1
1-2-1 Historic Growth in Energy Supply	2
1-3 Relationship between Energy, Population, and Wealth	4
1-3-1 Correlation between Energy Use and Wealth	6
1-3-2 Human Development Index: An Alternative Means of Evaluating Prosperity	6
1-4 Pressures Facing World due to Energy Consumption	8
1-4-1 Industrial versus Emerging Countries	9
1-4-2 Pressure on CO ₂ Emissions	14
1-4-3 Observations about Energy Use and CO ₂ Emissions Trends	15
1-4-4 Discussion: Contrasting Mainstream and Deep Ecologic Perspectives on Energy Requirements	16
1-5 Energy Issues and the Contents of This Book	18
1-5-1 Motivations, Techniques, and Applications	18
1-5-2 Initial Comparison of Three Underlying Primary Energy Sources	19
1-6 Units of Measure Used in Energy Systems	22
1-6-1 Metric (SI) Units	22
1-6-2 U.S. Standard Customary Units	24
1-6-3 Units Related to Oil Production and Consumption	25
1-7 Summary	25
References	25
Bibliography	26
Exercises	26
2 Systems Tools for Energy Systems	29
2-1 Overview	29
2-2 Introduction	29
2-2-1 Conserving Existing Energy Resources versus Shifting to Alternative Resources	30
2-2-2 The Concept of Sustainable Development	31
2-3 Fundamentals of the Systems Approach	33
2-3-1 Initial Definitions	33
2-3-2 Steps in the Application of the Systems Approach	35

2-3-3	Stories, Scenarios, and Models	40
2-3-4	Systems Approach Applied to the Scope of this Book: Energy/Climate Challenges Compared to Other Challenges	43
2-4	Other Systems Tools Applied to Energy	46
2-4-1	Systems Dynamics Models: Exponential Growth, Saturation, and Causal Loops	46
2-5	Other Tools for Energy Systems	54
2-5-1	Kaya Equation: Factors That Contribute to Overall CO ₂ Emissions	54
2-5-2	Life-Cycle Analysis and Energy Return on Investment	56
2-5-3	Multi-Criteria Analysis of Energy Systems Decisions	58
2-5-4	Choosing among Alternative Solutions Using Optimization	60
2-5-5	Understanding Contributing Factors to Time-Series Energy Trends Using Divisia Analysis	63
2-5-6	Incorporating Uncertainty into Analysis Using Probabilistic Approaches and Monte Carlo Simulation	67
2-6	Summary	71
	References	71
	Bibliography	72
	Exercises	72
3	Economic Tools for Energy Systems	75
3-1	Overview	75
3-2	Introduction	75
3-2-1	The Time Value of Money	76
3-3	Economic Analysis of Energy Projects and Systems	78
3-3-1	Definition of Terms	78
3-3-2	Evaluation without Discounting	78
3-3-3	Discounted Cash Flow Analysis	79
3-3-4	Levelized Cost of Energy	88
3-4	Direct versus External Costs and Benefits	88
3-5	Intervention in Energy Investments to Achieve Social Aims	89
3-5-1	Methods of Intervention in Energy Technology Investments	90
3-5-2	Critiques of Intervention in Energy Investments ...	92
3-6	Net Present Value (NPV) Case Study Example	93
3-7	Summary	97
	References	97
	Bibliography	98
	Exercises	98

4	Climate Change and Climate Modeling	101
4-1	Overview	101
4-2	Introduction	101
4-2-1	Relationship between the Greenhouse Effect and Greenhouse Gas Emissions	102
4-2-2	Carbon Cycle and Solar Radiation	102
4-2-3	Quantitative Imbalance in CO ₂ Flows into and out of the Atmosphere	103
4-2-4	Consensus on the Human Link to Climate Change: Taking the Next Steps	106
4-2-5	Early Indications of Change and Remaining Areas of Uncertainty	107
4-3	Modeling Climate and Climate Change	110
4-3-1	Relationship between Wavelength, Energy Flux, and Absorption	111
4-3-2	A Model of the Earth-Atmosphere System	116
4-3-3	General Circulation Models (GCMs) of Global Climate	119
4-4	Climate in the Future	122
4-4-1	Positive and Negative Feedback from Climate Change	122
4-4-2	Scenarios for Future Rates of CO ₂ Emissions, CO ₂ Stabilization Values, and Average Global Temperature	124
4-4-3	Recent Efforts to Counteract Climate Change: The Kyoto Protocol (1997–2012)	127
4-4-4	Assessing the Effectiveness of the Kyoto Protocol and Description of Post-Kyoto Efforts	128
4-5	Summary	130
	References	130
	Bibliography	130
	Exercises	131
5	Fossil Fuel Resources	133
5-1	Overview	133
5-2	Introduction	133
5-2-1	Characteristics of Fossil Fuels	134
5-2-2	Current Rates of Consumption and Total Resource Availability	137
5-2-3	CO ₂ Emissions Comparison and a “Decarbonization” Strategy	140
5-3	Decline of Conventional Fossil Fuels and a Possible Transition to Nonconventional Alternatives	141
5-3-1	Hubbert Curve Applied to Resource Lifetime	141
5-3-2	Potential Role for Nonconventional Fossil Resources as Substitutes for Oil and Gas	148