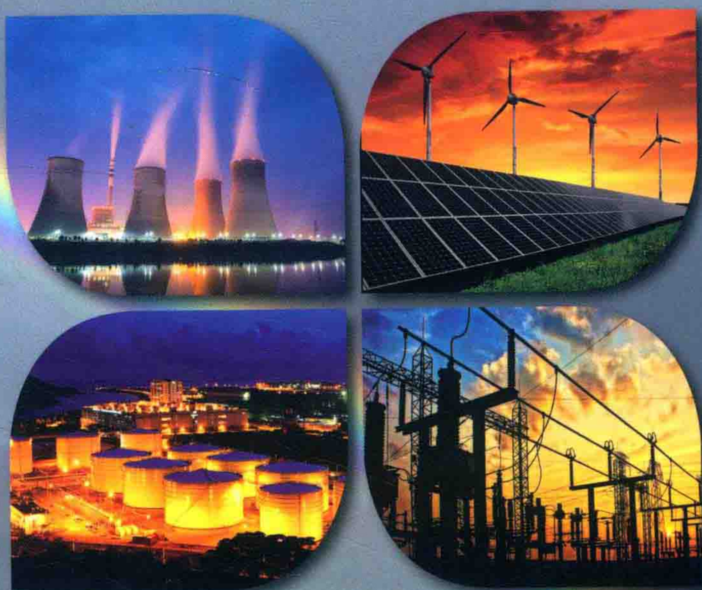
4th Edition

ENERGY
IN THE 21ST CENTURY

John R. Fanchi
and Christopher J. Fanchi



World Scientific

4th Edition

ENERGY

IN THE 21ST CENTURY

John R. Fanchi
Texas Christian University, USA

and

Christopher J. Fanchi
Fanchi Enterprises, USA

World Scientific

NEW JERSEY • LONDON • SINGAPORE • BEIJING • SHANGHAI • HONG KONG • TAIPEI • CHENNAI • TOKYO

Published by

World Scientific Publishing Co. Pte. Ltd.
5 Toh Tuck Link, Singapore 596224
USA office: 27 Warren Street, Suite 401-402, Hackensack, NJ 07601
UK office: 57 Shelton Street, Covent Garden, London WC2H 9HE

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

ENERGY IN THE 21ST CENTURY
Fourth Edition

ISBN 978-981-3144-77-4
ISBN 978-981-3144-78-1 (pbk)

Printed in Singapore by Mainland Press Pte Ltd.

4th Edition

ENERGY

IN THE 21ST CENTURY

PREFACE TO THE FOURTH EDITION

Energy in the 21st Century is a valuable source of information for students, decision makers, opinion leaders, and the general public. Oil and natural gas price volatility continue to affect both the supply and demand for energy. Advances in other technologies, such as nuclear, wind, solar, and tidal technology, are altering the comparative economics of competing energy sources. New government policies are changing the landscape of the global energy marketplace. The fourth edition updates data and includes more discussion of recent advances. Some of the highlights of the fourth edition are expanded discussion of climate change and anthropogenic climate change; the 2015 COP21 Paris Agreement on Climate Change; nuclear fusion reactor prototypes (tokomak ITER and stellarator W7-X); advances in solar thermal and solar photovoltaic power plants, space based solar power, transparent photovoltaic cells, and hybrid solar wind technology; tidal and wave energy converters; oil from algae; the EU Supergrid; and the Goldilocks Policy and Grand Energy Bargain.

Energy in the 21st Century has been used as the text for an introductory energy course for the general college student population. It has also been used to provide an overview of energy topics for MBA students. Several features enhance the value of the fourth edition as a textbook. The book includes learning objectives at the beginning of each chapter, end of chapter activities, a comprehensive index, a glossary, and an Appendix to help with converting units. Points to Ponder are abbreviated as P2P in the Learning Objectives boxes and are provided throughout the text. They are designed to encourage the reader to consider the material from different perspectives.

Most of the statistics presented in the book are from the United States Energy Information Administration (www.eia.doe.gov). The U.S. EIA has been selected because it is widely used by policy makers. Other sources are used when appropriate. Published statistical data are subject to revision, even if the data are historical data that have been published by a credible source. Data revisions may change specific numbers as database corrections are made and new information is received.

We want to thank students, guest speakers, and colleagues in academia and industry for their comments and suggestions. Kathy Fanchi and the editorial staff at World Scientific were again instrumental in preparing this book for publication.

John R. Fanchi
July 1, 2016

Christopher J. Fanchi
July 1, 2016

To the pioneers in the emerging energy industry –
for the benefit of future generations.

ABOUT THE AUTHORS

John R. Fanchi is a Professor in the Department of Engineering and Energy Institute at Texas Christian University, Fort Worth, Texas where he teaches courses in energy and engineering. Previously, Dr. Fanchi taught petroleum and energy engineering courses at the Colorado School of Mines and worked in the technology centers of four energy companies (Getty, Cities Service, Marathon, and Chevron). Dr. Fanchi is the author of many articles and books in the areas of energy, physics, engineering, earth science, and mathematics. His books include **Energy in the 21st Century, 3rd Edition** (World Scientific, 2013), **Integrated Reservoir Asset Management** (Elsevier, 2010), **Energy: Technology and Directions for the Future** (Elsevier-Academic Press, 2004), **Principles of Applied Reservoir Simulation, 3rd Edition** (Elsevier, 2006), **Math Refresher for Scientists and Engineers, 3rd Edition** (Wiley, 2006), **Shared Earth Modeling** (Elsevier, 2002), **Integrated Flow Modeling** (Elsevier, 2000), and **Parametrized Relativistic Quantum Theory** (Kluwer, 1993). Dr. Fanchi has a Ph.D. in physics from the University of Houston, has been President of the International Association for Relativistic Dynamics, and was Vice President of the Board of Trustees of Littleton Public Schools in Colorado. He co-edited the General Engineering volume of the **Petroleum Engineering Handbook** (SPE, 2006, Volume 1). Some of his books have been translated into Arabic, Chinese, and Russian.

Christopher J. Fanchi has a B.A. in Business Administration and Economics from Colorado State University, and is in the MBA program at Texas Christian University, Fort Worth, Texas. He co-authored **Energy in the 21st Century, 3rd Edition** (World Scientific, 2013). He has worked for Fanchi Enterprises since 2000, including contributions to **Integrated Reservoir Asset Management** (Elsevier, 2010), **Math Refresher for Scientists and Engineers, 3rd Edition** (Wiley, 2006) and **Integrated Flow Modeling** (Elsevier, 2000).

CONTENTS

CHAPTER 1

A BRIEF HISTORY OF ENERGY CONSUMPTION

After reading this chapter, you should be able to…

- Define energy and how it is used
  - *P2P*: What does an energy unit mean to me?*
- Define energy density and explain its significance
  - *P2P: Why is energy density important?*
- Describe historical energy consumption
- Connect energy consumption to quality of life
  - *P2P: Using quality of life to forecast energy consumption*
- Discuss the transition from wood to coal to oil to a broad energy mix
  - *P2P: Why should I care about the global distribution of energy?*

* Point to Ponder

We all make decisions about energy. We decide how much electricity we will use to heat or cool our homes. We decide how far we will travel every day and the mode of transportation we will use. Those of us in democratic societies choose leaders who create budgets that can support new energy initiatives or maintain a military capable of defending energy supply lines. Each of these decisions and many others impact the global consumption of energy and the demand for available natural resources. The purpose of this book is to give you the information you need to help you understand the issues and make informed decisions.

The choices we make today will affect generations to come. What kind of future do we want to prepare for them? What kind of future is possible? We can make the best decisions by being aware of our options and the consequences of our choices. In this book, we consider the location, quantity and accessibility of energy sources. We discuss ways to distribute available energy, and examine how our choices will affect the economy, society, and the environment. We begin by defining energy and reviewing our history of energy consumption.

1.1 WHAT IS ENERGY?

Energy is the ability to do work. It can be classified as stored (potential) energy, and working (kinetic) energy. Potential energy is the ability to produce motion, and kinetic energy is the energy of motion. Forms of energy include energy of motion (kinetic energy), heat (thermal energy), light (radiant energy), photosynthesis (biological energy), stored energy in a battery (chemical energy), stored energy in a capacitor (electrical energy), stored energy in a nucleus (nuclear energy), and stored energy in a gravitational field (gravitational energy).

Sources of energy with some common examples include biomass (firewood), fossil fuels (coal, oil, natural gas), flowing water (hydroelectric dams), nuclear materials (uranium), sunlight, and geothermal heat (geysers). Energy sources may be classified as renewable or nonrenewable. Nonrenewable energy is energy that is obtained from sources at a rate that exceeds the rate at which the sources are replenished. Examples of nonrenewable energy sources include fossil fuels and nuclear fission material such as uranium. Renewable energy is energy that is obtained from sources at a rate that is less than or equal to the rate at which the sources are replenished. Examples of renewable energy include solar energy and wind energy.

Renewable and nonrenewable energy sources are considered primary energy sources because they provide energy directly from fuels. A fuel is a material which contains one form of energy that can be transformed into another form of energy. Primary energy is energy that has not been obtained by anthropogenic conversion or transformation. The term "anthropogenic" refers to human activity or human influence. Primary energy is often converted to secondary energy for more convenient use in human systems. Secondary energy sources are produced from primary sources of energy and can be used to store and deliver energy in a useful form. Hydrogen and electricity are considered secondary sources of energy, or "carriers" of energy.

1.1.1 Energy Transformation

Modern civilization depends on the observation that energy can change from one form to another. If you hold a book motionless above a table and then release it, the book will fall onto the table. The book has potential energy when it is being held above the table. The potential energy is energy associated with the position of the book in a gravitational field. When you drop the book, the energy of position is transformed into energy of motion, or kinetic energy. When the book hits the table, some of the kinetic energy is transformed into sound (sonic energy), and the rest of the kinetic energy is transformed into energy of position (potential energy) when the book rests on the table top.

Energy transformation is needed to produce commercial energy. As an illustration, suppose we consider a coal-fired power plant. Coal stores energy as chemical energy. Combustion, or burning the coal, transforms chemical energy into heat energy. In steam power plants, the heat energy changes water into steam and increases the energy of motion, or kinetic energy, of the steam. Flowing steam spins a turbine in a generator. The mechanical energy of the spinning turbine is converted to electrical energy in the generator. In a real system, energy is lost so that the efficiency of electrical energy generation from the combustion of coal is less than 100%. A measure of the energy that is available for doing useful work is called exergy.