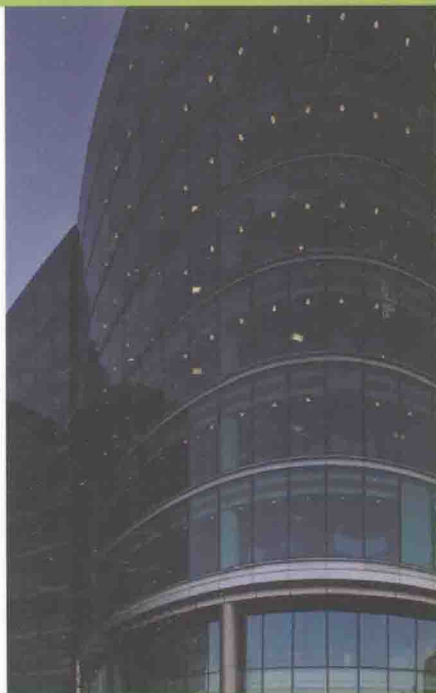
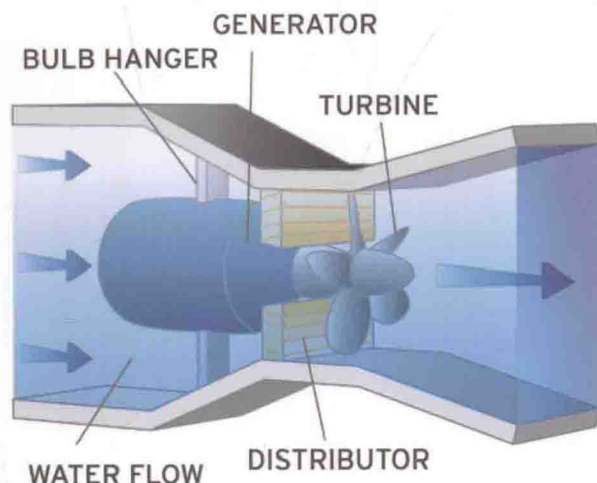
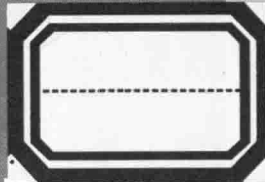


# Alternative Energy Systems in Building Design

Peter Gevorkian

建筑设计中的绿色能源系统





A GreenSource BOOK 影印版

# ALTERNATIVE ENERGY SYSTEMS IN BUILDING DESIGN

PETER GEVORKIAN

---

## 建筑设计中的绿色能源系统



哈尔滨工业大学出版社  
HARBIN INSTITUTE OF TECHNOLOGY PRESS

# 黑版贸审字08-2014-018号

Peter Gevorkian

Alternative Energy Systems in Building Design

ISBN 978-0-07-162147-2

Copyright © 2010 by McGraw-Hill Education.

All rights reserved. No part of this publication may be reproduced or transmitted in any form or by any means, electronic or mechanical, including without limitation photocopying, recording, taping, or any database, information or retrieval system, without the prior written permission of the publisher.

This authorized English reprint edition is jointly published by McGraw-Hill Education (Asia) and Harbin Institute of Technology Press Co. Ltd. This edition is authorized for sale in the People's Republic of China only, excluding Hong Kong, Macao SAR and Taiwan.

Copyright © 2014 by McGraw-Hill Education (Asia), a division of McGraw-Hill Education (Singapore) Pte. Ltd. and Harbin Institute of Technology Press Co. Ltd.

版权所有。未经出版人事先书面许可，对本出版物的任何部分不得以任何方式或途径复制或传播，包括但不限于复印、录制、录音，或通过任何数据库、信息或可检索的系统。

本授权英文影印版由麦格劳-希尔（亚洲）教育出版公司和哈尔滨工业大学出版社有限公司合作出版。此版本经授权仅限在中华人民共和国境内（不包括香港特别行政区、澳门特别行政区和台湾地区）销售。

版权©2014由麦格劳-希尔（亚洲）教育出版公司与哈尔滨工业大学出版社有限公司所有。

本书封面贴有McGraw-Hill Education公司防伪标签，无标签者不得销售。

## 图书在版编目（CIP）数据

建筑设计中的绿色能源系统 = Alternative energy systems in building design: 英文/（美）格沃钦（Gevorkian, P.）著. —哈尔滨：哈尔滨工业大学出版社，2014.3

ISBN 978-7-5603-4497-3

I. ①建… II. ①格… III. ①生态建筑-建筑设计-英文 IV. ①TU2

中国版本图书馆CIP数据核字（2014）第000268号



责任编辑 杨 桦

出版发行 哈尔滨工业大学出版社

社 址 哈尔滨市南岗区复华四道街10号 邮编 150006

传 真 0451-86414749

网 址 <http://hitpress.hit.edu.cn>

印 刷 哈尔滨市石桥印务有限公司

开 本 787mm×960mm 1/16 印张 34.25

版 次 2014年6月第1版 2014年6月第1次印刷

书 号 ISBN 978-7-5603-4497-3

定 价 158.00元

（如因印刷质量问题影响阅读，我社负责调换）

# **ALTERNATIVE ENERGY SYSTEMS IN BUILDING DESIGN**

---

**PETER GEVORKIAN, Ph.D., P.E.**



New York Chicago San Francisco Lisbon London Madrid  
Mexico City Milan New Delhi San Juan Seoul  
Singapore Sydney Toronto

## McGRAW-HILL'S GREENSOURCE SERIES

---

### **Gevorkian**

*Alternative Energy Systems in Building Design*

### **Gevorkian**

*Solar Power in Building Design: The Engineer's Complete Design Resource*

### **GreenSource: The Magazine of Sustainable Design**

*Emerald Architecture: Case Studies in Green Building*

### **Haselbach**

*The Engineering Guide to LEED—New Construction: Sustainable Construction for Engineers*

### **Luckett**

*Green Roof Construction and Maintenance*

### **Melaver and Mueller (eds.)**

*The Green Building Bottom Line: The Real Cost of Sustainable Building*

### **Nichols and Laros**

*Inside the Civano Project: A Case Study of Large-Scale Sustainable Neighborhood Development*

### **Yudelson**

*Green Building Through Integrated Design*

### **Yudelson**

*Greening Existing Buildings*

### **About GreenSource**

A mainstay in the green building market since 2006, *GreenSource* magazine and GreenSourceMag.com are produced by the editors of McGraw-Hill Construction, in partnership with editors at BuildingGreen, Inc., with support from the United States Green Building Council. *GreenSource* has received numerous awards, including American Business Media's 2008 Neal Award for Best Website and 2007 Neal Award for Best Start-up Publication, and FOLIO magazine's 2007 Ozzie Awards for "Best Design, New Magazine" and "Best Overall Design." Recognized for responding to the needs and demands of the profession, *GreenSource* is a leader in covering noteworthy trends in sustainable design and best practice case studies. Its award-winning content will continue to benefit key specifiers and buyers in the green design and construction industry through the books in the *GreenSource* Series.

### **About McGraw-Hill Construction**

McGraw-Hill Construction, part of The McGraw-Hill Companies (NYSE: MHP), connects people, projects, and products across the design and construction industry. Backed by the power of Dodge, Sweets, *Engineering News-Record (ENR)*, *Architectural Record*, *GreenSource*, *Constructor*, and regional publications, the company provides information, intelligence, tools, applications, and resources to help customers grow their businesses. McGraw-Hill Construction serves more than 1,000,000 customers within the \$4.6 trillion global construction community. For more information, visit [www.construction.com](http://www.construction.com).

## About the Author

---



**Peter Gevorkian, Ph.D., P.E.**, is President of Vector Delta Design Group, Inc., an electrical engineering and solar power design consulting firm, specializing in industrial, commercial, and residential projects. Since 1971, he has been an active member of the Canadian and California boards of professional engineers. Dr. Gevorkian is also the author of *Sustainable Energy Systems in Architectural Design*, *Sustainable Energy Systems Engineering*, and *Solar Power in Building Design*, all published by McGraw-Hill.

# INTRODUCTION

---

In the coming decades, the alternative energy technology industries will undergo unprecedented growth and will represent a significant component of the U.S. gross national product. The replacement of conventional fossil fuel and nuclear fission energy resources by renewable-energy sources will mandate that industries, academia, and research institutions provide immediate technological solutions to curb global environmental pollution. To mitigate global environmental and atmospheric pollution and to accelerate technological growth, it is imperative that international academia keep up with industry by educating carrier professionals to meet these imminent challenges.

In the very near future, global economies will face enormous challenges that they will need to resolve, increasing the ever-growing need for ecologically friendly renewable-energy resources. Despite its status as the economic bastion and technological leader of the free world and the largest atmospheric polluter of our planet, the United States has in the past few decades totally neglected the economic promotion of key alternative energy technologies such as solar and wind energy power generation. Even though both these technologies were invented in the United States, the nation has fallen far behind all developing countries, including Japan, Germany, and, soon, China.

Some of the most compelling factors supporting the promotion of alternative energy studies are discussed below. They indicate that alternative energy technologies will come to represent billions of dollars of new markets in the United States and around the world. A few highlights of the alternative energy industry, covered by the Renewable Energy Laboratories and the American Solar Electric Power Association, are as follows:

- By 2020, California's installed photovoltaic capacity is expected to increase 30- to 40-fold, at an average of 36 percent a year.
- Solar power generation, by 2020, is expected to provide approximately 10–17 percent of the electricity in California, as well as 3–6 percent of electricity in the United States.
- Over the next 3–7 years, California's unsubsidized solar energy cost to consumers is expected to compete with the cost of with grid power.
- Since 1970, the price of solar photovoltaic power has decreased 100-fold.
- Currently, the U.S. solar industry employs 3000 men and women. By 2020, this figure is estimated to exceed 150,000.
- By 2020, the solar photovoltaic industry is estimated to be worth close to \$27 billion per year.
- The national goal of the United States is to meet 10 percent peak power by 2030, or the equivalent of 180 million barrels of oil per year.

- State-by-state analysis shows that U.S. photovoltaic grid-connected potential in 2010 will be 2900 MW/year, and solar power will be reduced to \$2.00–\$2.50 per installed watt, representing a \$6.6 billion business.
- Residential rooftop space available could accommodate 710,000 MW of solar electric power.
- The Pacific and Mid-Atlantic regions of the United States will account for 52 percent of solar power installation.
- California has the potential to accommodate 40 percent of the total building rooftop solar power market in the United States.
- Projections of global solar power demand for 2020 indicate that solar power energy will be in parity with grid energy.
- By 2020, global solar power production is expected to increase from 10 to 300 GW, an investment that will represent approximately \$500 billion.
- Over the next decade, 20–40 GW of solar power installed globally would provide 15 percent of the annual power consumed.
- Global polysilicon production capacity is estimated to triple within the next 5 years. The cost of silicon ingot production may drop by as much as 50–60 percent.
- In California, principal electric service providers are undertaking measures to integrate substantial amounts of green energy into their grids.

All these indicators suggest that alternative energy technologies, particularly the solar photovoltaic industry, in the United States and the rest of the world will be expanding at an unprecedented rate that will result in the creation of thousands of job opportunities for trained scientists, engineers, and technologists.

*Alternative Energy Systems in Building Design* is intended primarily to be a design reference guide for engineers, architects, scientists, management personnel, and university students. This book also can be supplemented with a teacher's reference guide, which will allow it to be used in undergraduate and postgraduate courses.

The main objective of this book is to provide readers with a pragmatic design reference manual for the design and implementation of some of the most commercially viable alternative energy technologies. In view of the unprecedented worldwide demand for solar power cogeneration systems, this book has extensive coverage of solar physics, associated technologies, and pragmatic design guidelines for professionals who must assume responsibility for all aspects of a solar power project design. Design guidelines discussed in the book reflect my personal experiences as a consulting engineer and educator.

Material on fusion reactors is included. Although fission reactors are not considered an alternative energy technology, the coverage is intended to provide a comparative reference with the specifics of fusion reactors. In writing this book, I have attempted to incorporate all significant alternative energy technologies; in the process, I have made extensive use of material from my previous publications and published articles from the Department of Energy (DOE), National Renewable Energy Laboratories (NREL), Web resources such as Wikipedia, and many contributors (as cited and acknowledged throughout the book).



As part of solar power system design and implementation, this book also includes specific coverage of LEED design, energy conservation, and the unique economics of solar power financing and return on investment, which covers the details of personnel, material cost breakdowns, and energy cost analyses. In view of the recent developments of new financial strategies, this book includes a discussion about power purchase agreements (PPAs), brief coverage of the Kyoto Protocol, and a discussion of the national and international carbon cap and trade system, which would be of significant importance to program managers.

As custodians of our global village, we must urgently apply our collective human ingenuity and resources to stop and reverse global atmospheric and environmental pollution within the next generation. In the past couple of centuries, as engineers and scientists, we have advanced these technologies, elevated living standards, and, in the process, grossly neglected the need for harmony with Mother Nature. Even though the challenges ahead may seem difficult to overcome, historically, as a nation, we have overcome equally insurmountable challenges and succeeded in realizing the seemingly impossible.

*Peter Gevorkian, Ph.D., P.E.*

# ACKNOWLEDGMENTS

---

I would like to thank my colleagues and other individuals who have encouraged and assisted me in writing this book. I am especially grateful to all agencies and organizations that provided photographs and allowed use of some textual material, and my colleagues who read the manuscript and provided valuable insight.

My thanks go to Ken Touryan, Ph.D.; Zareh Astourian, MMPE, Corporate President, TMAD TAYLOR & GAINES; Jorn Christensen, Ph.D., Aerospace Communication; Robert McConnell, Ph.D., Senior Vice President Business Development, and Vahan Garboushian, President, AMONIX; Mark Gangi, AIA; Mary Olson Kanian; Gene Beck, EnviroTech Financial, Inc.; William Nona, Architect, National Council of Architectural Registration Boards; Frank Pao, CEO, Atlantis Energy Systems; Deborah Blackwell, Vice President, Hyperion Power Generation, Inc.; Gustavo Fernandes; and Ricardo Abecassis. Special thanks go to Carla Gharibian for her meticulous editing of the manuscript.

Thanks also go to AMONIX, Torrance, CA; MARTIFER USA, Santa Monica, CA; A&M Energy Solutions, Santa Monica, CA; Atlantis Energy Systems, Inc., Sacramento, CA; California Energy Commission, Sacramento, CA; Fotoworks Studio, Los Angeles, CA; Museum of Water and Life, Hemet, CA, Center for Water Education; SolarWorld California, Camarillo, CA; SunPower Corporation, Oakland, CA; Solar Integrated Technologies, Los Angeles, CA; U.S. Green Building Council, Los Angeles Chapter; U.S. Department of Energy; National Renewable Energy Laboratories; Sandia National Laboratories; Hyperion Power Generation, Inc., Washington, DC; DWP Solar; Solectria Inverters; Solargenix Energy, Newport Beach, CA; TMAD TAYLOR & GAINES, Pasadena, CA; UMA/Heliocol, Clearwater, FL; and EnviroTech Financial, Inc., Orange, CA.

## **DISCLAIMER NOTE**

---

This book examines solar power generation and renewable energy sources, with the sole intent to familiarize the reader with the existing technologies and to encourage policy makers, architects, and engineers to use available energy conservation options in their designs.

The principal objective of the book is to emphasis solar power cogeneration design, application, and economics.

Neither the author, individuals, organizations, or manufacturers referenced or credited in this book make any warranties, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, products, and processes disclosed or presented.

Reference to any specific commercial product, manufacturer, or organization does not constitute or imply endorsement or recommendation by the author.

---

# **ALTERNATIVE ENERGY SYSTEMS IN BUILDING DESIGN**

---

# CONTENTS

---

<b>Introduction</b>	<b><i>xiii</i></b>
<b>Acknowledgments</b>	<b><i>xvii</i></b>
<b>Disclaimer Note</b>	<b><i>xix</i></b>
<b>Chapter 1 Global Warming: Climatic and Atmospheric Changes</b>	<b>1</b>
Climate Change Factors	1
Variations within the Earth's Climate	1
Natural Factors Driving Climate Change	2
The Memory of Climate	6
Human Influences on Climate Change	6
The Transition of Various Forms of Sequestered Solar Energy Use and Their Effect on Societies	9
Industrial Sources of Atmospheric Pollution	12
The Little Ice Age	15
<b>Chapter 2 Energy Systems</b>	<b>19</b>
Conservation of Energy	19
The Concept of Energy in Various Scientific Fields	19
<b>Chapter 3 Solar Power System Physics and Technologies</b>	<b>23</b>
Brief History of the Photoelectric Phenomenon	23
Solar Cell Physics	26
Solar Cell Electronics	30
Solar Cell Manufacturing and Packaging Technologies	30
Dye-Sensitized Solar Cells	34
Multijunction PV Cells	40
Polymer Solar Cells	42
Concentrators	43
Solar Panel Arrays	44
Solar Power System Components	44
Crystalline, Amorphous, Thin-Film, and Sun-Tracker Technologies	51
Solar Power System Design	69
Storage Battery Technologies	77
Solar Power System Configurations	86
Ground-Mounted PV Module Installation and Support	97
Roof-Mounted Installations	98
Electrical Shock Hazard and Safety Considerations	100
Solar Tracking Systems	103
Field Safety Recommendations	106

Solar Power System Maintenance	107
Troubleshooting	108
Solar Power System Warning Signage	109
PV System Design Guidelines	110
Solar Power System Design Considerations	111
Solar Power Rebate Application Procedure	124
Solar Power System Deployment	126
Economics of Solar Power Systems	139
Special Note	155

## **Chapter 4 California Solar Initiative Program 157**

CSI Fund Distribution	158
CSI Power-Generation Targets	158
Incentive Payment Structure	159
Expected Performance-Based Buydown (EPBB)	160
Performance-Based Incentive (PBI)	161
Host Customer	161
Solar Power Contractors and Equipment Sellers	162
PV System Sizing Requirements	163
Energy-Efficiency Audit	163
Warranty and Performance Permanency Requirements	164
Insurance	164
Grid Interconnection and Metering Requirements	165
Inspection	165
CSI Limitations	165
CSI Reservation Steps	166
Incentive Payments	168
Equipment Distributors	168
Special Funding for Affordable Housing Projects	169
Special Funding for Public and Charter Schools	169
Principal Types of Municipal Leases	169

## **Chapter 5 Energy Conservation 173**

Energy-Saving Measures	173
Power-Factor Correction	177
Electric Power Generation and Distribution	178
Computerized Lighting Control	180
California Title 24 Electric Energy Compliance	186
Demand-Side Energy Management and Control	195
LEED—Leadership in Energy and Environmental Design	203
State of California Green Building Action Plan	204
LEED	206

## **Chapter 6 Passive Solar Heating Technologies 223**

Passive Solar Water Heating	223
Concentrator Solar Technologies	233
Solar Cooling and Air-Conditioning	236
Direct Solar Power Generation	240
Innovations in Passive Solar Power Technology	241

<b>Chapter 7 Fuel Cell Technology</b>	<b>245</b>
Fuel Cell Design	245
Fuel Cell Application	251
Fuel Cells as Alternatives to Internal Combustion Fuels	259
Hydrogen Economy	260
<b>Chapter 8 Wind Energy Technologies</b>	<b>267</b>
History of Wind Power	267
Wind Power Generation	268
Wind Power Management	268
Betz' Law of Fluid Dynamics	271
Structural Considerations	274
Basics of Wind Turbine Operation	276
Wind Turbine Energy Economics	279
<b>Chapter 9 Ocean Energy Technologies</b>	<b>287</b>
Tidal Power	287
Tidal Physics: Effects of the Terrestrial Centrifugal Force	287
Tidal Power Generation	288
Current Tidal Generation Technologies	292
Marine-Current Turbine Technologies	300
Some Interesting Oceanic Technologies	303
<b>Chapter 10 Hydroelectric and Micro-Hydro Turbine Power</b>	<b>307</b>
Hydroelectric Power Plants	307
Environmental Effects of Hydroelectric Power	309
Hydroelectric Power Technology	312
Classification of Hydropower Energy Facilities	313
Hydroelectric Plant Equipment	313
Case Studies of Hydroelectric Power Plants	315
Micro-Hydropower Generation	323
<b>Chapter 11 Geothermal Energy</b>	<b>333</b>
Thermal Power Extraction Potential	334
Geothermal Technologies	335
Geothermal Potential	337
Cost of Geothermal Energy and Economics	339
Geothermal Case Study in an Air-Conditioning Application	341
Ocean Thermal Energy	344
<b>Chapter 12 Biofuel, Biogas, and Thermal Depolymerization Technologies</b>	<b>345</b>
History	345
Chemical Composition	346
Origins of Biomass	346
Biomass Energy Potential	347
Energy Value of Biomass	348
Benefits of Biomass Energy	348
Microturbine Generators	350
Landfill, Wastewater Treatment, and Plant Biogas Generators	353

Hot Water and Generators	356
Economic Benefits of Using Landfill Gas	357
Environmental Benefits of Using Landfill Gas	357
Case Study of Successful Application of Microgenerator Technology	357
Cal Poly Biogas Case Study	360
Biomass Energy	362
Biofuels and Thermal Depolymerization	362
Biomass Energy Implementation	365
Carbon Black	366
Gasification Process	367
Biopower	368
Bioproducts	369
Some Interesting Facts about Bioenergy	370
Biodiesel	371

## **Chapter 13 Fission- and Fusion-Type Nuclear Power 375**

Properties of Uranium	375
Nuclear Fission Power Plant	377
Construction of a Nuclear Power Plant	378
Subcriticality, Criticality, and Supercriticality	378
Advantages and Disadvantages of Fission Nuclear Reactors	378
Effects of Nuclear Radiation	379
Radioactive Decay	380
Radiation Danger	381
Nuclear Radiation Accidents	381
Case Study: San Onofre	383
Canadian CANDU Reactor	384
Pebble-Bed Reactor	387
Hyperion Nuclear Power Reactor	389
Fusion Reactors	394
Fusion as a Future Energy Source	401
Future Fusion-Reactor Research and Development	403

## **Chapter 14 Air Pollution Abatement 405**

Effects of Pollution on Human and Animal Life	406
Pollution-Abatement Equipment	407
Emerging Future Technologies: Bioreactors	415
Groundwater Replenishment System	415

## **Chapter 15 Carbon Dioxide Sequestration and Carbon Trading Economics 421**

Chemical and Physical Properties of Carbon Dioxide	421
Carbon Dioxide Production	422
Industrial Production of Carbon Dioxide	423
Industrial Uses of Carbon Dioxide	423
Carbon Dioxide in Photosynthesis	423
Carbon Dioxide Sequestration in Ocean Waters and Aquatic Life	424
Pesticides and Plastics	424
Carbon Dioxide in the Oil and Chemical Industries	425
Role of Carbon Dioxide in Human Physiology	425
Carbon Dioxide Use in the Production of Ammonia and Fertilizer	425



Carbon Credits	426
Economics of Global Warming	428
Disagreement and Criticisms of the Kyoto Protocol	430

<b>Appendix A Unit Conversion and Design Reference Tables</b>	<b>433</b>
<b>Appendix B Photo Gallery</b>	<b>475</b>
<b>Appendix C Historical Time Line of Solar Energy</b>	<b>485</b>
<b>Appendix D Glossary of Renewable Energy Power Systems</b>	<b>493</b>
<b>Bibliography</b>	<b>503</b>
<b>Index</b>	<b>505</b>