



Second Edition

# TUTURE ENERGY

Improved, Sustainable and Clean  
Options for Our Planet

Trevor M. Letcher



# FUTURE ENERGY

Improved, Sustainable and  
Clean Options for Our Planet

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SECOND EDITION

*Edited by*

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# FUTURE ENERGY

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SECOND EDITION

# Preface

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As a result of the interest shown in the first edition of *Future Energy*, and because the subject has expanded enormously with new developments in traditional fields and new approaches in emerging technologies, a new edition of the book has been produced with 31 chapters as opposed to the 20 chapters in the first edition. The new edition has additional chapters devoted to hydraulic fracturing, coal-bed methane, LNG as a transport fuel, lithium ion batteries, hydrogen as an energy carrier, carbon dioxide capture and sequestration, energy storage systems, environmental impacts of energy production, distribution and transport, smart grids, energy resources in developing countries, transition to future energy, and energy options and predictions in China. China has been singled out as it is the most rapidly developing superpower, and if its development continues at its present rate, it will soon produce more energy than any other country on Earth. It is already producing more carbon dioxide by utilisation of fossil fuels than any other country.

The book looks at all types of energy that may be used in the future including the sustainable types such as solar, wind, tidal and wave energy. Fossil fuel in all its forms, from coal, oil, methane gas and methane hydrates, occupies a prominent place in this book as these energy sources will be with us for many decades before we have expanded and developed renewable energy forms, built new nuclear fission plants or possibly even developed new types of energy such as nuclear fusion (Chapter 10) and space solar power (not included in this book) in which orbiting solar panels collect energy from the sun and beam it back down to Earth using lasers or microwaves.

This book, like the first edition, has been produced in order to allow the reader to have a reasonable, logical and correct understanding and insight into our future use of energy. The final decision as to which energy options should be developed in a country or region must take into account many factors including sustainability, the general safety and health of the general public, the overall energy requirements of society, the geographical position of each region, and above all, the alarming rise in atmospheric carbon dioxide over the past 50 years, which threatens to change the world's future climate through global warming.

The first edition of this book had its origins in the committee meetings of the International Association of Chemical Thermodynamics (IACT),<sup>1</sup> an organisation affiliated to the International Union of Pure and Applied Chemistry (IUPAC).<sup>2</sup> The logo of the IACT is on the front cover of this book. The book is supported by IUPAC through its Physical Chemistry Division and the IUPAC's logo also appears on the front cover.<sup>3</sup> The IUPAC's adherence to the International System of Quantities, via editing by its Interdivisional Committee for Terminology, Nomenclature and Symbols (ICTNS), is reflected in the book with the use of SI units throughout. Flexibility and accommodation are ensured for various constituencies by including alternate non-SI units that may be more familiar to specific areas. The ICTNS<sup>4</sup> and the Commission on Physicochemical Symbols, Terminology and Units<sup>5</sup> provide the so-called *Green Book*<sup>6</sup> that is available online.<sup>7</sup> The index notation is used to remove any ambiguities; for example, billion and trillion are written as  $10^9$  and  $10^{12}$ , respectively. To further remove any ambiguities the concept of the quantity calculus is used. It is based on the equation: physical quantity = number  $\times$  unit. To give an example: power = 200 W and hence: 200 = power/W. This is of particular importance in the headings of tables and the axis labels of graphs. One can only plot a number on a graph and the axis label reflects this reality.

This volume is unique in the genre of books of similar or related titles currently on sale in that each chapter of *Future Energy* has been written by an expert scientist or engineer, working in the field. Authors have been chosen for their expertise in their respective fields and come

<sup>1</sup>[www.iactweb.org](http://www.iactweb.org)

<sup>2</sup>[www.iupac.org](http://www.iupac.org)

<sup>3</sup>[http://www.iupac.org/nc/home/projects/project-db/project-details.html?tx\\_wfqbe\\_pi1%5Bproject\\_nr%5D=2012-041-1-100](http://www.iupac.org/nc/home/projects/project-db/project-details.html?tx_wfqbe_pi1%5Bproject_nr%5D=2012-041-1-100)

<sup>4</sup>[http://www.iupac.org/nc/home/about/members-and-committees/db/division-committee.html?tx\\_wfqbe\\_pi1%5Btitle%5D=Interdivisional%20Committee%20on%20Terminology%2C%20Nomenclature%20and%20Symbols&tx\\_wfqbe\\_pi1%5Bpublicid%5D=027](http://www.iupac.org/nc/home/about/members-and-committees/db/division-committee.html?tx_wfqbe_pi1%5Btitle%5D=Interdivisional%20Committee%20on%20Terminology%2C%20Nomenclature%20and%20Symbols&tx_wfqbe_pi1%5Bpublicid%5D=027)

<sup>5</sup>[http://www.iupac.org/nc/home/about/members-and-committees/db/division-committee.html?tx\\_wfqbe\\_pi1%5Btitle%5D=Commission%20on%20Physicochemical%20Symbols%2C%20Terminology%2C%20and%20Units&tx\\_wfqbe\\_pi1%5Bpublicid%5D=110](http://www.iupac.org/nc/home/about/members-and-committees/db/division-committee.html?tx_wfqbe_pi1%5Btitle%5D=Commission%20on%20Physicochemical%20Symbols%2C%20Terminology%2C%20and%20Units&tx_wfqbe_pi1%5Bpublicid%5D=110)

<sup>6</sup>R.E. Cohen, T. Cvitaš, J.G. Frey, B. Holmström, K. Kuchitsu, R. Marquardt, et al., *Quantities, Units and Symbols in Physical Chemistry*, For IUPAC, RSC Publishing, Colchester, UK, 2007.

<sup>7</sup>[http://www.iupac.org/nc/home/publications/e-resources/nomenclature-and-terminology/quantities-units-and-symbols-in-physical-chemistry-green-book.html?sword\\_list%5B%5D=book](http://www.iupac.org/nc/home/publications/e-resources/nomenclature-and-terminology/quantities-units-and-symbols-in-physical-chemistry-green-book.html?sword_list%5B%5D=book)

from 21 countries: Australia, Belgium, Brazil, Canada, China, England, Finland, France, Germany, India, Indonesia, Ireland, Italy, Japan, Luxembourg, Korea, The Netherlands, Norway, Scotland, South Africa and the United States of America.

This book is divided into eight sections:

- Introduction
- Fossil fuels (energy sources)
- Nuclear power (energy sources)
- Transport energy (energy sources)
- Transport energy (energy storage)
- Renewable energy (energy sources)
- New possible energy options
- Environmental and related issues.

A vital concern of future energy options is: what is to be done when it appears that politicians misunderstand or ignore and corporations overlook the realities of finite fuel sources and our changing climate? The solution lies in sound scientific data and education. As educators we believe that only a sustained grassroots movement, to educate citizens, politicians and corporate leaders of the world, has any hope of success. This book is part of that education process. It presents a non-political and unemotional set of energy options for readers to consider and arrive at sensible solutions to the problems facing the world today. We hope that not only students, teachers, professors and researchers of new energy, but politicians, government decision makers, captains of industry, corporate leaders, journalists, editors and all interested people will read the book, take heed of its contents and absorb its underlying message.

I wish to thank all the authors for their co-operation, help and especially for writing their chapters. It has been a pleasure working with each and every one of our authors. I thank my wife, Valerie, for all the help she has given me over these long months of putting the book together. I also thank Sean Coombs and Jill Cetel of Elsevier for their help in getting this volume together. Finally I wish to thank Professor Ron Weir of IUPACs ICTNS for his help with the editing.

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*5 August 2013*

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# Contents

---

Preface xv

List of Contributors xix

## I

---

### INTRODUCTION

#### 1. Introduction with a Focus on Atmospheric Carbon Dioxide and Climate Change

TREVOR M. LETCHER

- 1.1 Why Is It Important to Consider Our Future Energy Options? 3
  - 1.2 The Need for a Sustainable, Safe and Non-polluting Energy Source 4
  - 1.3 Climate Change 5
  - 1.4 Atmospheric Pollution and Climate Change 7
- 1.5 What Are Our Options for Electricity Generation? 10
  - 1.6 What Are Our Options for Transport Fuel? 11
  - 1.7 The Situation in the World Today 12
- 1.8 How Can We Reduce the Stranglehold of Fossil Fuels? 14
  - References 15

## II

---

### FOSSIL FUELS (ENERGY SOURCES)

#### 2. Conventional Oil and Gas

ANTHONY R.H. GOODWIN, LAURENT PIROLI, ERIC F. MAY  
AND KENNETH N. MARSH

- 2.1 Introduction 19
- 2.2 Hydrocarbon Reservoirs 22
- 2.3 Hydrocarbon Recovery, Reserves, Production and Consumption 28
  - 2.4 Global Warming and the Hydrocarbon Economy 41
  - 2.5 Conclusion 46
  - References 46

### 3. Coal Processing and Use for Power Generation

MARIA HOLUSZKO AND ARNO DE KLERK

- 3.1 Introduction 53
- 3.2 Coal Reserves, Production and Use 55
- 3.3 Coal Properties 57
- 3.4 Processing of Coal Before Combustion 58
- 3.5 Clean Coal Technologies 66
- 3.6 Role of Coal in the Energy Mix for the Future 69
- 3.7 Conclusions 70
- References 71

### 4. Frontier Oil and Gas: Deep-Water and the Arctic

ERIC F. MAY, KENNETH N. MARSH  
AND ANTHONY R.H. GOODWIN

- 4.1 Introduction 75
- 4.2 Deep-Water 77
- 4.3 Arctic 81
- 4.4 Clathrate Hydrates 82
- 4.5 Geothermal-Geopressurised Natural Gas 87
- References 90

### 5. Unconventional Oil and Gas: Oilsands

ARNO DE KLERK, MURRAY R. GRAY  
AND NESTOR ZERPA

- 5.1 Introduction 95
- 5.2 Bitumen Production from Oilsands 96
- 5.3 Transport Fuel Production from Bitumen 101
- 5.4 Bitumen Characterisation 103
- 5.5 Bitumen Upgrading Processes 106
- 5.6 Future of Oilsands 111
- References 115

### 6. Shale-Hosted Hydrocarbons and Hydraulic Fracturing

JEREMY BOAK

- 6.1 Introduction 117
- 6.2 Shale-Hosted Hydrocarbons 118
- 6.3 Extraction Methods 126
- 6.4 The Future of Shale-Hosted Hydrocarbons: Production  
Projections 136
- 6.5 Conclusions 138
- References 138

## 7. Coal Bed Methane: Reserves, Production and Future Outlook

MARIA MASTALERZ

- 7.1 Introduction 145
- 7.2 Properties and Origin of Coal Bed Gas 145
- 7.3 CBM Availability and Production 148
- 7.4 Drilling and Extraction Techniques 152
- 7.5 Environmental Issues of CBM Extraction 153
- 7.6 Future Outlook 155
- References 156

## 8. Methane Hydrates

RAY BOSWELL, KOJI YAMAMOTO, SUNG-ROCK LEE, TIMOTHY COLLETT,  
PUSHPENDRA KUMAR AND SCOTT DALLIMORE

- 8.1 Background 159
- 8.2 Estimates of Gas Hydrate Resources 160
- 8.3 Gas Hydrate Exploration 164
- 8.4 Gas Hydrate Production Technology 166
- 8.5 Conclusions 173
- References 174

# III

## NUCLEAR POWER (ENERGY SOURCES)

### 9. Nuclear Fission

MATTHEW GILL, FRANCIS LIVENS AND AIDEN PEAKMAN

- 9.1 Introduction 181
- 9.2 Nuclear Reactor Technology 185
- 9.3 Managing Irradiated Fuel 190
- 9.4 Thorium as an Alternative Fuel 193
- 9.5 Practicalities of Nuclear Energy 194
- 9.6 Conclusions 197
- References 197

### 10. Nuclear Fusion

LARRY R. GRISHAM

- 10.1 What Is Nuclear Fusion 199
- 10.2 Desirable Characteristics of Fusion Power 201
- 10.3 Why Fusion Power Is Difficult 203
- 10.4 Approaches to Fusion Reactors 205

- 10.5 Economics of Fusion Energy 209  
10.6 Prospects for Fusion Energy 210  
References 211

---

## IV

---

### TRANSPORT ENERGY (ENERGY SOURCES)

#### 11. Biofuels for Transport

CARLOS H. BRITO CRUZ, GLAUCIA MENDES SOUZA  
AND LUIZ A. BARBOSA CORTEZ

- 11.1 Introduction 215  
11.2 Biofuels for Transport 216  
11.3 Biofuels in the World Today 219  
11.4 Biofuel Policies and Perspectives 224  
11.5 Sustainability Challenges 231  
11.6 Scientific Challenges and Opportunities 237  
11.7 Perspectives and Conclusions 239  
References 241

#### 12. Transport Fuel: Biomass-, Coal-, Gas- and Waste-to-Liquids Processes

ARNO DE KLERK

- 12.1 Introduction 245  
12.2 Overview of Alternative Carbon Feed-to-Liquid (XTL) Processes 246  
12.3 Direct Liquefaction 249  
12.4 Indirect Liquefaction 254  
12.5 Environmental Footprint of Liquefaction 264  
12.6 Future Energy 267  
References 268

#### 13. Transport Fuel – LNG and Methane

GOUTHAMI SENTHAMARAIAKKANNAN, DEBANJAN CHAKRABARTI  
AND VINAY PRASAD

- 13.1 Introduction 271  
13.2 Sources of Natural Gas 272  
13.3 Natural Gas Extraction 273  
13.4 Natural Gas Reserves 274  
13.5 Utilisation of Natural Gas as a Transportation Fuel 278  
13.6 Regional Trends in NGVs 281  
13.7 Prospects for the Future Use of Natural Gas as  
a Transportation Fuel 283  
13.8 Conclusions 285  
References 286

---

## V

---

### TRANSPORT ENERGY (ENERGY STORAGE)

#### 14 Transport Energy – Lithium Ion Batteries

JUSTIN SALMINEN, TANJA KALLIO, NOSHIN OMAR, PETER VAN DEN BOSSCHE,  
JOERI VAN MIERLO AND HAMID GUALOUS

- 14.1 Background 292
- 14.2 Lithium Ion Battery Types and Materials 293
- 14.3 Overview of Battery Performance and Expectations 298
- 14.4 Future Technologies 303
- 14.5 Conclusions 305
- References 307

---

## VI

---

### RENEWABLES (ENERGY SOURCES)

#### 15. Wind Energy

DAVID INFIELD

- 15.1 The Global Resource 313
- 15.2 Resource Assessment 314
- 15.3 Wind Turbine Technology 320
- 15.4 Power System Integration 324
- 15.5 Environmental Impact 330
- 15.6 Future Developments and Research Requirements 331
- References 332

#### 16. Tidal Current Energy: Origins and Challenges

ALAN OWEN

- 16.1 Introduction 335
- 16.2 Tidal Current Drivers 337
- 16.3 Devices 346
- 16.4 Anchors and Fixings 349
- 16.5 Biofouling 354
- 16.6 Conclusions 354
- References 355
- Recommended Reading 356

#### 17. Wave Energy

RAYMOND ALCORN

- 17.1 Background, Context and Drivers of Wave Energy 357
- 17.2 What Is Ocean Wave Energy? 358

- 17.3 The Energy Resource and How It Is Measured 362
  - 17.4 Forecasting and Prediction 365
  - 17.5 Challenges and Benefits 366
  - 17.6 Converter Types 367
  - 17.7 Device Rating 372
  - 17.8 Modern Devices 373
- 17.9 Economics of Wave Energy 375
  - 17.10 Alternative Output 380
  - 17.11 Future 381
  - References 381

## 18. Solar Energy: Photovoltaics

ADRIA E. BROOKS

- 18.1 Introduction 383
- 18.2 Electrical Operating Characteristics 388
  - 18.3 PV Physics 391
  - 18.4 PV Cell Design 395
  - 18.5 Field Performance 396
  - 18.6 Barriers to Growth 401
  - References 404

## 19. Solar Energy – Concentrating Solar Power

ROBERT PITZ-PAAL

- 19.1 Introduction – Concept and Basic Characteristics 405
  - 19.2 State of the Art 409
  - 19.3 Cost and Market 420
  - References 428

## 20. Solar Energy – Water Heating

KATE HUDON

- 20.1 Solar Water Heater Basics 433
- 20.2 Market Assessment 442
- 20.3 The Future of Solar Water Heating 447
  - 20.4 Summary 451
  - References 451

## 21. Hydroelectric Power

ÅNUND KILLINGTVEIT

- 21.1 Introduction 453
- 21.2 Hydropower Resources 456
- 21.3 Technology 459
- 21.4 Sustainability Issues 461
- 21.5 Cost Issues 465



- 21.6 Integration into the Broader Energy System 468  
 21.7 Future Deployment 469  
 References 470

## 22. Geothermal Energy

RONALD DIPIPPA AND JOEL L. RENNER

- 22.1 Heat Flow and Subsurface Temperatures 471  
 22.2 Tectonic Controls 472  
 22.3 Types of Geothermal Systems 474  
 22.4 Worldwide Geothermal Potential 476  
 22.5 Worldwide Geothermal Development 477  
 22.6 Methods for Electrical Generation 479  
 22.7 Direct Use of Geothermal Energy 484  
 22.8 Environmental Challenges 486  
 22.9 Recent Progress in Geothermal Energy Usage 488  
 22.10 The Future 488  
 22.11 Sources of Additional Information 490  
 Acknowledgements 491  
 References 491

# VII

## NEW POSSIBLE ENERGY OPTIONS

### 23. Hydrogen: An Energy Carrier

MARY HELEN MCCAY

- 23.1 Introduction 495  
 23.2 Hydrogen 495  
 23.3 Basic Elements Needed for Hydrogen Utilisation 497  
 23.4 Current Status 505  
 23.5 Now and the Future Around the World 506  
 References 509  
 Recommended Websites 510

### 24. Fuel Cells: Energy Conversion Technology

MANOJ K. MAHAPATRA  
 AND PRABHAKAR SINGH

- 24.1 Introduction 511  
 24.2 SOFC Power System 514  
 24.3 Electrical Losses 518  
 24.4 SOFC Materials 519  
 24.5 Research Trend 535  
 24.6 Challenges 537  
 24.7 Concluding Remarks 538  
 References 539