

SUSTAINABLE ENERGY TECHNOLOGIES

Options and Prospects

Edited by K. HANJALIĆ, R. van de KROL, and A. LEKIĆ

Publisher: Springer, Dordrecht, The Netherlands, 2008
ISBN 978-1-4020-6723-5 (HB) ISBN 978-1-4020-6724-2 (e-book)

In pursuit of feasible near-future sustainable and environmentally acceptable energy solutions to specific needs and based on the available – often specific and limited resources as pertinent to many smaller transitional countries, the Academy of Sciences and Arts of Bosnia and Herzegovina in cooperation with Dubrovnik Inter-University Centre invited a panel of experts to present and discuss the state-of-the-art in the development of new energy technologies at a conference held in Dubrovnik, Croatia, on September 23-25, 2006. Up-to-date reviews of the status and prospects of different options in energy conversion and storage technologies were presented by some of the world leading authorities – members of the national and international academies of sciences, directors of institutes, directors of national and international (EU) energy programmes and academics from Belgium, France, Germany, Italy, Japan, the Netherlands, Portugal, and Switzerland. The articles covered new clean and zero-emission coal technologies, solar, wind, nuclear, fuel cells, hydrogen and hybrid technologies, accompanied by treatises on the challenge of increasing global energy needs and consumption, issues of sustainability, and on efficient production and use of energy based on modern rationing technologies. This overview was complemented by several regional surveys of needs, resources and priorities, as well as specific initiatives towards meeting future energy objectives, pursued in several countries in South Eastern Europe.

This volume has grown out of (but is not confined to) extended and revised invited articles presented at the Dubrovnik conference under the auspices of the Academy of Sciences and Arts of Bosnia and Herzegovina. The book aims at providing information and guidance to engineers and planners in energy sector, employees in energy utility companies, various levels of governmental organizations and offices. It is also intended to serve as a graduate-level textbook to meet growing demand for new courses in alternative, renewable, and sustainable energy technologies at technical and general universities.

Recent record increases in crude-oil prices have once again brought the energy issue into the prime focus of world politics and public awareness. Developing sustainable and renewable energy sources is again seen as the top priority in many countries, especially those that are highly developed. Thus, it is not only the alarming observation of melting polar ice caps or other incontestable evidences of climate change, nor Kyoto, post-Kyoto or similar protocols and declarations that compel us to search for new energy alternatives. It is rather the issues of national security, independence from imports, the immediate and near-future prospects for our economies and possible undesired social and societal implications, that provide the prime motivation for extensive research on new renewable as well as conventional energy sources, conversion and storage technologies. It should be no surprise that the issue of security of energy supplies and absolute necessity for new energy efficient technologies appeared as primary items on the agenda of the recent Annual Meeting of the World Economic Forum in Davos, Switzerland.

However, the problems and challenges in different parts of the globe are very different and so are the motivations, public attitudes, priorities, and official policies. The highly developed countries, the USA, EU, Japan, see the issues from a different perspective than the highly populated countries such as Brazil, China, India, Indonesia, and very different still from smaller economies in transition, such as those in South Eastern Europe. Hydrogen has the future, Hydrogen is the answer to energy question, claims the European Commissioner for Research. Wind, solar, tidal, *etc.*, have the potential to satisfy all our needs, claim others. Yet, according to some (unconfirmed) evidence, there are currently over 850 large fossil-fuel plants under construction or in the design stage worldwide, most in China, India, Indonesia, Russia, South America, and also in the USA.

While every tonne of fossil fuel replaced by a renewable source should be welcome, and the research into and development of novel renewable and sustainable technologies should be stimulated even at a larger scale than hitherto (see *e. g.* the recent EU Energy Technology Plan), we should ask ourselves:

Which of the proposed options in alternative and renewable energy technologies provides the fastest route towards meeting the challenges and fulfilling promises by providing efficient, safe, environmentally acceptable and reliable solutions?

What are the feasible near-future options, in particular for specific countries and regions?

The total installed capacity of renewable energy sources, apart from hydroelectric power and biomass, is still relatively small, although growing strongly. The technical limit of 15% of intermittent electricity is being quickly approached in some countries of the European Union. Will the storage technologies come next or will the intermittent technologies stay limited? Will these sources need to be subsidised for a long time to come?

How real are the perspectives for the revival of nuclear energy? Is it time to reconsider existing bans and previously made decisions in many countries to phase out nuclear plants? How can we assure ourselves and the public that nuclear power can be safe? Since the fuel is limited for current nuclear technologies, will new technologies evolve in time?

Or, is the solution for many countries to be found in so-called lean fossil fuel technology, which combines efficiency improvements with CO₂ sequestration?

The widespread consensus among experts is that the solution is not in one single energy source or technology, but that all options need to be pursued and explored. The 2007 Report on Energy and Climate Change by the World Energy Council (WEC) emphasizes that no single energy source can meet the energy needs of the world and its emission goals at the same time, nor can any single policy or measure provide the full solution. This statement can be projected to a single country or even a region: each country should develop its own strategy to climate change and to energy needs. The three criteria of the WEC (Accessibility to affordable energy, environmental Acceptability of the energy sources, and reliable and secure Availability) can serve as guidance for assessing possible technological options and policy decision.

This volume presents an overview of recent developments in sustainable energy technologies (excluding vehicle propulsion) and provides a platform for answering some of the above-posed and other questions when projected to specific situations. It also aims at stimulating activities in selecting, researching and pursuing specific technologies that are feasible, economically viable and realisable with special emphasis on the needs and potential of countries in South Eastern Europe and their counterparts in other regions of the world. A panel of internationally renowned experts presented recent research advances and prospects for different options. These are complemented with a series of short regional overviews of initiatives, trends and activities in some of the countries of South Eastern Europe.

The material is organised in two parts. Part I begins with discourses of some global energy issues, such as the challenge of increasing global energy needs and consumption, the concept of sustainability, and potential improvement of efficiency in production and use of energy. Different novel conversion and storage technologies, their development status and perspectives of implementation are then presented. Part II contains overviews of current activities in some of the countries in South Eastern Europe. In addition to giving an insight into current initiatives, policies and actions, these chapters provide examples of possible measures towards short- and mid-term mitigation of energy shortage in small and medium-sized countries as a precursor for major undertakings.

The first three chapters deal with different topics, but their common denominator is in their global concern and significance. In Chapter 1, M. Combarous and J.-F. Bonnet review the world energy situation, current status and future trends. A distinction is made between explicit energy sources and main energy sectors and their correlation with world population evolution, emission of green-house gases and climate change. Using the average individual energy consumption as a key parameter, different future energy scenarios are considered and possible solutions are discussed. Recognising the enormous complexity of the energy systems, their size and inertia to implementing technological novelties, and rigorous safety issues, the authors conclude that all feasible measures should be pursued. They especially emphasize energy saving, the development of all forms of energy production, developing technologies for carbon capture, and the need for a more balanced geographical distribution of resources.

Overall sustainable growth cannot be ensured if sustainability is not accounted for in all major planning exercises and undertakings that involve future use of energy, water, and other natural resources. N. H. Afgan introduces in Chapter 2 the sustainability concept and measures of sustainability, defined in terms of a sustainability index. Examples of multi-criteria assessment of an energy system for several different scenarios illustrate the feasibility of the approach. In Chapter 3, S. V. Alekseenko gives a Russian perspective on efficiency of production and use of energy, based on modern rationing technologies. Presented are novel developments in both conventional and renewable conversion and storage technologies, new types of energy sources, as well as some interesting innovative methods for efficient use of energy, such as powerful light sources based on a plasmatron. Modernisation of existing and introduction of new environmentally acceptable technologies based primarily on gas, coal, and nuclear fuel, together with energy rationing, are seen as priorities, though admittedly all require immense investments. Some of the technologies discussed are specifically targeted towards the Russian landscape which is characterised by a harsh climate, huge space and distances, and widely dispersed consumers. Nevertheless, many of the issues, solutions and novelties discussed are ubiquitous and relevant to broader communities worldwide.

The next nine chapters deal with specific prospective technologies of energy conversion and storage, some already matured and ready for large-scale implementation, and some foreseen as feasible solutions in the mid-term period of the next two or three decades. Considered are wind, solar, nuclear, and hydrogen energy, fuel cells and their hybrid systems, clean and zero-emission coal conversion and combustion technologies, while missing are the conversion technologies of significance in future energy systems, like solar thermal, concentrated solar power, wave energy, heat pumps, biomass and biofuels and demand side efficiency and management technologies like passive buildings, modal shift in transport, dynamic road pricing, *etc.*

In Chapter 4, G. van Kuik, B. Ummels, and R. Hendriks present the state-of-the-art and perspectives of wind energy, emphasising its successful development and spreading over the last three decades. Issues considered include market and costs perspectives, technological development of wind turbines and wind power plants with a specific account of off-shore applica-

tions, grid integration, local and global impacts, and research agenda. The chapter closes with optimistic forecast on wind energy as a soon-to-become mainstream electricity source in a number of countries.

Chapter 5 presents a review of the development, technology and applications of photovoltaic cells and their role in a renewable energy scenario. Reiterating that solar radiation is the most abundant and the most fundamental sustainable energy source, and its direct conversion into electricity the most attractive and cleanest way of electricity production, A. J. McEvoy and M. Grätzel discuss various options of photovoltaic semiconductor materials, cell designs and their performances. Projected decreases in the production costs and current market trends (>30% growth per year) are expected to work in favour of PV. It is estimated that in 2030, PV could generate 4% of electricity worldwide.

R. van de Krol and J. Schoonman go a step further in Chapter 6 and consider the direct conversion of solar energy into hydrogen. The potential of using metal oxide semiconductors that can split water into oxygen and hydrogen is considered as a challenging alternative to photovoltaic cells, since hydrogen can be stored and used as a clean fuel for a variety of purposes, including vehicle propulsion. Interested readers can learn about the principles of operation, design concepts and their efficiencies, material requirements, main impediments and research challenges, as well as recent innovations based on nanotechnology that offer new promises in the development of this exciting new technology.

Another new concept, researched in Japan, is presented by K. Suzuki, H. Yoshida, and H. Iwai in Chapter 7. Anticipating that massive production of hydrogen from renewable energy sources will not reach a wide commercial appeal anytime soon, distributed energy generation is considered using the solid-oxide fuel cell, which can be combined with a micro gas turbine. This hybrid concept, based on mature modern technologies, is claimed to match the efficiency of most advanced oil-fired large-scale combined-cycle electricity generation plants. Distributed energy systems of this kind are seen as very promising, providing a low-emission, interim solution especially in areas with high concentration of population, business and industry, although, admittedly, high cost and durability of fuel cells still pose a serious challenge.

The next two chapters deal with nuclear energy, the revival of which is viewed by many as the most effective interim solution for stopping the ominous climate change before it is too late. In Chapter 8, D. G. Cacuci reviews the evolution of generations I to IV of nuclear fission reactor designs. Based on thousands of years of cumulated operation, convincing arguments are provided that matured industrial technologies are available today for all stages of fuel cycles, including spent-fuel treatment and the conditioning and storage of waste. Yet, in order to receive a wider public acceptance and to establish itself as a viable long-term energy option, a number of technological and societal prerequisites are still to be fulfilled. Current international initiatives and activities towards meeting the acceptance criteria are reviewed, leading to the conclusion that novel generation IV nuclear fission reactors will fulfil the criteria for sustainable nuclear energy. In Chapter 9, M. Cumo provides further support to optimistic prospects of nuclear energy by presenting a new fission reactor concept called MARS (Multi-purpose Advanced Reactor, inherently Safe), developed at the University of Rome "La Sapienza". Based on a passive safety concept, the MARS reactor meets very high safety standards and thus should be suitable for electricity production, district heating, water desalination, and other applications even in highly populated areas.

The last three chapters in Part I consider technologies for clean conversion of fossil fuels and related carbon-capturing methods. Recognising that fossil fuels will for long remain the dominant primary energy source in many countries, P. Mathieu discusses in Chapter 10 three possible options for capturing CO₂ during power generation: post-combustion removal of CO₂

from flue gases, pre-combustion carbon removal from fuel, and oxy-fuel combustion systems. The impact of each technology on plant performances, costs and pollutant emissions is considered. It is argued that all three technologies are proven and mature though associated with high costs. Each has its own pros and cons, but their scale up to large power systems and market penetration depends on political will and substantial financial incentives.

In Chapter 11, K. Okazaki presents a new CO₂ coal utilisation technology researched in Japan, which is based on system integration of clean coal combustion, CO₂ recovery and sequestration, and hydrogen production from coal and its utilisation. It is argued that such combined systems could play an important role in suppressing CO₂ emissions in the interim period up to 2030-2050 when fossil fuels could be to a large degree eliminated by widespread use of renewable energy. Part I closes with Chapter 12 in which H. Spliethoff also gives a brief overview of possible CO₂ separation methods, but focusing on coal-fired power plants. Oxy-fuel processes are then considered in more detail, followed by a feasibility analysis of steam generator designs suited for coal combustion with pure oxygen. Different methods for limiting the maximum temperature are discussed. Among several schemes, an innovative controlled fuel/oxygen staged combustion with rich/lean burners, researched at the Technical University of Munich, is seen as a promising technology for coal utilisation in power production.

Part II, entitled Initiatives in South-East Europe begins with Chapter 13 in which E. Kakaras, A. Doukelis, D. Giannakopoulos, and A. Koumanakos present an analysis of possible retrofitting of domestic low-quality coal-fired power plants by oxy-fuel combustion and flue gas decarbonisation by amine scrubbing. The study, based on thermodynamic simulations, indicates the potential to reduce CO₂ emission by 70-85%, though at considerable energy penalties and associated reduction in plant efficiency. Nevertheless, the study shows that retrofitting could provide electricity at costs comparable to natural gas units.

Chapter 14 by U. Lavrenčič-Štangar and E. Kranjčević gives a survey of renewable energy in Slovenia. Despite a relatively significant share of 11% in the country's total energy supply, it is recognised that the major contribution comes from the conventional hydro-plants and that major efforts are needed to utilise the relatively large potential of other renewable sources. This exemplary analysis of the current and potential participation of renewable energy closes with a short description of several new initiatives for promoting the exploitation of renewable energy sources. The contribution from Bulgaria, presented by P. Stankov, D. Mladenov, and K. Stanchev in Chapter 15, deals with energy wood production and use in the framework of the country existing laws and regulations, the energy market and entrepreneurship. Considered is the present status of the wood processing industry, the structure of wood biomass and its potential for energy production. This is followed by an outlook of the perspectives for further development of wood biomass industry and its increased role in providing a portion of Bulgaria energy needs. Most countries in the area have a similar climate and orography with large percentages of the land covered by forest and agriculture. Thus, sufficient bio-resources for sustainable development of biomass energy should be available.

The last three chapters in Part II present overviews of the current status and plans for future developments in the energy sectors in Serbia, Macedonia, and Bosnia and Herzegovina, while Albania, Croatia, and Montenegro are ominously missing. Comprehensive information on the energy status and prospects in smaller and transitional countries is scarce in the open literature, in contrast to the detailed surveys available for the large, developed and populous states. Although the reviews presented here may not be exemplary, some features are common to a number of countries of a similar size, level of development and structure of the energy sector.

In Chapter 16, S. Oka gives a review of the available energy resources, present and projected future consumption, and the state of the current energy industry in Serbia, and identifies

energy efficiency as the most critical issue. The problems are rooted in outdated technology, energy-intensive industry, inadequate management, inappropriate energy strategy and pricing policy, and the lack or neglect of standards and regulations. It is argued that apart from technology modernisation, which requires large investments, most other causes of inefficiency could be removed or diminished in a relatively short time. The National Energy Efficiency Programme offers plausible solutions that could significantly improve the country energy situation, but is still awaiting political decision and, admittedly, a more favourable economic environment.

Because of modest primary energy resources in Macedonia, B. Donevski in Chapter 17 advocates the country future economic developments to be based on low-energy-consuming industries that should bring significant reduction in energy consumption and demand. Another prospect is seen in expanding the grid connections with neighbouring countries and taking the advantage of the favourable geostrategic location of Macedonia to become a major energy hub in the region.

In contrast, A. Lekić in Chapter 18 considers that substantial primary energy resources in Bosnia and Herzegovina offer prospects for a profitable energy industry. Subject to political consolidation of the country, substantial foreign investments are expected both for modernisation of the existing and erection of new coal-fired and hydro power plants, which could make Bosnia and Herzegovina a significant energy exporter in the region.

Neven Duić

Professor, University of Zagreb, Croatia