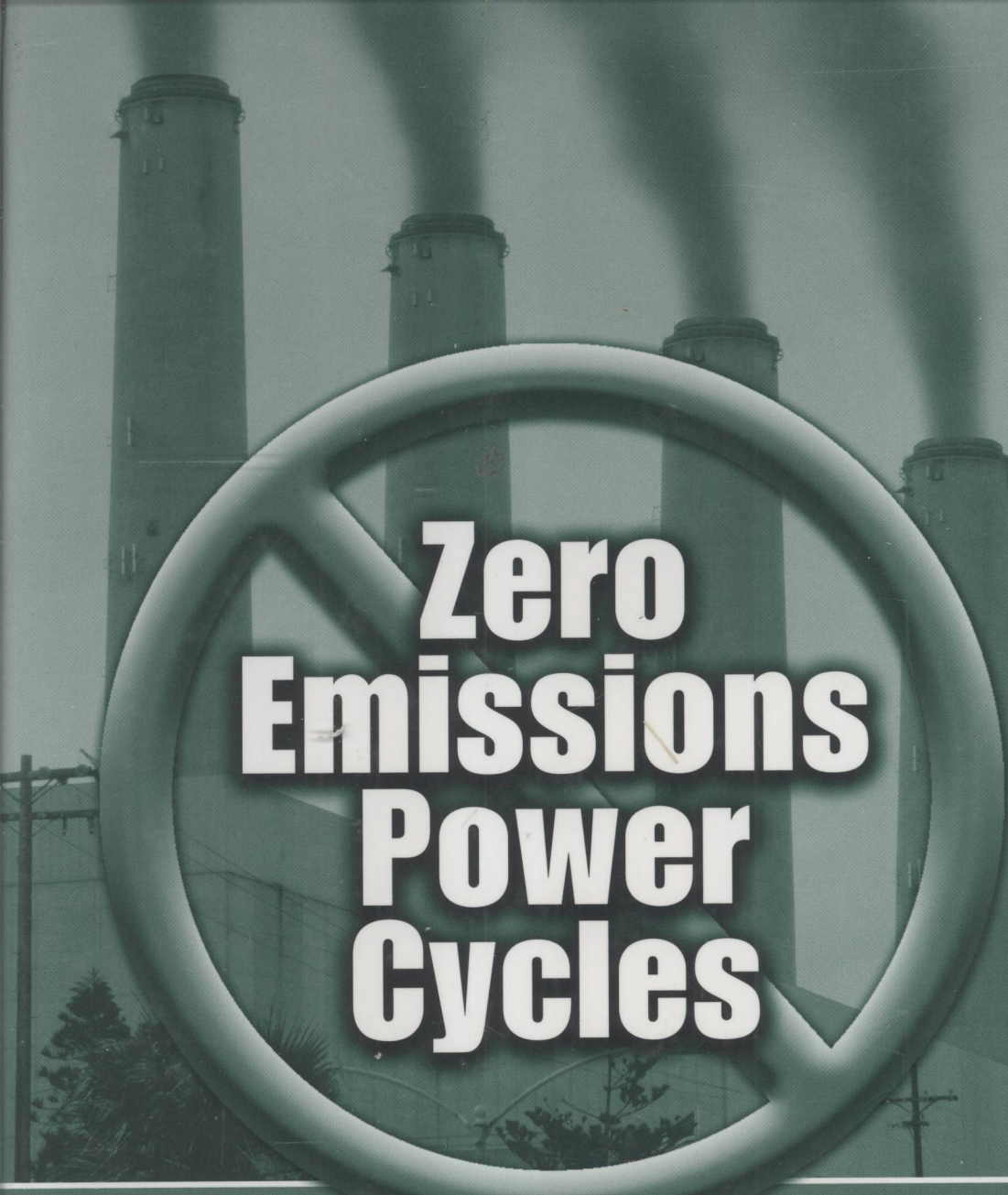

Zero Emissions Power Cycles

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CRC Press
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Zero Emissions Power Cycles

Preface

The idea for this book originated long ago in discussions with Professors David A. Frank-Kamenetsky, John O'M. Bockris, and Gustav Lorentzen.

The present text is compiled from the papers published since 1991, alone or with colleagues including Professors J. A. McGovern, J. W. Gorski, M. K. Shokotov, and N. N. Akinfiev. I am very thankful to all of them for the permission to integrate and use these works. The papers are listed in the references.

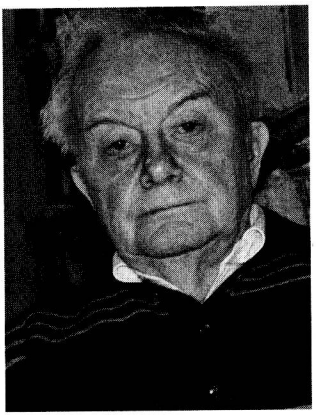
At the beginning of the twenty-first century, it is possible to speak realistically about electric power production burning fossil fuel without pollution, by using developments in materials, combustion technologies, cooling techniques, and creative cycle concepts. Alternative approaches to the production of power using fossil fuels without pollution have been proposed in the United States and Europe, and these proposals are being continually improved. This volume describes and evaluates some existing alternative approaches for the potential benefit of students, industry members, and regulators. This work does not deal in detail with the so-called renewable technologies, such as photovoltaics (solar cells), wind turbines, tidal motion systems, or geothermal systems, because these systems do not employ fossil fuel for combustion as a means of generating electricity. In this work, the focus is on fossil-fuelled, nonpolluting power generation systems. Numerous alternative technologies are emerging and we seek here to explain these technologies and their relative merits. The topics and technologies described in this work are continually advancing, but the basic concepts and operational characteristics of the systems described are not expected to change significantly in the coming years. We believe the time is right to record and describe some of the new emerging technologies. The G-8 meeting of world leaders set a goal of "50% till 2050" to reduce emissions (with a multi-trillion dollar funding). It makes for great business with the building of hundreds of zero emissions power plants.

Note: in the book, Chapters 3 and 6 have been written with Jan Gorski, and Chapter 7 and Section 9.3 were written with Mykola Shokotov.

I wish to thank leading researchers of Clean Energy Systems, Inc., Dr. R. Anderson, and Dr. S. Doyle for their help in editing the first two chapters of the book and for the moral support of the book publishers.

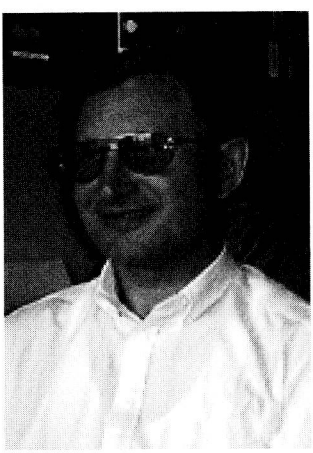
E. Yantovsky
Aachen, Germany

Biographical Notes



E. Yantovsky, Ph.D., was born in Kharkov, Ukraine, in 1929. His main areas of interest are magnetohydrodynamic generators and pumps, heat pumps, zero emission power plants with membrane oxygen for combustion, energy and exergy currents, and exergonomics. Professor Yantovsky graduated from the Aviation Institute in Kharkhov and moved to Taganrog to work on the production of large hydroplanes. In 1953, he returned to Kharkov and worked in a large electrotechnical plant where he was responsible for testing the air and heat flow of electrical machinery. For a short time, he worked as a designer of large synchronous motors. From 1959 to 1971, he was the head of the MHD Laboratory in Kharkov, where the magnetohydrodynamic (MHD) liquid metal generator was built and tested, with the intention of powering a space ship to Mars. professor Yantovsky joined the Krjijanovski Energy Institute in 1971 as a senior researcher, and then in 1974, he began work in the same capacity for the Institute for Industrial Energetics. Between 1986 and 1995, Professor Yantovsky was chief researcher at the Energy Research Institute of the Russian Academy of Science. He has also undertaken numerous visiting lectureships throughout Europe and the U.S. As an author, Professor Yantovsky has written six books and published over 40 articles in English (including *The Thermodynamics of Fuel-Fired Power Plants without Exhaust Gases* in 1991 and *The Concept of Renewable Methane* in 2000). He lives in Aachen, Germany.

(From *Founders of 21st Century,* Intern. Biogr. Centre, Cambridge, 2003, p. 661).



Jan Gorski, Ph.D., D.Sc., was born in 1945 in Letownia, Poland. He is a specialist in the area of applied thermal sciences and energy conversion systems. The particular subjects of his research interest are the problems of dense gas phenomena in the thermodynamic and flow process simulation. In over 30 years of professional experience, he has worked in the aeronautical industry as a gas turbine design engineer. Since 1974, he has been a tutor and an associate professor at both the Mechanical & Aeronautical Faculty of the Rzeszow University of Technology and the Faculty of Civil & Environmental Engineering. He is a member of EUROMECH and a member of two committees of the Polish Academy of Sciences.

Dr. Gorski has also worked as a visiting professor at the Universidad Nacional Autonóma de México in 1982 and has given a number of lectures throughout the European Union.

Mykola Shokotov was born in 1926 near the city of Lugansk, Ukraine. Between 1943 and 1945, he served in the military in WWII, including the storm of Berlin. Between 1950 and 1955, he attended the Kharkov Polytechnic Institute (KhPI), followed by three years as a designer of turbines and superchargers in a piston-engine factory. For 40 years, he worked as a lecturer then docent and professor in the Department of Internal Combustion Engines at KhPI. Along with lecturing, he was engaged in the scientific development of diesel engines for transport and industry. For many decades, he was a consultant to a large Kharkov mill, manufacturing diesel engines for the transport sector. Professor Shokotov has published about 200 papers in technical journals and six textbooks. Since 1998, he has lived in Germany.

Acronyms

AZEP	Advanced zero emission power
BFW	Boiler feed water
C	Compressor
CAR	Ceramic autothermal recovery
CC	Combustion chamber
CES	Clean Energy Systems, Inc.
CHP	Combined heat and power
COOPERATE	CO_2 prevented emission recuperative advanced turbine energy
CW	Cooling water
DOE	Department of Energy
EG	Electric generator
EM	Electric motor
EOR	Enhanced oil recovery
ECBM	Enhanced coal bed methane recovery
ESA	European Space Agency
FBC	Fluidized bed combustor
FT	Fuel tank
GHG	Green house gas
HE	Heat exchanger
HP	High pressure
HPT	High pressure turbine
HTT	High temperature turbine
HRSG	Heat recovery steam generator
HX	Heat exchanger
IEA	International Energy Agency
INJ	Fuel injector
IP	Intermediate pressure
IPT	Intermediate pressure turbine
IGCC-MATIANT	Integrated gasification coal cycle MATIANT
ITM	Ion transport membrane
ITMR	Ion transport membrane reactor
L	Luft (air)
LHV	Lower heating value
LP	Low pressure
LPT	Low pressure turbine
MATIANT	Cycle designed by MAThieu and IANTovski
MCM	Mixed conducting membrane
MHX	Multi-heat-exchanger
MPT	Mean pressure turbine
NG	Natural gas

OITM	Oxygen ion transport membrane
P	Pump
PE	Piston engine
R	Radiator
RH	Reheater
SOFC	Solid oxide fuel cell
TC	Air turbocompressor
TIT	Turbine inlet temperature
WS	Water separator
ZECA	Zero Emission Coal Alliance
ZEMPES	Zero emissions membrane piston engine system
ZENG	Zero Emission Norwegian Gas
ZEITMOP	Zero emissions ion transport membrane oxygen power
ZEPP	Zero emission power plant

Contents

1 Controversial Future

1.1 INTRODUCTION AND FORECAST

Energy policy is full of controversies. Some people believe that fossil fuels will soon run out and contend that we need to think more about nuclear and renewable energy sources (solar, wind, geothermal, tidal) especially in view of perceived global warming. Greenhouse warming is caused by the greenhouse effect of the Earth's atmosphere. Some contend that warming is caused by the emission of combustion products from power plants and motor vehicles. Other people, including the authors of this book, believe that enough fossil fuels (gas and coal) are available to last at least for this century, that nuclear power is dangerous, and the German government's decision to eventually shut down all the German nuclear reactors may be a precedent for other countries. Renewables are beneficial alternative energy sources but only for the next century. Because of their high cost, renewables cannot dominate the energy supply for this century.

The world energy balance for 2030, as forecast by the International Energy Agency (IEA) and shown in Figure 1.1, illustrates the expected trends in energy supplies.

The IEA forecast anticipates the nuclear share to significantly decrease, while the share for renewables remains the same, and the share for fossil fuels is projected to increase by 2%, from 80% in 2002 to 82% in 2030.

The projected increase in the percentage of energy being provided by hydrocarbon fuels is important in view of the irreconcilable controversy between "peakists" and "non-peakists." The former are certain that the world soon will run out of oil and some years later, run out of gas, which will lead to serious economic problems, possibly escalating to wars over oil. The crucial point is that there will be a peak of oil production with a gradual decline afterward. Graphs of production versus time are depicted by a bell-shaped curve.

Specialized groups of "peakists" actively promote their views in the public media and on numerous Internet sites (e.g., www.energy-bulletin.net, and www.lifeafter-theoilcrash.net). Their opponents, "non-peakists," contend that a peak in oil production due to dwindling resources has been forecasted many times, and all of the forecasts were wrong. The oil resources are finite in principle but still rather large. Natural gas, mainly methane, is chemically much simpler than oil and, according to the abiogenic theory of gas origination, it might be produced naturally in the Earth's depths. The discovery of seas of liquid methane on cold planets adds credence to that theory. The most radical "non-peakists" refer to the "peakists" as "professional pessimists."

The world's largest oil company, Exxon Mobil, concluded on their website (www.exxonmobil.com) that, "With abundant oil resources still available — and industry, governments and consumers doing their share — peak production is nowhere in sight."

Considering the forecast of the IEA, the most authoritative international body in the energy field, the authors believe hydrocarbon fuels, including coal, will be

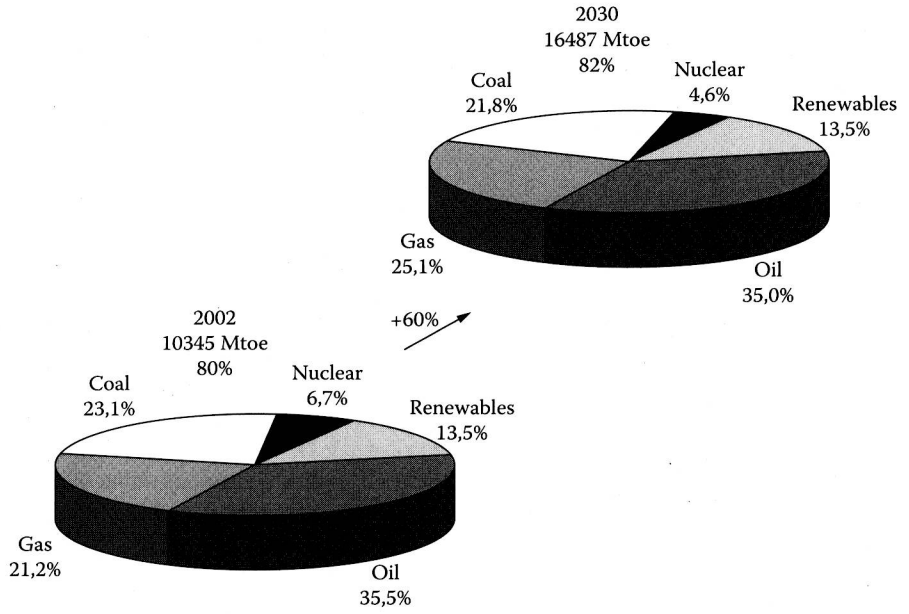


FIGURE 1.1 Forecast of the International Energy Agency published in 2004 on the world energy balance in 2030. (Data from World Energy Outlook, 2004.)

the dominant fuels in the 21st century. This means the primary impediment to their continued use is atmospheric pollution, which is a real cause for concern. This book shows alternative ways to prevent such pollution.

The reality of global warming now seems to be beyond controversy. It definitely exists. Not only precise measurements but also anecdotal evidence, such as the melting of polar ice and other climatic events, reveal the global temperature is increasing. It is now clear that there is a problem. Controversy remains over the appropriate response and the solution to the problem. This controversy generates two questions: (1) who is responsible, and (2) what should be done?

The most authoritative evaluation to date of the first question has been done by the United Nations' Intergovernmental Panel of Climate Change (IPCC), organized jointly by the World Meteorological Organization (WMO) and the United Nations Environment Program (UNEP). In its most recent report, the IPCC stated that climatic changes seen around the world are "very likely" to have a human contribution. By "very likely," the IPCC means greater than 90% probability.

At the launch of its Fourth Assessment reports, the IPCC chairman, Dr. Rajendra Pachauri stated the following: "If one considers the extent to which human activities are influencing the climate system, the options for mitigating greenhouse gas emissions appear in a different light, because one can see what the costs of inaction are."

The accuracy of IPCC forecasts is evident. The IPCC 2001 report forecast a temperature increase in 5 years as 0.15 to 0.35°C. The actual measured change was 0.33°C,

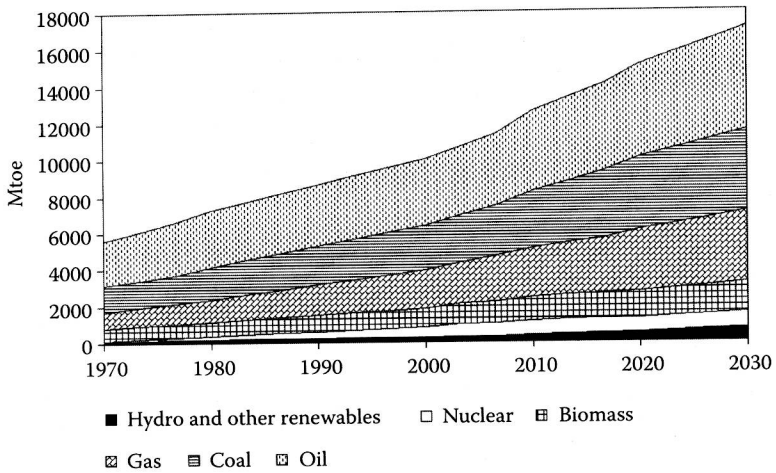


FIGURE 1.2 World primary energy demand by fuel in the reference scenario. (*Source*: World Energy Outlook 2006, International Energy Agency, OECD/IEA, 2006.)

very near to the top of IPCC range. The world energy demand as forecast in the 2006 IEA report and shown in Figure 1.2 offers the same forecast as in Figure 1.1.

The authors believe that the domination of fossil fuels as an energy source is beyond dispute and will persist for decades. This presents a real problem considering the gradually increasing share of energy that oil and gas are anticipated to provide.

Historically, world generation of electrical energy and the forecast through 2030 are even more significant. The history and forecast are presented in Figure 1.3.

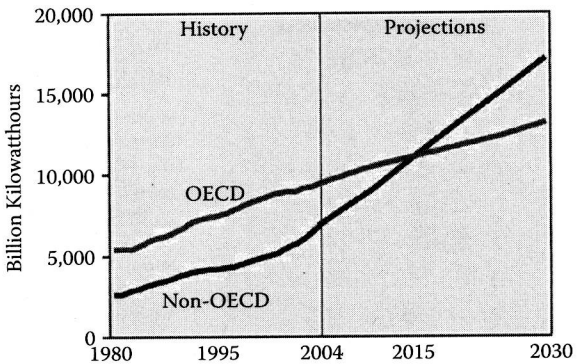


FIGURE 1.3 Historic and projected world electrical power generation by region. (*Source*: History: *International Energy Annual* 2004, Energy Information Administration (EIA), May–July 2006, (www.eia.doe.gov/iea); (Projections: System for the Analysis of Global Energy Markets, Energy Information Administration (EIA), 2007.)

From Figure 1.3, it is evident that significant growth is expected in the Organisation for Economic Co-operation and Development (OECD) sector and the growth in the non–OECD sector is even more pronounced. China and India play major roles in the latter sector.

1.2 REASONS FOR CLIMATE CHANGE

The possibility of global warming due to increasing concentrations of carbon dioxide in the atmosphere was forecast by Joseph Fourier in 1827 and, in more detail, by Svante Arrhenius in 1896. M. I. Budyko, in 1970, gave a description of the phenomenon, using all available geophysical information. Many controversies have appeared, pointing out not only warming, but also cooling effects in the atmosphere. Recent data have confirmed the excess of warming as measured in radiative forcing (i.e., positive and negative energy currents expressed in watts per square meter) and the skyrocketing increases in the concentration of greenhouse gases (CO_2, ppm, CH_4, ppb, and N_2O, ppb) in the atmosphere which are major forcing factors. The radiative forcing currents and the concentrations of greenhouse gases are shown in Figure 1.4.

"Positive forcing" means warming, whereas "negative forcing" represents cooling. From Figure 1.4, it can be seen that in ancient time, before human impact, positive and negative forces were almost equal with the possibility of cooling (ice ages). In recent times, the concentrations of greenhouse gases have skyrocketed, producing strong positive radiative forcing.

The authors thus conclude that there is incontestable evidence that global warming is occurring. Qualified international cadres of experts also believe that there is a significant human contribution to the problem, that it is essential for humanity to address this issue, and reasonable and effective ways to minimize human contributions to global warming must be found.

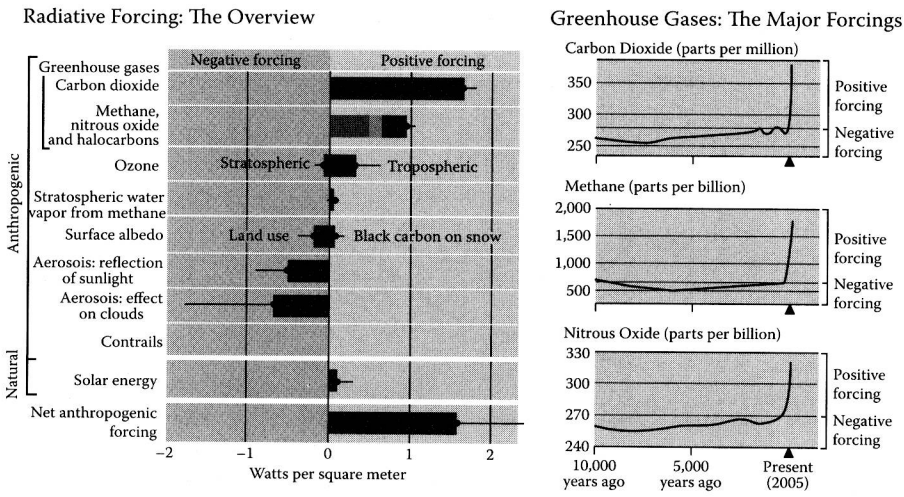


FIGURE 1.4 Overview of radiative forcing factors and the concentration of greenhouse gases in the atmosphere (*Sci. Am.* 8/2007, 67. With permission of the artist, Deaniela Naomi Molnar).