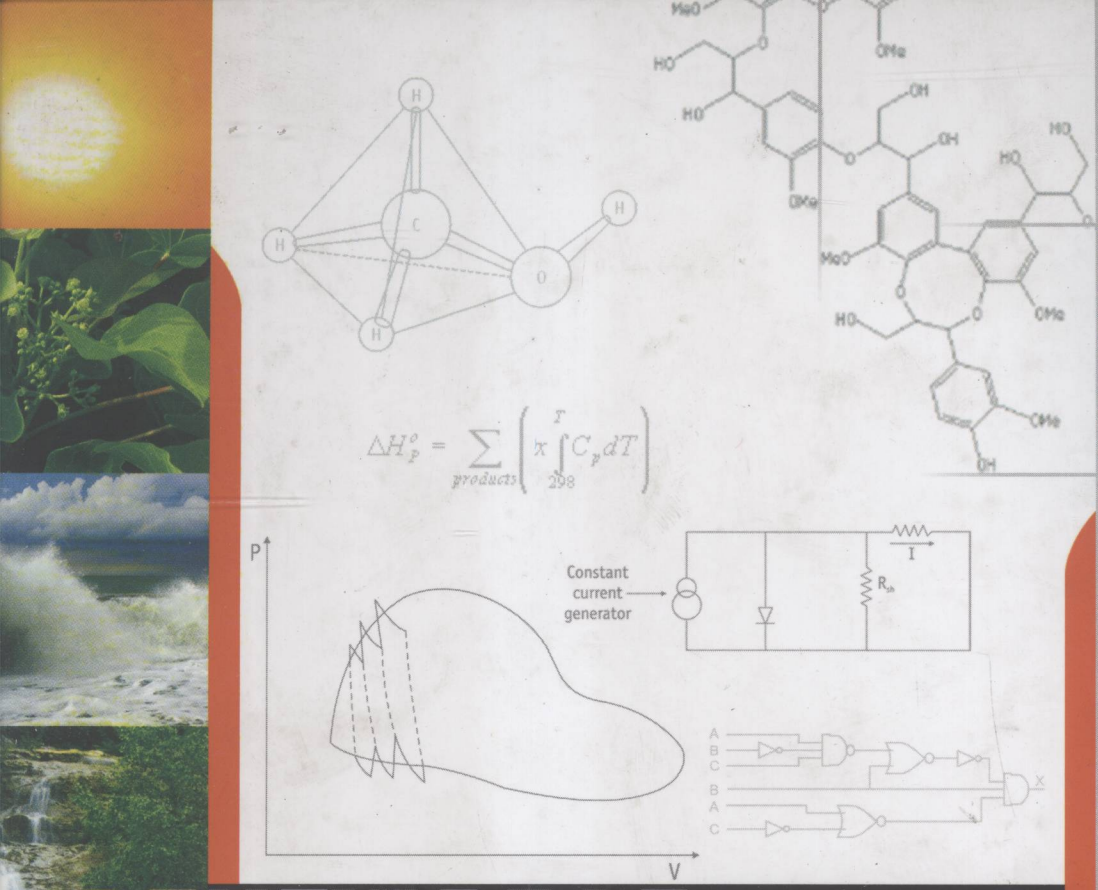

RENEWABLE ENERGY ENGINEERING AND TECHNOLOGY

PRINCIPLES AND PRACTICE

Edited by
V V N Kishore

Renewable Energy Engineering and Technology

Principles and Practice

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Renewable Energy Engineering and Technology

Foreword

As humanity progresses in the 21st century, it would in future encounter major challenges in terms of ensuring adequate and equitable provision of energy. While the 20th century was characterized by growing dependence on fossil fuels, the current century would have to deal with the depletion of reserves of fossil fuels, growing environmental problems as a result of production and use of these fuels as well as the threat of climate change, which results from the emissions of GHGs (greenhouse gases) due to the combustion of fossil fuels. There are, therefore, several reasons for the world to explore with some urgency alternative sources of energy supply. The IPCC (Intergovernmental Panel on Climate Change) has clearly established that warming of the earth is unequivocal and that while adaptation measures in the short run would require to be implemented with a sense of urgency, mitigation measures to reduce the emissions of GHGs are crucial and essential.

This poses a major challenge for those dealing with energy decisions, particularly in the context of bringing about a major transition to renewable sources of energy. In 1998, I was the president of the International Association for Energy Economics, a body then consisting of about 3000 professionals including academics and senior leaders from the energy supply industry as well as other sectors. In my presidential address, on the occasion of the annual international conference of this body, I made the following statement: 'one area where our profession needs to make a much stronger entry than it has thus far achieved is in the field of energy–environment interface issues. Not only are the direct environmental effects of energy, such as air and water pollution and acid rain, serious enough to merit attention, but there is also now a definite basis for concern over the effects of energy use and production on the global climate. We can postpone a deeper interest in the subject only at the risk of a continuing insularity and myopia. Climate changes are already resulting in serious problems in the tropics in the form of frequent droughts and floods.'

Recent statements by several world leaders express the need to bring about deep cuts in the emission of GHGs, particularly carbon dioxide. This would be possible only with a major shift towards renewable energy technologies. The IPCC's *Fourth Assessment Report* has assessed several scenarios. In one of the scenarios, concentration of GHGs can be stabilized to limit temperature increase at an equilibrium of 2.0–2.4 °C. In order to reach this level of stabilization, a reduction of 50%–85% in the current level of emissions would be required by 2050. Needless to say, such a shift towards a low-carbon economy can only be achieved through a major movement towards greater use of renewable energy.

Development of renewable energy systems for various applications, coupled with their implementation, is a challenging task as it involves understanding of a multitude of disciplines. Developing countries including India need diverse renewable energy products and services, which need to be developed locally to make them affordable and sustainable. This book, which covers several aspects of design, sizing, and system integration, attempts to address the basic needs of a renewable energy designer and developer. The emphasis on the basics of engineering design and practical examples will make the task of system designers easy. The book is well timed to fulfil the needs of students as well as practitioners at all levels. It will also help students from diverse backgrounds such as architecture, biochemistry, and physics to understand the required basics of engineering science. I congratulate the editor and authors of *Renewable Energy Engineering and Technology – a knowledge compendium* for publishing such an important and useful piece of work.

R K Pachauri

Preface

This book is the partial outcome of a dream project that aimed at putting 'everything under the sun' in one place. Conceived nearly three years ago, this book was planned to cover various items, including core subjects like solar thermal engineering, photovoltaics, wind energy, biomass energy, along with ancillary subjects like economic/financial analysis, rural energy, techno-social interaction, energy planning, among others. In addition, we thought of covering different manufacturers, standards, policy issues, educational institutes, renewable energy experts, and so on. It was soon realized that it would not be possible to produce such a mammoth work in such a short span of time, and we settled to cover only the core subjects as a first attempt.

Every branch of engineering has its own genesis, growth, and stabilization. For example, as late as the 1960s, chemical engineering was considered as a new and somewhat risky branch with uncertain job markets, compared to conventional branches such as civil, mechanical, and electrical engineering. Soon, however, it established itself as a core branch of engineering. More recently, because of the IT (information technology) revolution, several branches of engineering have emerged, which were hitherto not considered as viable career options.

Renewable energy engineering is yet to establish itself as a viable branch. However, it may happen sooner than later. The Nobel Peace Prize for the IPCC (Intergovernmental Panel on Climate Change) is the ultimate recognition of the fact that climate change is a result of rapid development and that there are no viable solutions other than sustainable energy solutions. There will be a huge interest in the study of philosophy, science, engineering, and technology of sustainable energy in the coming years. In India, for example, the demand for energy professionals is growing rapidly, and the 1000-odd postgraduates coming out of various 'centres of energy' are deemed as inadequate compared to the demands of the growing industry. This book lays the foundation for an entirely new branch of engineering, renewable energy engineering.

There is vast and rich literature available on renewable energy. Several books on renewable energy, published both in India and abroad, are available, but most of these are in the specialization category. Also, many of these books are not targeted at practitioners. It is well known that renewable energy is a multidisciplinary area, requiring knowledge of basic sciences such as physics, chemistry, biology; applied sciences such as material science; and engineering subjects such as mechanical, chemical, and electrical. Many existing books on renewable energy cover only a few basics relevant to the topic. The main aim of this book is to provide a broad background so as to cover as many renewable energy topics as possible.

The other important aspect of the book is that almost all the authors who have contributed to the various chapters are essentially practitioners. Right from its formative years, TERI laid a lot of stress on product development and field implementation, along with basic and applied research. Thus, along with incorporating the scientific and technical content, we endeavoured to capture the rich practical experience gained at TERI during the past two decades.

The first two chapters establish the raison d' être of renewable energy. The third chapter tries to establish a foundation of broad scientific and engineering principles required to understand the design basis of renewable energy systems. This chapter includes topics like properties of matter, material and energy balances, thermodynamics, fluid flow, heat transfer, mass transfer, and is normally covered in the first two years of chemical/mechanical engineering streams. This chapter serves as a bridge material for non-engineering students and as a brief review for engineering students.

Chapters 4–7 cover solar energy basics and applications. The resource characteristics of solar radiation are covered in Chapter 4, followed by photovoltaics, solar thermal engineering, and solar passive architecture in Chapters 5, 6, and 7, respectively.

Wind energy is covered in Chapters 8 and 9, and small hydro is covered in Chapter 10. Four important energy sources, namely, geothermal, tidal, wave, and ocean thermal are covered in Chapter 11. We realize that each of these subjects deserves complete and independent treatment, but we had to limit the coverage owing to two reasons. First, not much work has been done in India and, hence, expertise was found to be lacking. Second, the potential for these resources, either technical or economical, is yet to be established firmly in the Indian context.

Chapters 12–15 cover various topics in bio-energy utilization, which is emerging as a very important subject both in developed and developing

economics. The resource characteristics are covered in Chapter 12, followed by thermo-chemical conversion, biochemical methods of conversion, and liquid biofuels in Chapters 13, 14, and 15, respectively.

As mentioned earlier, there is an urgent and huge task of human resource development in renewable energy so as to tackle the challenges of climate change and sustainable development in the current millennium. We hope that this book serves as a pilot for much bigger human resource development initiatives.

V V N Kishore

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The editor and authors thank Dr R K Pachauri, Director-General, TERI, for his overall support, encouragement, and perseverance during the course of writing this book.

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Contributors

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Dr V V N Kishore is a Senior Fellow at the Energy–Environment Technology Division, TERI, and Adjunct Faculty at the Centre for Energy and Environment, TERI University.

He is a chemical engineer by training. After graduating from Andhra University, Waltair, he obtained his MTech degree and his doctorate from IIT (Indian Institute of Technology), Kanpur. He started working in the area of renewable energy technologies in 1978, first at IIT Kanpur and later at CSMCRI (Central Salt and Marine Chemicals Research Institute), Bhavnagar. He joined TERI in 1984 and served in various capacities as Area Convener, Dean (Energy–Environment Technology Division), Advisory Board member, and Resource Adviser. Over a long span of about three decades, he has acquired a vast experience in the broad area of renewable energy utilization, covering basic research, product/process development, field testing, technology transfer, execution of turnkey projects, policy research, consultancy, training and capacity building, and teaching. He has trained a large number of professionals in renewable energy in a wide range of topics such as solar thermal energy, biomass gasification, biomass densification, bio-methanation, solar passive building design, techno-economics of renewable energy systems, emission measurements, system integration, and so on. His current activities include distributed power generation through biomass gasification, gasifier thermal applications, high performance biomass cook stoves, lignocellulosic ethanol, and solar thermal–biomass hybrid systems. He has eight books, 160 publications in journals/conference proceedings, numerous reports, 30 products/end-use packages, and eight patents to his credit. He was a visiting fellow at Kennedy School of Government, Harvard University, USA and a consultant for the World Bank and for Winrock International, Washington. He teaches and guides PhD students at TERI University. He was on many expert evaluation/monitoring committees of MNRE (Ministry of New and

Renewable Energy), TIFAC (Technology Information, Forecasting, and Assessment Council), CSIR (Council of Scientific and Industrial Research), among others, and served SESI (Solar Energy Society of India) for many years as secretary and secretary/treasurer. He is a member of ASME (American Society of Mechanical Engineers), AIChE (American Institute of Chemical Engineers), and ACS (American Chemical Society), and a Fellow of World Technology Network. He is the recipient of Dr K S Rao Memorial Award of SESI for 2001 for outstanding contributions to the field of new and renewable sources of energy. He has travelled extensively all over the world on account of professional assignments, conferences, and so on.

Amit Kumar

Amit Kumar is a Senior Fellow and Director, Energy–Environment Technology Division, TERI. He studied mechanical engineering with specialization in thermal engineering from IIT, Roorkee. He has been working on the development and diffusion of renewable energy in India for 25 years. His experience ranges from policy and programme formulation, to project implementation, design and development of renewable energy technologies, and manufacturing of solar energy devices.

At present, he is responsible for research activities in the field of renewable energy, sustainable building design, and resource-efficient process technology applications in TERI. Besides coordinating part of a multi-country GEF-(Global Environment Facility) supported study to assess solar and wind resources in developing countries, he is also actively involved in a project related to the development of Sri Lanka's policy framework for renewable-resource-based electricity generation. At the field level, he managed the construction and commissioning of one of the largest solar ponds at Bhuj in western India from 1987 to 1996, and Asia's first solar-powered cold storage in the early 1980s.

Besides, he is also actively involved in activities related to knowledge management and sharing. He was a member of the Renewable Energy Subcommittee of the International Performance Measurement and Verification Protocol, US Department of Energy and the Climate Change Advisory Group to the Government of India. He was involved in the preparation of the National Renewable Energy Policy Statement and was member, Working Group for Non-conventional Energy Sources for formulation of the Tenth Five-year Plan; besides being an Alternate Member, Working Group on Non-traditional Sources of Energy and on R&D (research and development) in India within the Subgroup on Energy Security set up by the National Security

Council Secretariat, Government of India. He also worked as Renewable Energy Expert for the Asian Development Bank. He has published more than 20 papers in reputed national and international journals.

K V Rajeshwari

K V Rajeshwari is a Fellow at the Energy–Environment Technology Division, TERI. Her areas of interest include research and technology development in the field of waste water treatment and solid waste management. After having completed 10 years of research in the field of application of biochemical process for waste treatment, she has gained expertise in designing of biodigesters and various microbiological and analytical techniques. She has been involved in the development of reactor designs for industrial effluent treatment and solid waste digestion at IIT Delhi and TERI. A patent has been filed for her research resulting in the development of a novel process for degradation of solid wastes.

Jami Hossain

Jami Hossain is the Director, Programmes, and Secretary, Indian Wind Energy Association. A mechanical engineer by training, he is a known international expert on wind energy. Having implemented the very first wind farm projects with grid-connected wind turbines in India, he has more than 20 years of experience with renewable energies, primarily with wind energy. He also conducted the very first studies of assessment of potential for wind farms in India, grid integration of renewables, and assessment of wind energy sites based on geomorphological indicators that provided useful inputs to policy-makers in the early stages of wind power development in the country. He has played a key role in wind turbine technology transfer and was responsible for introducing cutting-edge wind turbine technologies from Europe to India through joint ventures and collaboration in manufacturing. He specializes in wind turbine technology, wind resource assessment, wind farm site selection, project planning and implementation, renewable energy programmes, policy formulation and interpretation, and modern communication approaches and technologies. In India, large wind farms have come up on many sites selected by him.

Jami Hossain has worked closely with various wind turbine manufacturers such as Enercon, Vestas, Micon, and Suzlon, and has been associated with research institutions such as TERI, New Delhi, and DRAL (Duff, Rutherford Appleton Laboratory), UK. He initiated wind energy research at TERI in 1986

and has trained many professionals under him, who are now serving the industry. He has also worked with international NGOs (non-governmental organizations) like Winrock International in their Clean Energy Group and has been a part of World Bank missions to Cambodia and Sri Lanka. He has been an external evaluator for many prestigious wind energy projects. He has published two books and more than 20 papers in international journals and conference proceedings.

In addition to interests in wind energy, Jami Hossain also has interests in journalism and interacts with industry associations. He has worked as Associate Editor in the Business Publications Division of the Indian Express group of newspapers. Currently, he is the editor of a magazine, *In Wind Chronicles*. He has been associated with the Independent Power Producers' Association of India and currently heads the programmes of InWEA (Indian Wind Energy Association). He also works closely with the WWEA (World Wind Energy Association) and is the member and coordinator of the International Programme Committee of the WWEA.

Malini Balakrishnan

Dr Malini Balakrishnan is a Fellow, Energy–Environment Technology Division, TERI. She currently leads the group on Resource Efficient Process Technology Applications. She has nearly 20 years of professional experience and her major interests are development and dissemination of environmentally sound technologies, with emphasis on membrane applications and value-added utilization of waste materials. In addition to research activities, she teaches postgraduate courses and guides doctoral students at TERI University, where she is an Adjunct Faculty. Dr Balakrishnan obtained her doctorate in biochemical engineering from IIT Delhi, masters in chemical engineering from the University of Waterloo, Canada, and a bachelors degree in chemical engineering from BITS (Birla Institute of Technology and Science), Pilani. She has over 70 publications in journals and conferences to her credit.

Sanjay P Mande

Sanjay Mande is a Fellow at the Energy–Environment Technology Division, TERI. After obtaining a bachelors degree in mechanical engineering, he completed his masters from IIT Mumbai, with thermal and fluids engineering as specialization. He has also completed his PhD in environmental sciences. For

almost two decades, he has been working on the development and promotion of various renewable and energy-efficient technologies. He has been working on low-temperature solar thermal systems, development of solar double chimney system for thermal conditioning of buildings in composite climate, and development and promotion of biomass gasification technologies (both thermal as well as power applications) for various applications. Recently, he has initiated research activities in the area of liquid biofuels, optimizing bio-diesel production, and utilization technologies. He has one book, over 30 national international project reports, and over 55 publications in several national and international journals/conference proceedings to his credit. He has two patents—'energy-efficient dryer for cash crops' and 'an updraft gasifier use with a large cardamom drying system'. He is also an Adjunct Faculty at TERI University, where he teaches and guides PhD students. He is a life member of SESI, ISREE (Indian Society of Renewable Energy Education), Indian Chapter of the ICTP (International Centre for Theoretical Physics), and member of BUN India, India Section of the International Biomass User's Network. He has served as associate editor for the SESI journal and editor of the SESI newsletter for several years.

Ashish V Kulkarni

Ashish V Kulkarni is a Research Associate, Energy–Environment Technology Division, TERI. An electrical engineer from Nagpur, he has experience of working on different aspects of renewable-resource-based power-generating plants. He is involved in activities ranging from resource assessment, product development, installation, commissioning, and regulatory and policy-related aspects. He has also worked on electrical research and development projects such as development of electronic load controller at IIT Delhi.

Mahesh C Vipradas

Mahesh C Vipradas is a Fellow, Energy–Environment Technology Division, TERI. His core research area is solar thermal devices and he has been involved in design, development, and testing of a solar desalination system. He is presently working on a roadmap for renewable power in the restructured power sector. In addition, he has worked in the areas of climate change and developed baselines for renewable energy project in India. He holds an MSc degree in physics and MTech degree from IIT Delhi in energy studies.

Parimita Mohanty

Parimita Mohanty is an Associate Fellow, Energy–Environment Technology Division, TERI. She holds an MTech degree in energy science and technology from Jadavpur University. She has been involved in activities related to solar PV (photovoltaic) technology such as solar-PV-based product design and customization, testing of various solar PV products, project development and formulation of off-grid electrification project, study on rooftop grid interactive PV system, among others. She is actively involved in developing TERI Solverter ™ (patent applied), a solar-based power supply solution. She has also conducted various feasibility studies for electrification through solar home systems and power plants. She is also involved in sizing and developing appropriate PV system in buildings. She has also carried out studies on assessing various solar PV technologies.

Shirish Garud

Shirish Garud is a Fellow, Energy–Environment Technology Division, TERI. After completing his MTech in Energy Systems Engineering from IIT Mumbai (1986), he has been working in solar thermal and PV technologies for the past 20 years, during which he worked on various projects and technologies. He has wide experience in solar system designing, manufacturing, and project implementation. His areas of specialization include solar energy utilization; solar thermal systems and project development and management; designing of integrated PV project; solar system designing using simulation software; renewable energy project designing software like TRNSYS, RETScreen and HOMER; and hydrogen energy utilization. His outstanding contributions include design and installation of one of the world's largest solar water heating system of 120 000 litres per day capacity, commercialization of solar selective coating technology, and advanced solar system designs. He has published two papers and has contributed in many publications. He has also worked on the development of solar steam generation system using parabolic concentrators. He is known for his acumen/skill in training engineers and professionals in solar technologies.

Kusum Lata

Kusum Lata is a Fellow, Energy–Environment Technology Division, TERI. She is responsible for initiating and coordinating projects and activities related to research and consultancy on biomass energy, which mainly includes biomass

gasification. She has handled various projects, some of the prominent ones being preparation of integrated energy management master plan for Bhutan, analysis and treatment of waste water generated in biomass gasifier systems, development of biomass-gasifier-based crematorium, field testing of gasifier-based systems, formulation of biomass policy options for promotion of biomass technologies, development of clean development mechanism project design document for conversion of municipal solid waste (500 tonnes per day) into RDF (refuse-derived fuel) pellets at Okhla, New Delhi, India, and so on. She is also a member of BUN India, SESI, and Indian chapter of ICTP. She has an MSc degree in microbiology and has submitted her PhD thesis for open defence to Jiwaji University, Gwalior.

Linoj Kumar N V

Linoj Kumar N V is a Research Associate, Energy–Environmental Technology Division, TERI. He has obtained his masters degree in Environmental Technology from Cochin University of Science and Technology, Kerala. Thereafter, he has been working in the field of liquid biofuels for the last five years. He has been Principal Investigator for various projects in this area, which are mainly supported by the Department of Science and Technology, Government of India; Praj Industries Ltd, Pune; GTZ (German Technical Development Corporation); and Coir Board, Government of India. While the major focus of his laboratory studies were cellulose-based ethanol production and biodiesel production from vegetable oil, he has also simultaneously addressed the policy issues related to the sustainability of biofuel programmes in India. He has five publications to his credit. He has recently been selected for the BOYSCAST Fellowship, one of the prestigious fellowships offered to outstanding young scientists by the Department of Science and Technology, Government of India. He is also an active member of Indo-US Network on Green Chemistry.

Stuart L Ridgway

Stuart L Ridgway did his BS mathematics from Haverford College in 1943, and obtained his PhD degree in Nuclear Physics from Princeton University in 1952. His career in politically inspired technology development began in 1957, when he led a small group at Ramo-Wooldridge for developing a lead tolerant afterburner for automobile exhaust.

He became interested in ocean thermal energy conversion in the early 1970s, when there was an Arab oil embargo in the US. He has invented two