

Green Energy and Technology

Malti Goel
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Solar Energy

Made Simple for a Sustainable Future



Climate Change
Research Institute



Springer

Green Energy and Technology

Climate change, environmental impact and the limited natural resources urge scientific research and novel technical solutions. The monograph series Green Energy and Technology serves as a publishing platform for scientific and technological approaches to “green”—i.e. environmentally friendly and sustainable—technologies. While a focus lies on energy and power supply, it also covers “green” solutions in industrial engineering and engineering design. Green Energy and Technology addresses researchers, advanced students, technical consultants as well as decision makers in industries and politics. Hence, the level of presentation spans from instructional to highly technical.

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Dedicated to SuryaDeva (Hindi name for Sun God)

*Om Adityaya Vidmahe Sahasra Kiranaya
Dhimahi Tanno Surya Prachodayaat //*

*—I meditate on the Sun God, the one with
thousands of rays. Let the Sun God (Surya
Deva) illuminate my intellect.*

Preface

...We should be using Nature's inexhaustible sources of energy—sun, wind, and tide... I'd put my money on the sun and solar energy. What a source of power! I hope we don't have to wait until oil and coal run out before we tackle that.

—Thomas Edison in 1931 in conversation with Henry Ford¹

Solar energy is people's energy. The book *Solar Energy: Made Simple for a Sustainable Future* provides glimpses of vast application areas of solar energy. Its 14 chapters aim to create public awareness about solar energy, educate the youth about the fundamental principles of its conversion, and create understanding among the masses about its large-scale applications. Since ancient times, many world regions have harnessed Sun's energy for human comfort. Solar as an alternative for electricity generation became known in the last seventy years. The book explores new ways of harnessing solar energy as chemical energy, in addition to solar heat and light, and covers large-scale applications in buildings and cities. Fundamentals of solar collectors, and various other devices, being used in households and industry for power production, process heating, and cooling are described.

Progress in solar energy is helping us to meet our national commitments for international agreements and protocols such as Paris Agreement on climate change and achieving sustainable development goals. The book has a particular chapter on International Solar Alliance, an Indian initiative with a vision to realize “One Sun, One World, One Grid”. India being a tropical country, there is plenty of sunshine throughout the year, and “solar hotspots” are many. India has set a laudable target to achieve the installed capacity of 175 GW from renewable energy sources by 2022, out of which 100 GW is to be met from solar energy. A total of 48 GW has been achieved as of December 2021.

¹ 1987, *Uncommon Friends: Life with Thomas Edison, Henry Ford, Harvey Firestone, Alexis Carrel, & Charles Lindbergh* by James D. Newton (James Draper Newton), Quote Page ix, Harcourt Brace Jovanovich, San Diego, California.

Dr. A. P. J. Abdul Kalam, late President of India, greatly appreciated the first author's book on Energy Sources and Global Warming published by Allied Publishers in 2005. The author covered all renewable and non-renewable sources, and its two chapters discussed solar energy. The original idea for writing a new book came after the Paris Agreement 2015. The need was felt for revising, and the current book incorporates recent advancements in solar energy covered in the 14 chapters. It includes discrete chapters on solar resource assessment and utilization, solar PV plants, solar thermal energy, solar chemical energy, green hydrogen, solar cooling, solar buildings, solar rooftops, and solar cities.

The book is a quick reading for experts, researchers, and an inclusive knowledge resource to students and policymakers to expose them to solar energy's scientific and technological breakthroughs. It delves into the understanding of Sun's energy potential from idea to several applications and examples in practical use. The reader will learn how science has provided tools for harnessing solar energy, why you should pursue solar science and technology, and how it helps in clean energy transition contributing to the improvement in the environment toward net zero.

Acknowledgements For their inspiration, we convey our thanks to Shri. K. S. Popli, Ex-CMD, IREDA, Shri. P. S. Bami, Ex-CMD, NTPC Ltd., and Shri. R. V. Shahi, Ex-Secretary, Ministry of Power. Our thanks are due to Prof. D. P. Agrawal, Ex-Chairman, Union Public Service Commission, for his encouragement. Dr. Neha is especially thankful to Prof. P. S. N. Rao, Director, School of Planning and Architecture, for the motivation.

Many of our near and dear ones were taken away by pandemic COVID-19. May their souls be blessed and rest in peace! Authors remember late Pankaj Gupta, a close relative, as a great motivator, who was always very encouraging and inspiring all to learn and advance in their area of work and become a better person to do something for the country. By writing this book, we continue his legacy of knowledge sharing.

Lastly, the book aims to empower youth, city leaders, policymakers, students, and communities to understand the potential for solar energy and comprehend how its enhanced deployment could benefit sustainability and a move toward net zero.

New Delhi, India
December 2021

Malti Goel
V. S. Verma
Neha Goel Tripathi

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Award 2016 in recognition of her outstanding contributions and achievements in the field of Climate Change Research in India. Dr. Malti is author and editor of 13 scientific books and published nearly three hundred scientific papers in international reputed journals and conferences. She became a fellow of National Environment Science Academy in 2008. Currently as President, Climate Change Research Institute she is devoted to public engagement in science after being an active scientist and science policy maker for 40 years.



Shri. V. S. Verma obtained his BE (Mech) and ME (App. Thermo science) degree from IIT (Roorkee) and has been an adjunct professor in IIT (Kanpur) and distinguished professor in CPRI (Bangalore). Shri. Verma has been Member of Central Electricity Regulatory Commission (CERC) and officiated as Chairman CERC also for a brief period. Prior to that Shri. Verma was Member (Planning) CEA responsible for planning of electricity availability for the country. He has been Director General of Bureau of Energy Efficiency (BEE). His initiatives were responsible for improved availability of generating stations and transmission networks and preparation of CO₂ baseline data for power sector. He chaired Expert committee to set up Geothermal Project in Ladakh, J&K, and National Electricity Plan for XI plan; and the 16th Electric Power Survey was prepared under his guidance and leadership. He has also played a lead role in implementation of Energy efficiency and energy conservations programmes in various Indian industries and the power sector in the country. Shri. Verma was awarded life time achievement awards by CBI&P, Rajeev Gandhi Institute of Technology (Bhopal) and Council of Power Utilities. He is a distinguished alumnus of IIT (Roorkee). He has visited large no of foreign countries on official assignments, published more than 50 Tech papers in the national and International workshops and conferences.



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Abbreviations

A-h	Ampere hour
a-Si	Amorphous silicon
A.U.	Astronomical Units
AC	Alternating current
ACRE	Australian Cooperative Research Centre for Renewable Energy
AFD	Agence Francaise de Développement
BIPV	Building-integrated photovoltaic
BPDS	Big parabolic dish system
CLFR	Compact Linear Fresnel Reflector
CASE	Commission of Alternate Sources of Energy
CCAC	Climate and Clean Air Coalition
CDM	Clean Development Mechanism
CdSe	Cadmium selenide
CdTe	Cadmium telluride
CERC	Central Electricity Regulatory Commission
CH ₄	Methane
CIAL	Cochin International Airport Limited
CIGS	Copper Indium Gallium Diselenide
CIS	Copper indium diselenide (CuInS ₂)
CO ₂	Carbon dioxide
COP	Coefficient of performance
COPs	Conference of Parties
CRMM	Common risk mitigation mechanism
CRTS	Central receiver tower system
CSP	Concentrated solar power
DC	Direct current
DDG	Decentralized Distributed Generation
DHI	Diffuse Horizontal Irradiance
DISCOM	Distribution Companies
DNES	Department of New Energy Sources
DNI	Direct normal irradiation

DST	Department of Science and Technology
EIB	European Investment Bank
EMC	Equilibrium Moisture Content
EXIM	Export Import Bank of India
FF	Fill factor
FICCI	Federation of Indian Chambers of Commerce and Industry
GBI	Generation Based Incentive
GDAS	Global Data Assimilation System
GHGs	Greenhouse gases
GHI	Global Horizontal Irradiance
GIS	Geographic Information System
GIZ	The Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GNI	Global Normal Irradiance
GW	Gigawatt
GWP	Global warming potential
H	Hydrogen
He	Helium
HFCs	Hydrofluorocarbons
HTST	High-temperature solar system
IGCC	Indo-German Chamber of Commerce
IMD	India Meteorological Department
ISA	International Solar Alliance
IR	Infrared
IREDA	Indian Renewable Energy Development Agency
KJ	Kilo Joules
kWh	Kilowatt hour
L	liter
LCOE	Levelized cost of electricity
LCZ	Lower convective zone
LSTM	Long Short-Term Memory networks
m ²	square meter
mc-Si	Monocrystalline silicon
MIT	Massachusetts Institute of Technology
MNRE	Ministry of New and Renewable Energy
MPPT	Maximum Power Point Tracker
MW	Megawatt
N ₂ O	Nitrous oxide
NCZ	Non-convective zone
NDCS	Nationally Determined Commitments
NISE	National Institute of Solar Energy
NIWE	National Institute of Wind Energy
NWP	Numerical Weather Forecasting
NZEB	Net zero emission building
OMC	Operation and Maintenance (O&M) cost