

Sustainability: Contributions through Science Technology

Series Editor : Michael C. Cann

# Green Chemistry for Environmental Sustainability



Edited by  
Sanjay Kumar Sharma  
Ackmez Mudhoo



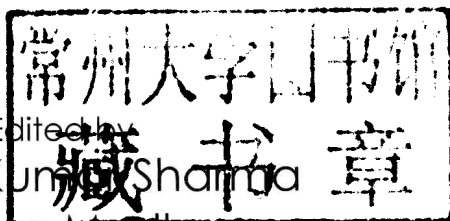
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# Green Chemistry for Environmental Sustainability

# Sustainability: Contributions through Science Technology

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Series Editor: Michael C. Cann, Ph.D.  
Professor of Chemistry and Co-Director of Environmental Science  
University of Scranton, Pennsylvania

## Preface to the Series

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Sustainability is rapidly moving from the wings to center stage. Overconsumption of non-renewable and renewable resources, as well as the concomitant production of waste has brought the world to a crossroads. Green chemistry, along with other green sciences technologies, must play a leading role in bringing about a sustainable society. The **Sustainability: Contributions through Science and Technology** series focuses on the role science can play in developing technologies that lessen our environmental impact. This highly interdisciplinary series discusses significant and timely topics ranging from energy research to the implementation of sustainable technologies. Our intention is for scientists from a variety of disciplines to provide contributions that recognize how the development of green technologies affects the triple bottom line (society, economic, and environment). The series will be of interest to academics, researchers, professionals, business leaders, policy makers, and students, as well as individuals who want to know the basics of the science and technology of sustainability.

**Michael C. Cann**

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## Published Titles

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Green Chemistry for Environmental Sustainability  
*Edited by Sanjay Kumar Sharma, Ackmez Mudhoo, 2010*

## Forthcoming Title

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Microwave Heating as a Tool for Sustainable Chemistry  
*Edited by Nicholas E. Leadbeater, 2010*

*For my loving wife, Pratima, on our tenth wedding anniversary*

**—Sanjay K. Sharma**

*With affection for Aryanna, mum, and dad*

**—Ackmez Mudhoo**

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# Preface

The thinking behind writing this book rests much on the following mighty saying of Albert Einstein (1879–1955).

We shall require a substantially new manner of thinking if mankind is to survive.

The last five decades have been a time of unprecedented change in the general way of living in the world in many walks of life. Aside from all the political, economic, and social developments that have taken place, many of the key changes in society have stemmed from the numerous advances in science and technology. These various technological and societal developments are highly interactive and have consequences that may be either desirable or undesirable from the viewpoint of energy consumption, ecological, and environmental degradation.

Some of these advances in modern society for the betterment in the overall living conditions of humans, and to some extent for animals, have brought with them negative consequences in complex mechanisms that cause collateral environmental damage, are virtually irreversible, and have yet to be faced head-on. As well as air pollution and global warming, which are thought to arise from the ever-expanding use of energy, there are other problems of a global nature that may be grossly categorized as the following: environmental pollution of natural waters and soils, bioaccumulation of heavy metals and other harmful molecules in living biota including humans, unequal distribution of energy, and ecological disruption in several biospheres. Additionally, inequalities in the geographic distribution of natural resources, especially petroleum, make some countries wealthy and others relatively poor.

Following the establishment of the 12 Principles of Green Chemistry (Anastas and Warner, 1998), there has been a gradual and constructive growth in our understanding of what green chemistry means. Green chemistry is a relatively young science in its own respect. Interest in this subject, however, is growing rapidly and, although no concerted agreement has been reached as yet about the exact content and limits of this interdisciplinary field, there appears to be increasing interest in umpteen environmental topics, which are based on chemistry embodied in this subject. To the pleasant surprise of all, this increased understanding of the principles that are the backbone of green chemistry has spurred many outstanding efforts to implement chemical processes and innovative technologies that are incrementally moving society toward more sustainable practices and products that embody and foster environmental stewardship and environmental protection. Environmental stewardship is the responsibility for environmental quality shared by all those whose actions affect the environment. In 2005, the Environmental Protection Agency laid out a vision for environmental stewardship recognizing it as a means to a more sustainable future.

However, the green chemistry community has always strived to convince many people in the chemical community that green chemistry is different from the historical pollution prevention initiatives of the 1980s that green chemistry burgeoned from. The proposal and risk of changing the way chemistry is done and applied, the development of new chemistries and chemical synthetic pathways, and the establishment of novel and benign chemical processes that are significantly more efficient using nonpetrochemical and renewable feedstocks have been challenging notions for a world that has been surrounded by the products of petroleum for more than a century. Green chemistry has hence brought a relatively prompt and positive shift in the paradigm as it concerns the overall use and management of natural resources and raw materials for the development of society with a promise to cause far less pronounced harm to the environment at large.

By adopting green chemistry principles and methodologies, researchers all over the globe are devising new processes to help protect and ultimately save the environment from further damage. The writing of this book was undertaken because it was earnestly intended to be a work that encompassed some of the various relevant aspects linked and linking green chemistry practice to environmental sustainability. In this book, research on and the application of green chemistry and engineering in addressing current issues that are both of environmental and social nature have been presented. The book covers sustainable development and environmental sustainability through chapters contributed in green chemistry and engineering research, the design and synthesis of environmentally benign chemical processes, green approaches to minimize and/or remediate environmental pollution, the development of biomaterials, biofuel and bioenergy production, biocatalysis, and policies and ethics in green chemistry. We hope the book provides an insightful text on the chemical and biochemical technologies that are being studied, optimized and eventually developed to promote environmental sustainability. We also feel it provides up-to-date information on some selected fields where the Principles of Green Chemistry are being embraced for safeguarding and improving the quality of the environment.

## REFERENCE

Anastas, P.T. and Warner, J.C. 1998. *Green Chemistry: Theory and Practice*. New York: Oxford University Press.

**Sanjay K. Sharma**  
**Ackmez Mudhoo**



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# Acknowledgments

This undertaking has provided us with a unique opportunity to renew some old friendships and hopefully to weave some new ones in the pursuit to gather the expertise required for compiling this edited book on “Green Chemistry” and “Environmental Sustainability.” The primary acknowledgment, without any reservation, goes to our pool of esteemed contributors for the way they have graciously responded with characteristic good humor and indulgence to our relatively modest deadlines. We hope they feel that the final result does ample justice to their painstaking efforts and mental strain exercised in writing and getting their respective chapter(s) ready for this book. We are also appreciative and grateful to other colleagues and fellow researchers who volunteered their help in reviewing the scientific contents of manuscripts received for this book.

Professor S.K. Sharma especially expresses his heartfelt gratitude to his respected parents, Dr. M.P. Sharma and Smt. Parmeshwari Devi. He also wishes to extend his warmest regards to Professor R.K. Bansal who has been a source of inspiration to him, and to Dr. V.K. Agrawal, Chairman of the Institute of Engineering and Technology, Alwar (India), for his encouraging words. Ackmez Mudhoo equally expresses his appreciation for the faith his parents, Azad A. Mudhoo and Ruxana B. Mudhoo, his brother, Assad, and sister-in-law, Tina, have placed in him throughout the writing of this book. Ackmez Mudhoo is also grateful to Professor Romeela Mohee (University of Mauritius, Mauritius), Dr. Vinod K. Garg and Meetali (both from Guru Jambheshwar University of Science and Technology, Hisar, Haryana, India) and Dr. Zhi-Qing Lin (Southern Illinois University, Edwardsville, Illinois) for their encouragement.

**Sanjay K. Sharma**  
**Ackmez Mudhoo**

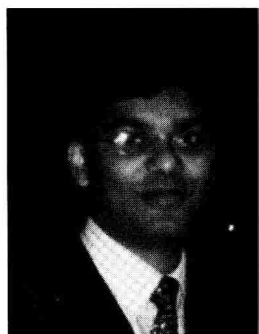
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# Editors



**Professor Sanjay K. Sharma** is a very well-known author of many books and hundreds of articles over the last 20 years. He is presently a professor and head of the Department of Chemistry and Environmental Engineering at the Institute of Engineering and Technology (IET), Alwar, Rajasthan, India. Dr. Sharma did his postgraduate (1995) and PhD (1999) work from the University of Rajasthan, Jaipur. His field of work was synthetic organophosphorus chemistry and computational chemistry for which he attained his PhD. In 1999, he joined IET and started working in the field of environmental chemistry and established a Green Chemistry

Research Laboratory. His work in the field of green corrosion inhibitors is very well recognized and praised by the international research community. He is a member of the American Chemical Society and the Green Chemistry Network (Royal Society of Chemists, United Kingdom) and is also a lifetime member of various international professional societies including the International Society of Analytical Scientists, Indian Council of Chemists, International Congress of Chemistry and the Environment and Indian Chemical Society. Dr. Sharma has 6 textbooks and over 40 research papers of national and international repute to his credit. Dr. Sharma is also serving as editor-in-chief for two international research journals *RASAYAN Journal of Chemistry* and *International Journal of Wastewater Treatment and Green Chemistry* and is a reviewer in many other international journals.



**Ackmez Mudhoo** obtained his Bachelor's degree in Engineering (Hons.) in chemical and environmental engineering from the University of Mauritius in 2004. He then successfully completed his master of philosophy (M.Phil.) degree through research in the department of chemical and environmental engineering, University of Mauritius in 2007. His main research interests encompass the design of composting systems and analysis of composting processes and the biological treatment of solid wastes and wastewater. Ackmez has 24 international journal publications and 4 conference papers to his credit, and an additional 5 research and

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*Research*, and is the editor-in-chief for two international research journals *International Journal of Process Wastes Treatment* and *International Journal of Wastewater Treatment and Green Chemistry*. He worked as a consultant chemical process engineer for China International Water & Electric Corp. (CWE, Mauritius) from February 2006 to March 2008. Ackmez is presently a lecturer in the Department of Chemical and Environmental Engineering at the University of Mauritius.

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# 1 Green Chemistry and Engineering

## *A Versatile Research Perspective*

*Sanjay K. Sharma, Ackmez Mudhoo,  
and Wei Zhang*

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