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High-Performance Materials from Bio-based Feedstocks

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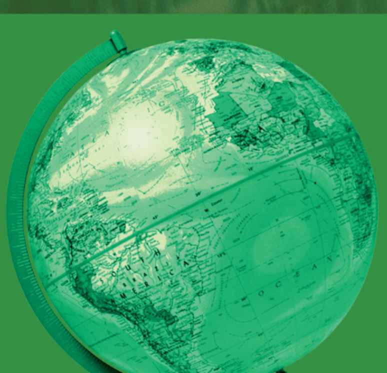
Andrew J. Hunt | Nontipa Supanchaiyamat
Kaewta Jetsrisuparb | Jesper T.N. Knijnenburg



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High-Performance Materials from Bio-based Feedstocks

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In memory of our friend and colleague Professor Janet L. Scott.

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Series Preface

Renewable resources, their use and modification, are involved in a multitude of important processes with a major influence on our everyday lives. Applications can be found in the energy sector, paints and coatings, and the chemical, pharmaceutical, and textile industries, to name but a few.

The area interconnects several scientific disciplines (agriculture, biochemistry, chemistry, technology, environmental sciences, forestry, etc.), which makes it very difficult to have an expert view on the complicated interactions. Therefore, the idea to create a series of scientific books, focusing on specific topics concerning renewable resources, has been very opportune and can help to clarify some of the underlying connections in this area.

In a very fast-changing world, trends are not only characteristic of fashion and political standpoints; science too is not free from hypes and buzzwords. The use of renewable resources is again more important nowadays; however, it is not part of a hype or a fashion. As the lively discussions among scientists continue about how many years we will still be able to use fossil fuels – opinions ranging from 50 to 500 years – they do agree that the reserve is limited and that it is essential not only to search for new energy carriers but also for new material sources.

In this respect, the field of renewable resources is a crucial area in the search for alternatives for fossil-based raw materials and energy. In the field of energy supply, biomass- and renewables-based resources will be part of the solution alongside other alternatives such as solar energy, wind energy, hydraulic power, hydrogen technology, and nuclear energy. In the field of material sciences, the impact of renewable resources will probably be even bigger. Integral utilization of crops and the use of waste streams in certain industries will grow in importance, leading to a more sustainable way of producing materials. Although our society was much more (almost exclusively) based on renewable resources centuries ago, this disappeared in the Western world in the nineteenth century. Now it is time to focus again on this field of research. However, it should not mean a "retour à la nature," but should be a multidisciplinary effort on a highly technological level to perform research towards new opportunities, and to develop new crops and products from renewable resources. This will be essential to guarantee an acceptable level of comfort for the growing number of people living on our planet. It is "the" challenge for the coming generations of scientists to develop more sustainable ways to create prosperity and to fight poverty and hunger in the world. A global approach is certainly favored.

This challenge can only be dealt with if scientists are attracted to this area and are recognized for their efforts in this interdisciplinary field. It is, therefore, also essential that consumers recognize the fate of renewable resources in a number of products. Furthermore, scientists do need to communicate and discuss the relevance of their work. The use and modification of renewable resources may not follow the path of the genetic engineering concept in view of consumer acceptance in Europe. Related to this aspect, the series will certainly help to increase the visibility of the importance of renewable resources. Being convinced of the value of the renewables approach for the industrial world, as well as for developing countries, I was myself delighted to collaborate on this series of books focusing on the different aspects of renewable resources. I hope that readers become aware of the complexity, the interaction, and interconnections, and the challenges of this field, and that they will help to communicate on the importance of renewable resources.

I certainly want to thank the people of Wiley's Chichester office, especially David Hughes, Jenny Cossham, and Lyn Roberts, in seeing the need for such a series of books on renewable resources, for initiating and supporting it, and for helping to carry the project to the end.

Last, but not least, I want to thank my family, especially my wife Hilde and children Paulien and Pieter-Jan, for their patience, and for giving me the time to work on the series when other activities seemed to be more inviting.

Christian V. Stevens
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June 2005

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High-performance Materials from Bio-based Feedstocks: Introduction and Structure of the Book

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1.1 Introduction

The overexploitation of the Earth's resources over the last century has led to a decrease in natural resources, a loss of natural habitat, climate change, and degradation of the environment, resulting in the extinction of several species [1]. The recovery of global economics after COVID-19 is also driving lifestyle changes, leading to increased high-performance materials production. As a result, a large number of nonrenewable resources are being utilized, which inevitably contributes to the generation of waste and may lead to detrimental effects to both environment and health. In addition, the scarcity of fossil resources and finite elements with potential global supply chain vulnerabilities are global concerns. Concerns over the supply of natural resources and potential damage to the environment have compelled governments to implement policies that mitigate the risk of further damage. The formation of the World Commission on Environment and Development (WCED) in 1983 and their report called "Our Common Future" in 1987 (also

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called "Brundtland report") was one of the catalysts for the move toward a sustainable future for humankind [2]. The definition of sustainable development is the development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" [3]. Importantly, sustainability is a complex balance between societal, economic, and environmental needs, where this must be achieved in unison [4]. Implementation of a bio-based circular economy including minimizing the waste by recycling materials and utilization of replenishable resources is key to sustainable development.

Historically, chemistry goes hand in hand with innovation, thus promoting a positive image of this industry. However, the perception of the industry can be tarnished with media reports of life-threatening accidents and environmental pollution [5]. Anastas and Warner pioneered the concept of green chemistry, "the invention, design and application of chemical products and processes to reduce or to eliminate the use and generation of hazardous substances" [6]. Today, green chemistry is recognized and widely accepted to pursue sustainable development. The 12 principles of green chemistry (stated next) are regarded as a blueprint for achieving the aims of green chemistry. Moreover, green chemistry can aid in the development of sustainable bio-based chemicals and importantly also high-performance materials.

The 12 principles of green chemistry as stated by Anastas and Warner [6] are:

1. **Prevention**
   It is better to prevent waste than to treat or clean up waste after it has been created.
2. **Atom Economy**
   Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. **Less Hazardous Chemical Syntheses**
   Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. **Designing Safer Chemicals**
   Chemical products should be designed to effect their desired function while minimizing their toxicity.
5. **Safer Solvents and Auxiliaries**
   The use of auxiliary substances (e.g. solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
6. **Design for Energy Efficiency**
   Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
7. **Use of Renewable Feedstocks**
   A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
8. **Reduce Derivatives**
   Unnecessary derivatization (use of blocking groups, protection/deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible because such steps require additional reagents and can generate waste.
9. **Catalysis**
   Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. **Design for Degradation**
    Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.