

Barriers To Innovation

Challenges in the Implementation of Green Chemistry and Engineering

Proving the Value of Sustainability

Green chemistry and engineering, a promising and innovative approach toward sustainable chemistry, is not yet established. As every adoption process is obstructed by barriers, 70% of planned organizational change initiatives fail. Thus, the minimization of disruptions is decisive. We present major barriers to green chemistry and engineering derived both from expert interviews and a survey. Barrier analysis is a powerful tool for the assessment of every company. Based on its results, companies can derive strategies for overcoming barriers.

The transition to a sustainable chemical industry requires radical technological innovation for new processes and products. This new paradigm implies added value from the use of chemicals without adding new risks to our society or transferring risk to future generations. Environmentally benign chemical synthesis – better known as green chemistry – is the most basic concept among a list of promising concepts to transform sustainable chemicals into action.

But green chemistry is not yet established in the chemical industry. The implementation of green chemistry can increase corporate value, mitigate a company's risk and strengthen long-term competitiveness. So why does the implementation of green chemistry lag behind expectations?

The focus of this article is to identify factors – known as barriers – related to the implementation of green chemistry in industrial chemistry that may hamper, decelerate or even block its adoption. As every adoption process is

obstructed by barriers, especially such essential innovations are affected. We have analyzed major barriers to the implementation of green chemistry. If barriers are not surmounted, green chemistry might fail and it might become a threat for the company. The discovery and consideration of as many barriers as possible is supposed to decrease vulnerability and increase resilience and, therefore, ensure the survival of the company.

Six Barriers to Green Chemistry and Engineering

In order to identify and evaluate these barriers, we analyzed literature and conducted an explorative survey. Primarily we focus on the six barrier categories identified at the Harvard workshop *Overcoming the Challenges to the Implementation of Green Chemistry*

- **Economic and financial:** The chemical industry is a well-established, mostly capital-intensive industry. There is a high investment barrier.
- **Regulatory:** Current regulation focuses on reducing risk through reductions in exposure while green chemistry promotes the reduction of inherent risk by reduction of hazard. Changes to more benign processes are inhibited by cost-intensive, control-oriented regulation.
- **Technological:** The number of disciplines involved in green chemistry is high and, accordingly, so is the number of “scientific” languages. The lack of appropriate training of chemists, including the ability to think on a more global or system level, has emerged as an important barrier.
- **Organizational:** The “promoters by know-how” – e.g., the chemist in research and development – are mostly not in a position of power. The “promoters by power” – e.g., the management execu-



tives – need an attitude toward the implementation of green chemistry to support it strongly enough.

- **Sociocultural:** Missing awareness within the different stakeholder groups can be a barrier to the implementation of green chemistry.
- **Definitions and metrics:** There is a lack of a consistent measurement for “green” chemical products or processes.

Barriers related to these identified classes might occur at different stages of the implementation process.

Methodology Of Barrier Analysis

Based on the barriers identified in this workshop, a questionnaire was developed to identify and assess those factors that may hamper, decelerate or even block green chemistry. The observation items were the perceived, i.e., subjective, barriers, as they embody risks, whereas an objectified measurement of barriers does not accomplish the same

aim; it is perception that influences human behavior and not objective measures. The study was designed as a written web-based survey.

For the visualization of the results of the questionnaire, a barriers profile was chosen. It shall assist the organization in designating a starting point for a deeper analysis of the identified barriers and to generate strategies to overcome them. This assessment method uses the averages and spreads to identify tendencies for possible barriers and to evaluate their relevance. Through this method it can be assessed whether potential barriers are perceived as barriers (the higher the average, the bigger the perceived barrier) as well as whether different views exist about barriers (the bigger the spread, the more different the perception of a barrier). This analysis aims to determine first trends (e.g., all interviewees perceive one barrier almost identically) and to identify starting points for the assessment of causes for barriers (e.g., strongly differing views on barriers suggest a need to ascertain the reasons behind those differences).

Results And Discussion

We matched our results with the six major barrier groups obtained as a result of the Harvard workshop. The barrier statements were sorted according to the Harvard groups by investigator triangulation, i.e., three persons classified the barriers independently and then discussed the results. Matching the barriers with the classification developed at the Harvard workshop, it can be seen that within each barrier group some prerequisites are already given, whereas others still have to be strived for. The results reveal that within each group (except the metrics and definition group) some barriers seem to be overcome, whereas others still have to be strived for.

To further analyze the causes of barriers to the implementation of green chemistry, the barriers were sorted along the innovation cycle. The innovation process was used because innovation is one of the main drivers for value in chemistry, and green chemistry solutions are innovations. That analysis shows a more differentiated picture than the analysis of the Harvard barrier groups in order to develop strategies for overcoming the barriers. Barriers seem to be perceived higher the later the stage of the innovation process. Activities to overcome barriers as sources for intangible risk should focus on the adoption and diffusion stage.

Value Of Green

Green chemistry as the most fundamental concept in sustainable chemistry has achieved a good awareness level. Yet implementation needs to be pushed forward. Activities to overcome barriers regarding the implementation of green chemistry should focus on the adoption and diffusion stage. While different strategies such as the stronger involvement of policies or the expansion of networks are advantageous, we

plead for the necessity of involving green chemistry aspects into corporate decision calculus. We argue that one aspect is the missing connection between green chemistry and the value of the company. Even though companies are persuaded by the concept of green chemistry and take an active role in the transition to a sustainable chemical industry, they will first ask for its contribution to the company's value. The primary issue from the company's perspective is that of economics.

“The chemical industry exists to make profits and products, in that order,” according to Green Chemistry in Practice by Joseph J. Bozell. In other words, unless there can be shown a value, they will not choose the green path.

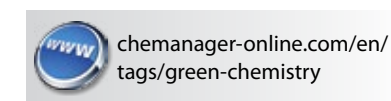
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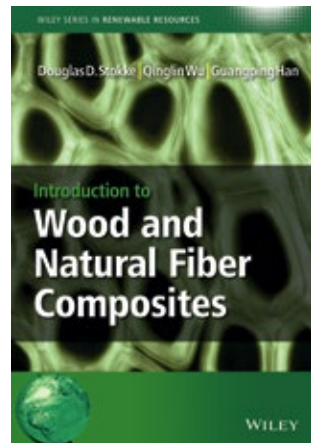


Wiley Series in Renewable Resources

The transition to a more bio-based industry and in general a more bio-based society is certainly not a theoretical concept anymore. Every day companies are performing considerable efforts to look at new resources, preferably renewable ones, to diminish the footprint of their processes and to reduce their dependency on fossil fuels. Today, the initial market push by governmental regulations to stimulate bio-based products has changed in a real market pull, initiated by some multinational companies that announced to produce their products in the near future based on renewable resources. Within this change, also a trend from readily usable “drop-in applications” to completely novel renewable materials and processes is noticeable.

Therefore, the initiative was taken to start a series of expert books on renewable resources covering the different areas, however paying close attention to the interconnections between the different fields of expertise. The series has been growing steadily, covering the different, but also the less obvious disciplines. The success of the books that are already published still leads to ideas for new books and we hope and are convinced that these will help to facilitate the transition to indeed a more bio-based society. Visit the product pages on wiley.com to find out more about the books, about authors and editors, the table of contents, read excerpts, and more. Look out for Google preview symbol and you'll be able to sample the book's content before you buy; books are available as e-books or in print.

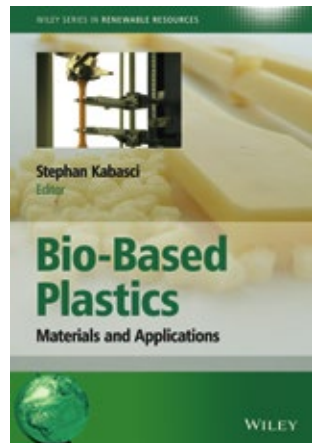
Coming Soon: Introduction to Wood and Natural Fiber Composites



This book draws together widely scattered information concerning fundamental concepts and technical applications, essential to the manufacture of wood and natural fiber composites. The topics addressed include basic information on the chemical and physical composition of wood and other lignocellulosic materials, the behavior of these materials under thermo-compression processes, fundamentals of adhesion, specific adhesive systems used to manufacture composite materials, and an overview of the industrial technologies used to manufacture major product categories. The book concludes with a chapter on the burgeoning field of natural fiber-plastic composites.

- ▶ “Introduction to Wood and Natural Fiber Composites”
Douglas D. Stokke, Qinglin Wu, Guangping Han
Hardcover, 336 pages, €89,90/US-\$ 99,95
December 2013, John Wiley & Sons
ISBN: 978-0-470-71091-3

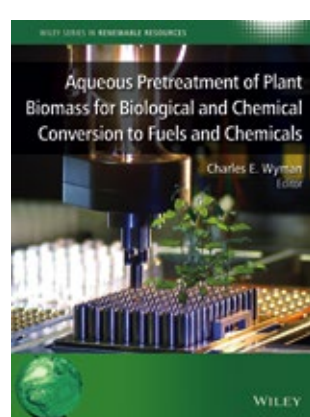
Coming Soon: Bio-Based Plastics



This book presents an up-to-date overview of the basic and applied aspects of bioplastics, focusing primarily on thermoplastic polymers for material use. Emphasizing materials currently in use or with significant potential for future applications, this book looks at the most important biopolymer classes such as polysaccharides, lignin, proteins and polyhydroxyalkanoates as raw materials for bio-based plastics, as well as materials derived from bio-based monomers like lipids, poly(lactic acid), polyesters, polyamides and polyolefines. Detailed consideration is also given to the market and availability of renewable raw materials, the importance of bio-based content and the aspect of biodegradability.

- ▶ “Bio-based Plastics: Materials and Applications”
Stephan Kabasci (Ed.)
Hardcover, 408 pages, approx. €129,-/US-\$ 180,-
December 2013, John Wiley & Sons
ISBN: 978-1-119-99400-8

New: Aqueous Pretreatment of Plant Biomass for Biological and Chemical Conversion to Fuels and Chemicals

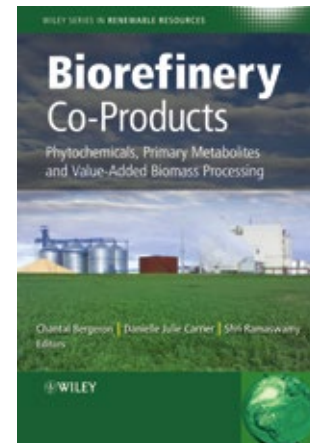


Plant biomass is attracting increasing attention as a sustainable resource for large-scale production of renewable fuels and chemicals. However, in order to successfully compete with petroleum, it is vital that biomass conversion processes are designed to minimize costs and maximize yields. Advances in pretreatment technology are critical in order to develop high-yielding, cost-competitive routes to renewable fuels and chemicals.

This book presents a comprehensive overview of the currently available aqueous pretreatment technologies for cellulosic biomass, highlighting the fundamental chemistry and biology of each method, key attributes and limitations, and opportunities for future advances.

- ▶ “Aqueous Pretreatment of Plant Biomass for Biological and Chemical Conversion to Fuels and Chemicals”
Charles E. Wyman (Ed.)
Hardcover, 566 pages, €155,-/US-\$ 160,-
May 2013, John Wiley & Sons
ISBN: 978-0-470-97202-1

Key Title: Biorefinery Co-Products



In order to successfully compete as a sustainable energy source, the value of biomass must be maximized through the production of valuable co-products in the biorefinery. Specialty chemicals and other biobased products can be extracted from biomass prior to or after the conversion process, thus increasing the overall profitability

and sustainability of the biorefinery. “Biorefinery Co-Products” highlights various co-products that are present in biomass prior to and after processing, describes strategies for their extraction, and presents examples of bioenergy feedstocks that contain high value products. Topics covered include: bioactive compounds from woody biomass; phytochemicals from sugar cane; citrus waste and algae; valuable products from corn and other oil seed crops; proteins from forage. “Biorefinery Co-Products” is an essential text for all scientists and engineers working on the efficient separation, purification and manufacture of value-added biorefinery co-products.

- ▶ “Biorefinery Co-Products: Phytochemicals, Primary Metabolites and Value-Added Biomass Processing”
Chantal Bergeron, Danielle Julie Carrier, Shri Ramaswamy
Hardcover, 382 pages, €112,-/US-\$ 140,-
March 2012, John Wiley & Sons
ISBN: 978-0-470-97357-8

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