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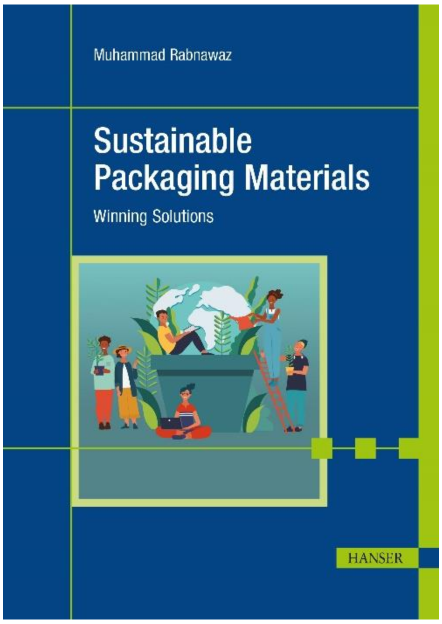

Sample Pages

Sustainable Packaging Materials

Muhammad Rabnawaz

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Foreword

I am Muhammad Rabnawaz, a professor, educator, author, inventor, and entrepreneur. Since 2016 I have been a professor in the School of Packaging at Michigan State University (MSU). I have developed and taught three advanced-level courses for MSU students (Stability and Recyclability of Packaging Materials, Advanced Polymer Synthesis, and Packaging with Plastics), as well as two short online courses for industry professionals on packaging sustainability. I am also the co-author of the book titled *Plastics Packaging* [1].

I have filed/issued over 45 patent applications and over nine licensed/optioned patents in sustainable packaging, recycling, and multifunctional coatings. In addition, I have published over 70 articles in peer-reviewed scientific journals. I have led projects funded by 27 awarded grants of over US$6 million to support my research at MSU.

I have been interviewed on radio and television about sustainability. In addition, I was awarded the College of Agriculture and Natural Resources (CANR) Faculty Laureate (2022), MSU Innovator of the Year Award (2021), the NSF Career Award (2021), and Senior Member of U.S. National Academy of Inventors (2023).

Why do I do all this? It is my vision to promote and create a waste-free packaging world. This vision has been fostered over the years since I joined the School of Packaging. I understand that my vision is ambitious, but it is certainly possible to achieve this goal if we are willing to consider all kinds of materials available for packaging.

I define **“sustainable packaging”** as a package that:

1. does not create harmful effects before, during, or after use,
2. is waste-free,
3. is recyclable/renewable/biodegradable,
4. is consumer safe,

5. provides protection and shelf-stability to products or goods being enclosed, and
6. is economically viable.

   Professionals affiliated with the packaging industry must keep these six attributes in mind when developing new packages or when reforming existing ones. If any feature is missing, the packaging is not sustainable.

I wrote this book for those interested in packaging sustainability. I hope it will be especially beneficial for the following people:

- Packaging industry professionals
- Decision makers in the packaging industry and NGOs interested in waste-free packaging and circular economy
- R&D packaging teams in industry and academia
- Experts and managers of packaging
- Entrepreneurs in the materials science and packaging businesses
- Packaging industry executives, especially CTOs
- Recyclers
- Packaging converters
- Legislators (Chapters 5 and 6)
- NGOs interested in waste-free packaging and circular economy
- Students and researchers

Why this Book?

I teach two short courses to industry professionals (thrice each year), and I interact regularly with packaging professionals, decision makers, managers, CTOs, and even legislators. Through these interactions, I have found many of them are confused about packaging sustainability.

Although there are many books, articles, and magazine stories published on this topic, they often provide conflicting or confusing information that complicates rather than simplifies the principles and practices of packaging sustainability.

For example, my students have asked me many questions hoping to get definitive research-based answers. Here are just a few: What is the future of recycling? Is recycling a viable approach? Are biodegradable/compostable materials better than recyclable packaging? Do oxo-degradable packaging materials have any future? Are glass, paper, and metal sustainable alternatives to plastics? Are extended producer responsibility (EPR) laws effective for the United States' waste management system? What materials are likely to be banned and what are their potential viable replacements? Should microplastics be a concern for packaging companies?

Thus, as a service to the packaging industry and to others concerned about our environment, I provide research and fact-based answers in this text to the questions mentioned. I hope you will use the information to make decisions likely to result in sustainable packaging.

Thus, I intend to help you to accomplish six goals:

1. You will be able to:
   a) identify potential packaging materials that are likely to be phased out to meet new regulations and
   b) be able to find alternatives to benefit your research and business.
2. You will be able to make informed choices about packaging materials by considering three factors: sustainability, performance, and cost.
3. You will be able to follow guidelines on the use of various packaging materials so that you may stay ahead of the demands of the industry.
4. You will be able to identify the emerging packaging trends in both academia and industry.
5. You will be able to understand and explain the EPR laws.
6. You will be able to understand emerging issues associated with microplastic pollution, and the actions recommended to mitigate these challenges.

Acknowledgements

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Preface

This book has been divided into six chapters.

In Chapter 1, I describe packaging materials including plastic, paper, glass, and metal that are destined to be phased out. My aim is to provide information about challenging packaging materials and more importantly, potential alternatives that will benefit your research and your business. Towards the end of this chapter, I present a decision-aid table that will help you to navigate the issues arising from problematic materials in packaging.

In Chapter 2, I reveal principles and methods for making decisions about your next packaging material. In this chapter I also describe how different packaging materials fit into the larger picture of sustainability including environment, performance, and cost. At the end of this chapter, I present a decision-aid table that can provide guidance as you choose your next packaging material.

In Chapter 3, I discuss guidelines to ensure that your new package complies with European Union (EU) packaging directives, plastics pacts, and upcoming EPR laws. I constructed a list of "Do's and Don'ts in Packaging Design" for all packaging formats and materials. I also clarify the issues in the debate of compostable versus recyclable versus biodegradable choices. I conclude this chapter by presenting a decision-aid table for packaging design.

In Chapter 4, I describe emerging, sustainable, packaging trends in materials selection and recycling including flexible and rigid packaging formats. This chapter will help decision makers to develop winning packaging solutions. These trends are briefly summarized at the end of this chapter so that they can be viewed at a glance.

In Chapter 5, I talk about the merits and shortcomings of EPR laws, including how a well-crafted EPR law can benefit packaging sustainability. Also, this chapter provides an overview of EU EPR laws and how they can be used in the United States context.

In Chapter 6, I discuss emerging challenges arising from microplastic pollution and the actions recommended to mitigate this problem. Packaging professionals can and must avoid or minimize microplastics generation from their packages.

Contents

1 Imminent Changes in Packaging Materials

As a professional and decision maker in packaging sustainability, you certainly want to avoid problematic packaging materials that are likely to be banned in the future. More importantly, I bet you are interested to know what the potential alternatives to these problematic materials are. This chapter will address the above two issues and help you make informed decisions. Towards the end of this chapter, I present a **decision-aid table** for problematic materials in packaging.

First, let's consider problematic packaging materials and potential alternatives. **Problematic packaging materials are:**

- harmful to the environment,
- difficult to collect and recycle, and/or
- an impediment to the recycling of other reusable materials in municipal solid waste.

If you are working in the field of packaging, you may be able to identify at least some of those problematic or unnecessary materials. There are lists of questionable materials, such as the one on the U.S. Plastics Pact webpage [2]. Here we will consider all types of problematic materials including paper, glass, metal, and paper, and also present viable options and alternatives.

1.1 Packaging Foams

Introduction and Uses

Foams are plastic materials with cellular structures. These cells are "bubbles" frozen in place. The bubbles can be interconnected in *open-cell foams* and isolated from one another in *closed-cell foams.* Figure 1.1 shows a polystyrene (PS) closed-cell foam cup that is widely used in the packaging sector.

Figure 1.1 A polystyrene foam cup (source: *iStock.com/Michael Burrell*)

Polymers such as PS, polyolefins (polyethylene, polypropylene), and polyurethanes are widely used foam packaging materials. Foams are typically prepared by either extrusion or expansion processes and are accordingly called extruded foams and expanded foams, respectively. Open-cell foams are mainly used to cushion materials during distribution. In contrast, closed-cell foams offer excellent thermal insulation and are used in food packaging such as hot and cold beverage cups. They keep the contents warm or cool and protect a consumer's hands (see Figure 1.1). High-impact-PS foams are also used for packaging such as trays for meat such as beef and pork, fish, and other products such as eggs.

However, these most useful materials present challenges. Because they are about 95% air by volume, foams have very high collection and transportation costs and thus increase the total cost of recycling. In addition, some foams, such as PS foams, are brittle and break down easily during the collection and sorting processes, thus contaminating the whole recycling stream during collection in recycling bins and processing (sorting). Making matters worse, PS foam particles cling to other materials. Thus, foam is not only costly to recycle, it also contaminates other useful recyclable materials.

Legislation Status

Many countries, such as Germany, Italy, the United Kingdom, and others have already banned PS foams. Eight states in the U.S. have already voted to ban PS foam in food service containers. New York City banned expanded polystyrene foams as well as from loosefill insulating materials in packaging and food service containers [3].

Potential Alternatives

There are good alternatives to PS foams including biodegradable/compostable foams made from polylactic acid (PLA), starch, polybutylene adipate terephthalate (PBAT), and other sustainable polymers. However, PLA is only compostable under industrial composting conditions and, upon leakage into the environment, will cause similar consequences as those encountered with PS and polyolefins foams. Nevertheless, owing to its compostable nature, PLA meets regulations demanding compostable packaging. Starch foam is truly biodegradable in soil and marine environments, but it is unsuitable and ineffective for many packaging applications because it becomes soggy at high relative humidity.

1.2 Pigments/Fillers

Introduction and Uses

Often micron size particles called fillers are added to plastics and paper. Some common examples of fillers include calcium carbonate, titanium dioxide, and talc. These materials are added to polymers to provide strength and stiffness and to reduce cost. Carbon black is widely used as a filler to offer protection from UV light, improve abrasion resistance, and impart a black color (as shown in Figure 1.2). Carbon black also increases the performance of the plastic by enhancing its stiffness, tear, and tensile strength. Black plastic packaging is primarily used in food trays and other plastic pots and tubs.

It is worth mentioning that the use of nanocomposites, where nanofillers such as nanoclays, cellulose micro/nanocrystals and cellulose fibrils, and graphene oxides are incorporated into a material, has become a very promising route towards recyclable/biodegradable high-barrier packaging. I don’t think these fillers (and their nanocomposites) are problematic materials if they are carefully selected for particular end-of-life options.

Challenges

Today, recycling facilities often use near-infrared light sensors to detect distinct materials. Unfortunately, because carbon black absorbs infrared light, plastics with carbon black pigments are invisible to these sensors and cannot be sorted at most material recovery facilities.

Figure 1.2 An example of carbon black as a filler in plastic foam meat tray (source: *iStock.com/subjug)*

Potential Alternatives

We need dark pigments that reflect infrared waves and can be used as an alternative for carbon black. Fortunately, some companies have already developed alternatives such as Sicopal® Black K 0098 FK, black iron oxide, and nigrosine. These alternatives will offer greater sustainability as they are not likely to interfere with sorting.

1.3 Per- and Polyfluoroalkyl Substances (PFAS)

Introduction and Use

I'll bet you have heard reporters on radio and television talk about "PFAS." What is that? PFAS substances are used to create fluoropolymer coatings and goods to provide barriers against oil, stains, grease, and water. Per- and poly-fluoroalkyl substances, PFAS, for short, are part of a class of compounds that has any molecule with at least one $-CF_3$ or $-CF_2-$ group (as illustrated in Figure 1.3). In 2022, the EPA revised the definition of PFAS to include additional chemicals such as branched PFAS, and PFAS with ether linkers.

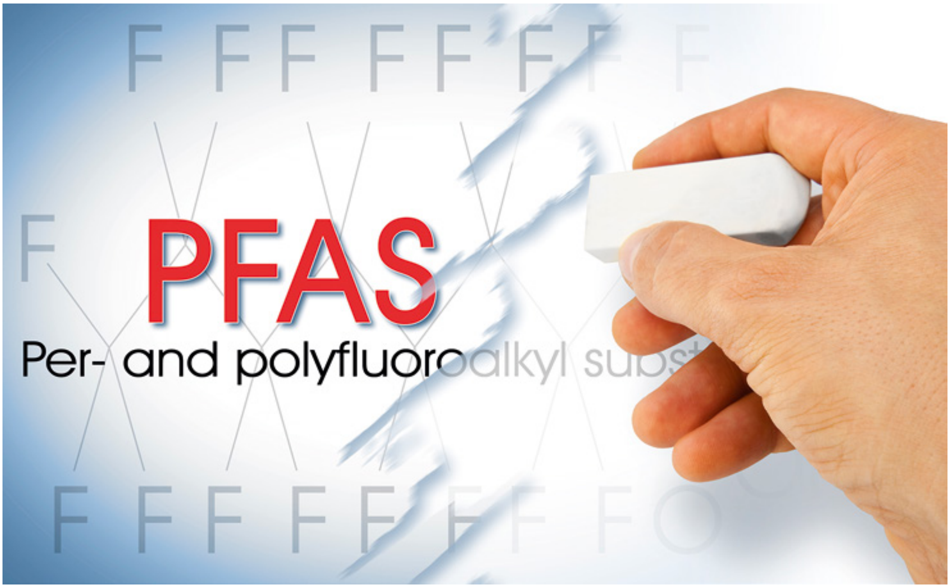

Figure 1.3 Image showing a generic chemistry of per-and polyfluoroalkyl substances (PFAS) used in products (source: *iStock.com/Francesco Scatena*)

So, Why Do We Use PFAS?

PFAS substances have low surface energies. In fact, they have the lowest surface energies among all known materials and chemicals. That means that these substances are "non-stick:" they repel water and oil. When forming a packaging shape in a mold using PFAS, it is relatively easy to remove the finished package article from the mold. It doesn't stick!

PFAS serve well as water- and oil-repellent coatings. Consequently, PFAS are widely used to coat paper and cardboard, in molded fiber containers (as shown in Figure 1.4), and in printing (where PFAS is added into ink formulations to prevent the ink from spreading on paper during the printing process).

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