Preface

Flexible plastic packaging is the fastest growing segment of packaging worldwide. Its increasing popularity is attributed to the many benefits flexible plastic packaging offers when compared with traditional packaging formats. Flexible plastic packaging extends food shelf life and minimizes spoilage; reduces waste by preserving and protecting products until they are consumed; reduces material use; minimizes overall size and weight; lowers shipping costs; generates less greenhouse gases (GHG) than alternative packaging; provides easy printing; and provides an attractive appearance.

Flexible plastic packaging takes the shape of a bag, pouch, liner, or overwrap. Most types of flexible plastic packaging have complex structures (e.g., laminates), such as pouches. Nowadays, pouches are the most preferred format and account for the majority of the flexible plastic packaging. Food is the largest end-use industry accounting for nearly half of the flexible packaging used.

Despite all its positive attributes, the disposal of flexible plastic packaging poses a threat to the environment. A substantial amount of flexible plastic packaging materials are made into disposable items, which are typically discarded within a year of manufacture. Most of the discarded flexible packaging ends up in the mainstream of municipal waste and is disposed in a landfill or incinerated. Improperly disposed packaging films and plastic bags often end up in the sea creating an environment menace because of their bulkiness and nonbiodegradability. Negative image publicity with upsetting images of dead marine animals after ingesting or being entangled in plastic packaging debris heightened the awareness of the public about the impacts of plastic packaging on marine life.

Current flexible plastic packaging materials are neither sustainable, as they are derived from fossil fuel—based resources, nor recyclable, as most of them are made of multilayer structures (e.g. pouches). Existing life-cycle assessments (LCAs) often ignore disposal of flexible plastic packaging in the environment and pay more attention to GHG emissions than to end-of-life impacts.

Among the proposed solutions to tackle the disposal problem of flexible plastic packaging waste is the use of biodegradable plastics, thermal decomposition, and recycling (i.e. recovery of the polymer(s) or monomer(s)). Biodegradable plastics has the potential to improve environmental performance, but it might be half the solution because the favorable degradation conditions required for the composting of these materials are not always achieved in the sea and in other natural environments. Thermal decomposition involves pollution risks as result of gas emissions generated during incineration/pyrolysis, while conversion of the plastic waste to fuel has not yet reached optimal reusability.

For most applications, recycling seems to be the obvious choice in terms of saving resources and reducing pollution. However, recycling is not without problems. Flexible plastic packaging is usually made of multiple layers. Multilayer packaging is very difficult to recycle because it contains many incompatible polymers.

The proposed book aims to give a thorough and detailed presentation of the issues surrounding the management of flexible plastic packaging waste and investigate feasible methods and viable technologies to increase the recycling and diversion of this type of waste from disposal. It provides all the current developments and trends towards a sustainable and recyclable flexible plastic packaging.

The book consists of eleven chapters:

Chapter 1 gives a general overview of flexible plastic packaging. It also presents the benefits and limitations of flexible plastic packaging as they are reflected in LCA studies. Flexible packaging is also compared with rigid packaging. Emphasis is given to the recycling problem of flexible multilayer plastic packaging. Further, it describes the various options of recycling and the waste management hierarchies used by EU and US EPA.

Chapter 2 studies the environmental and socio-economic effects of flexible plastic packaging. At first, the various degradation modes including hydrolytic degradation, thermooxidative degradation, photodegradation, biodegradation, and mechanical degradation by which plastics can be degraded in the environment are presented. Further, the dire consequences that the uncontrolled disposal of flexible plastic packaging can have in land and at sea are discussed. The damages inflicted to marine animals (mammals, turtles, birds, and fishes) by entanglement in and ingestion of plastic packaging debris are also discussed. Finally, the social and economic impacts of plastic packaging litter on to marine ecosystems and various human activities such as fishing and aquaculture, shipping, recreational activities, and tourism are examined.

Chapter 3 examines the main polymers used in flexible packaging as films, coatings, sealants, adhesives/tie layers, and inks, in terms of sustainability and recyclability. While there many polymers utilized in the flexible packaging industry, the most common ones are polyolefins, including the various types of polyethylene and polypropylene, poly(ethylene terephthalate) and poly(vinyl chloride), and secondarily polyamides, ethylene vinyl alcohol, poly(vinylidene chloride), ethylene-vinyl acetate, and ionomers.

The used polymers are homopolymers, copolymers, or polymer blends and are usually compounded with various additives (e.g., antioxidants, plasticizers, moisture absorbers, colorants, and the like) to improve certain properties of the flexible packaging materials.

Chapter 4 examines the various types, forms, and uses of flexible plastic packaging. The two main types of flexible plastic packaging are single film or monolayer and multilayer packaging. The main forms of flexible plastic packaging are bags, wraps, pouches and sachets, air pillows and envelopes, labels and sleeves, straps, tapes and six pack rings, net bags, and woven bags. Flexible plastic packaging finds multiple uses in food and beverage, cleaning products, pharmaceuticals, medical, personal care and cosmetics, construction and building, e-commerce, and others.

Chapter 5 examines the main strategies employed for the collection of flexible plastic packaging. The three main sources of flexible plastic packaging waste are postconsumer (residential or household) derived from residences, postcommercial generated by businesses, and post-industrial generated during processing. Curbside collection is currently the least preferred manner for the collection of flexible packaging materials. Return collection centers or drop-off sites are the principal means for collecting films and bags. A considerable amount of scrap is generated in the course of manufacture of packaging films, such scrap coming from trimming from roll ends (edge trims or off-cuts), film breakages, filling custom orders involving less than the full width of rolls of the film, or rolls out of specification. It is an industry practice to feedback at least part of this type of flexible plastic packaging waste. Reprocessing of scrap film can take place either on the site of film production or at a remote location.

Chapter 6 examines the main technologies used for the separation and sorting of flexible plastic packaging in material recovery facilities (MRFs) and/or plastic recovery facilities (PRFs), including manual and vacuum-assisted manual sorting, air separators, screens, mainly ballistic screens, grabbers, marking and labeling systems, optical sorters, fluorescent additives, robotic sorters, eddy current separators, volume reduction, and baling.

Chapter 7 examines the solvent and/or chemical agent technology for the separation or delamination of multilayer packaging films. Stripping solvents are used for the dissolution or swelling of the interlayer binder (tie layer) and separation of the individual layers from a multilayer packaging film and/or chemical agents for the separation or delamination of the aluminum foil from plastic layers. Cleaning systems, which use solvent and/or aqueous surfactant solutions for removing printing inks, film additives, impurities, etc, from flexible plastic packaging waste are also described. Further, selective dissolution—based processes in organic solvents for the separation of commingled and multilayer postconsumer plastic packaging products, which usually are mixtures of polyolefins, such as polyethylenes, with other polymers are described. Solvent-based recycling is selective for polyolefins and generates pure and high-quality recovered polymers from mixed postconsumer waste.

A large number of patents have been disclosed for this technology, which are applicable to both flexible and rigid multilayer plastic packaging. Despite the large number of disclosed patents and research and industrial projects with promising preliminary results, the solvent and/or chemical agent technology is still not commercially used.

Chapter 8 examines the main stages of postprocessing of flexible plastic packaging comprising size deduction using shredders and granulators; mechanical cleaning including wet cleaning and dry cleaning for the removal of residual contamination; sorting of the different polymers by density/gravity techniques including float sink, hydrocyclones, and centrifuge; extrusion; blending including compatibilization and solid-state shear pulverization; and compounding. In addition, it describes various recycled products disclosed in patent literature and reviews the available commercial uses of recycled flexible plastic packaging materials.

Chapter 9 examines the chemical (or tertiary) plastic recycling technology by which at least one polymer of a plastic article is depolymerized to yield repolymerizable monomers and/or oligomers, which are recovered for producing new polymers. The chemical recycling of polymers aims mainly at saving the material resources and less at reducing the amount of waste generated by slowly degrading polymers.

The main types of chemical recycling are solvolysis and thermolysis. A special type of chemical recycling is enzymatic depolymerization. The available processes for the depolymerization of rigid plastic packaging and nonpackaging films (e.g., agricultural films), fibers, foams, etc., can be equally applied to the depolymerization of flexible plastic packaging.

Chemical recycling is a promising option to recycle mixed, multilayer, or other complex plastics. However, the technology is still at early stages of development and is not expected to be fully operational before 2025.

Chapter 10 examines the EU legislation (directives and regulations) related to flexible packaging and packaging waste. It also briefly reviews the legislation and regulative measures taken in selected countries and regions including the United States, the United Kingdom, China, India, and Southeast Asia. The two main frameworks that are applied in the packaging industry for the effective control of waste, namely the Sustainable Materials Management (SMM) and the Circular Economy (CE) are also examined. Further, the Extended Producer Responsibility (EPR) environmental policy approach is discussed, as well the obligations of the producers for the removal of single-use plastic products pursuant to the EPR provisions as described in Directive 2019/904/EU. Another policy framework that is considered is the Corporate Social Responsibility (CSR) that holds accountable the manufacturers of goods that create post-consumer waste. Finally, the various programs, initiatives, and campaigns to raise awareness and encourage consumers to recycle packaging films and plastic bags are presented.

Chapter 11 reviews the global market of flexible plastic packaging and the markets of the main types of recycled film. Further, it investigates the main trends toward a sustainable and recyclable flexible plastic packaging including redesign, increase collection, improve sorting, new recycling technologies (e.g. use of compatibilizers, solvent separation and chemical recycling), alternative materials, such as bioplastics, the proposed measures to stimulate the market for recycled flexible packaging, and the four reuse models to reduce the need for single-use packaging. It also presents some legislative initiatives and recommendations for future legislation. Finally, a summary of the major programs/projects and reports for the recycling of flexible plastic packaging is given.

In this book, recycling is understood as the recovery of several components from flexible plastic packaging waste by mechanical, physical, chemical, and biological processes or their combination to convert them into monomers, oligomers, and/or polymers, which can be used, optionally in combination with virgin polymers, for the making of new products.

Decomposition (or destruction) recovery options such as incineration, pyrolysis, and gasification that convert flexible plastic packaging materials into energy, fuel, or chemicals do not fall under this recycling definition and are commented only in short.

Further, agricultural films and their recycling are outside the scope of this book.

Waste plastic bags—a form of flexible plastic packaging—have already been dealt in the author's previous book: "*Management of Marine Plastic Debris.*" In the present book, only the collection and recycling options of plastic bags are examined.

The writing of the book started in late autumn 2017. Till its completion in summer 2019, there were many changes in the waste management of flexible plastic packaging. Sustainable packaging materials, such as bio-plastics, gained ground, and there were significant breakthroughs in recycling technologies and the design of recyclable flexible plastic packaging materials. At the same time, there were many coordinated efforts for the efficient collection of large amounts of flexible packaging waste. New legislation addressing the issue of single-use plastic packaging was launched by the EU, namely Directive 2019/904/EU, and regulative measures with far reaching consequences were taken by China and Southeast Asia countries in banning the import of plastic waste. SMM, CE, EPR and CSR are used nowadays for the effective control of flexible packaging waste.

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