Contents

Acknowledgements xi
Preface xiii

1 General Introduction 1

1.1 What is Environmental Sustainability? 4
1.2 Facing the Contradictions of Plastics 8
1.3 Plastics at Play in Consumer Lifestyles 10
1.4 Controversies Concerning Plastics: Recent Examples 11
1.4.1 PVC and Phthalate Plasticizers 12
1.4.2 Plastic Shopping Bags 14
1.4.3 Health Effects of BPA (Bisphenol-A) 16
1.5 The Desire to be "Green" 19
1.5.1 Consumer Interest in Sustainability 19
1.5.2 Sustainability: Views and Counterviews 21
1.6 The Course of This Book: A Chapter-by-Chapter Overview 26
References 29

2 The Life Cycles of Plastics 31

2.1 "Green Principles" – A Basis for Discussion 33
2.2 Life Cycle Assessment (LCA) – A Baseline Tool 37
2.2.1 Life Cycle Inventory (LCI) 39
2.2.2 LCA: Controversies and Limitations 40
2.2.3 LCA/LCI: Plastics-related Examples 43

COPYRIGHTED MATERIAL

2.3 Plastic Lifetimes: Cradle-to-Gate... to Gate-to-Grave 46
2.3.1 The "Cradle": Polymer Feedstocks and Production 46
2.3.2 "Gate-to-Gate": General Plastics Use-life Impacts 50
2.3.3 The "Grave": Disposal, Recycling, and Biodegradability 52
2.4 Towards a Hierarchy of Choosing Plastics for Sustainability 66
References 68

3 Polymer Properties and Environmental Footprints 73

3.1 Background on Polymers and Plastics 75
3.1.1 "Green Chemistry" Principles Most Relevant to Plastics 76
3.2 Common Commodity Thermoplastics 82
3.2.1 Polyethylene (PE) 82
3.2.2 Polypropylene (PP) 87
3.2.3 Polyvinyl Chloride (PVC, or "Vinyl") 89
3.2.4 Polystyrene (PS) 91
3.2.5 Polyethylene Terephthalate (PET) and Related Polyesters 92
3.3 Traditional Engineering Thermoplastics 95
3.3.1 Nylon or Polyamide (PA) 96
3.3.2 Acrylonitrile-Butadiene-Styrene (ABS) 97
3.3.3 Polycarbonate (PC) 99
3.4 Traditional Thermosets and Conventional Composites 100
3.4.1 Unreinforced Thermosets 101
3.4.2 Conventional Composites 103
3.5 Biopolymers: Polymers of Biological Origin 104
3.5.1 Polylactic Acid (PLA) 106
3.5.2 Polyhydroxyalkanoates (PHAs): PHB and Related Copolymers 110
3.5.3 Starch-based Polymers 113
3.5.4 Protein-based Polymers 114

3.5.5 Algae-based Polymers 115
3.5.6 Blends of Biopolymers 115
3.6 Additives and Fillers: Conventional and Bio-based 116
3.6.1 Common Additives 117
3.6.2 Fillers 118
3.6.3 Fiber Reinforcement 119
3.6.4 Nanocomposites 125
3.7 Concluding Summary 125
References 126

4 Applications: Demonstrations of Plastics Sustainability 133

4.1 Trends in Sustainable Plastics Applications 136
4.2 Sustainable Plastics Packaging 137
4.2.1 Traditional Plastics Bags and Containers: Use, Disposal, and Recycling 140
4.2.2 Bio-based Plastic Packaging 142
4.2.3 "Greener" Foam Packaging 144
4.2.4 Key Points about Plastics Packaging and Sustainability 146
4.3 Sustainable Plastics in Building and Construction 146
4.3.1 Recycled/Recyclable Construction Applications 149
4.3.2 Wood-plastic Composites 150
4.3.3 Key Points about Plastics Sustainability in Construction 151
4.4 Automotive Plastics and Sustainability 152
4.4.1 Fuel-saving Contributions of Plastics 152
4.4.2 Recycling and Automotive Plastics 154
4.4.3 Bioplastics in the Automotive Industry 155
4.4.4 Key Points: Plastics Sustainability in the Automotive Industry 157
4.5 Specialized Applications and Plastics Sustainability 158
4.5.1 Electrical/Electronics Applications 158
4.5.2 Medical Plastics and Packaging 159

4.5.3 Agricultural Applications 161
4.6 Conclusions about Sustainable Plastics Applications 162
References 163

5 Design Guidelines for Sustainability 169

5.1 Green Design Principles 172
5.1.1 Minimize Material Content 174
5.1.2 Exploit a Material's Full Value in the Design 175
5.1.3 Design Only to Fulfill Service Durability Requirements 178
5.1.4 Minimize Non-functional Features 179
5.1.5 Focus on Single-material Designs 179
5.1.6 Incorporate Renewable Content 182
5.2 The Wildcard: Consumer Preferences in Green Design 183
References 184

6 Sustainable Considerations in Material Selection 187

6.1 A Broad Example of Materials Selection: Plastics vs. Metals and Glass 191
6.2 Material Selection for Common High-Volume Plastics Applications 193
6.2.1 Plastics Selection for Beverage Bottles: PET vs. rPET vs. bio-PET 193
6.2.2 Plastics Selection for Thermoformed and Flexible Packaging 197
6.2.3 Selection for Housewares and Food Service Tableware 199
6.3 Bio-based Plastic Selection 202
6.3.1 Selecting Bio-based Resins: PLA, PHA, TPS, and Bio-based PE 203
6.3.2 Selecting Natural Fiber Plastics Reinforcement 207
6.3.3 Selecting Engineering (Bio)polymers 212
6.4 The Selection Process: A Visual Approach 214
References 219

7 Processing: Increasing Efficiency in the Use of Energy and Materials **221**

7.1 Optimizing Resin Recycling 223
7.1.1 Reprocessing Scrap and Post-industrial Material 223
7.1.2 Recycling Technologies for Post-consumer Plastic 226
7.2 Optimizing Plastics Processes for Sustainability 231
7.2.1 Optimizing Process Water Use 231
7.2.2 Optimizing Process Energy Consumption of Existing Machinery 233
7.2.3 Choosing New Machinery for Sustainability 236
7.2.4 Sourcing Options for "Green" Processing Energy 237
References 238

8 Conclusion: A World with(out) Sustainable Plastics? **241**

8.1 Trends Affecting Future Global Plastics Use 244
8.1.1 Consumer Needs and Market Growth 244
8.1.2 Fossil Fuel Availability and Price 247
8.1.3 Alternative Feedstock Trends 248
8.1.4 Industry Priorities in Responding to Calls for Sustainability 250
8.1.5 Plastic Bans and (Never Ending?) Controversies 252
8.2 Future Progress in Promoting Plastics Sustainability 256
8.2.1 Improved Partnerships, Standards, Industry Practices, and Public Education 256
8.2.2 New Sustainability-Enhancing Uses of Both Fossil- and Bio-based Plastics 265
8.2.3 From R&D to Real World: Newer, More Renewably Based Polymeric Materials 268
References 269

Index **273**