CONTENTS

Contributors ix
Foreword xi
Preface xiii

1 Introduction 1

Jan Harmsen

1.1 Reason for This Book, 1
1.2 Scope of the Book, 2
1.3 Use in Education, 2
1.4 Use in Industry, 3

2 Sustainability Metrics, Indicators, and Indices for the Process Industries 5

Joseph B. Powell

2.1 Overview and Scope, 5
2.2 Hierarchy of SD Metrics, Indices, and Indicators, 7
2.3 Practical Tools for the Process Industries, 10
2.4 Summary and Conclusions, 17
References, 19

3 Resource Efficiency of Chemical Manufacturing Chains: Present and Future 23

Jean-Paul Lange

3.1 Introduction, 23
3.2 Resource Efficiency, 24
3.3 Economic Impact, 32
3.4 Conclusions, 35
References, 35
4 Regional Integration of Processes, Agriculture, and Society 39
Michael Narodoslawsky

4.1 The Formative Character of Raw Materials, 39
4.2 The Systemic Engineering Challenge, 44
4.3 Regional Integration of Technologies, 46
References, 57

5 Eco-industrial Parks in The Netherlands: The Rotterdam Harbor and Industry Complex 59
L. W. Baas and G. Korevaar

5.1 Introduction, 59
5.2 Industrial Ecosystem Programs in Rotterdam, 60
5.3 Conclusions, 76
References, 78

6 By-product Synergy Networks: Driving Innovation Through Waste Reduction and Carbon Mitigation 81
Andrew Mangan and Elsa Olivetti

6.1 Introduction, 81
6.2 BPS Origins, 83
6.3 The BPS Process, 87
6.4 Barriers and Challenges, 94
6.5 Benefits and Opportunities, 97
6.6 Examples, 100
6.7 Conclusions, 106
References, 106

7 Fast Pyrolysis of Biomass For Energy and Chemicals: Technologies at Various Scales 109
R. H. Venderbosch and W. Prins

7.1 Introduction, 109
7.2 Oil Properties, 114
7.3 Fast Pyrolysis Process Technologies, 120
7.4 Mass and Energy Balance for Production of Bio-oil and Char in a 2-ton/h Wood Plant, 136
7.5 Bio-oil Fuel Applications, 139
7.6 Chemicals from Bio-oil, 144
7.7 Economics, 148
7.8 Concluding Remarks, 149
References, 150
8 Integrated Corn-Based Biorefinery: A Study in Sustainable Process Development

Carina Maria Alles and Robin Jenkins

8.1 Introduction, 157
8.2 Technology Development for an Integrated Corn-Based Biorefinery, 159
8.3 LCA Results: ICBR Versus Benchmarks, 165
8.4 Final Reflections, 168
References, 169

9 Cellulosic Biofuels: A Sustainable Option for Transportation

Jean-Paul Lange, Iris Lewandowski, and Paul M. Ayoub

9.1 Introduction, 171
9.2 Case Studies, 175
9.3 Sustainability of Biomass Production, 183
9.4 Conclusions and Recommendations for R&D Activities, 194
   Note Added in Proof, 196
References, 196

10 Integrated Urea–Melamine Process at DSM: Sustainable Product Development

Tjien T. Tjioe and Johan T. Tinge

10.1 Short Summary of Melamine Development, 199
10.2 Current Uses of Melamine, 200
10.3 Urea Production, 201
10.4 Conventional DSM Stamicarbon Gas-Phase Melamine Production Process, 202
10.5 New Integrated Urea–Melamine Process, 205
10.6 Conclusions, 207
References, 207

11 Sustainable Innovation in the Chemical Industry and Its Commercial Impacts

Joseph B. Powell

11.1 Overview, 209
11.2 Historical Perspective, 210
11.3 Innovations in the Age of Sustainability, 212
11.4 Sustainability Driven by Innovation and Performance, 215
References, 216
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Authors</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Implementation of Sustainable Strategies in Small and Medium-Sized</td>
<td>Johannes Fresner and Jan Sage</td>
<td>219</td>
</tr>
<tr>
<td></td>
<td>Enterprises Based on the Concept of Cleaner Production</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.1</td>
<td>Overview</td>
<td></td>
<td>219</td>
</tr>
<tr>
<td>12.2</td>
<td>Active Strategies for Sustainable Management</td>
<td></td>
<td>220</td>
</tr>
<tr>
<td>12.3</td>
<td>Eloxieranstalt A. Heuberger GmbH: Sustainable Management in an</td>
<td></td>
<td>221</td>
</tr>
<tr>
<td></td>
<td>Anodizing Plant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.4</td>
<td>Analysis of the Results</td>
<td></td>
<td>226</td>
</tr>
<tr>
<td>12.5</td>
<td>Implementation of Sustainable Strategies</td>
<td></td>
<td>230</td>
</tr>
<tr>
<td></td>
<td>Appendix: A Successful Regional Cleaner Production Project</td>
<td></td>
<td>231</td>
</tr>
<tr>
<td></td>
<td>References</td>
<td></td>
<td>236</td>
</tr>
<tr>
<td>13</td>
<td>Sustainable Concepts in Metals Recycling and Mineral Processing</td>
<td>Nitosh Kumar Brahma</td>
<td>237</td>
</tr>
<tr>
<td>13.1</td>
<td>Overview</td>
<td></td>
<td>237</td>
</tr>
<tr>
<td>13.2</td>
<td>Bioleaching Process Design and Development</td>
<td></td>
<td>238</td>
</tr>
<tr>
<td>13.3</td>
<td>Bioleaching Reactor Design: Applicability of the Core Particle</td>
<td></td>
<td>241</td>
</tr>
<tr>
<td></td>
<td>Model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13.4</td>
<td>Industrial Applications</td>
<td></td>
<td>243</td>
</tr>
<tr>
<td>13.5</td>
<td>Conclusions</td>
<td></td>
<td>245</td>
</tr>
<tr>
<td></td>
<td>References</td>
<td></td>
<td>246</td>
</tr>
<tr>
<td>14</td>
<td>Industrial Ecosystem Principles in Industrial Symbiosis: By-product</td>
<td>Qingzhong Wu</td>
<td>249</td>
</tr>
<tr>
<td></td>
<td>Synergy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14.1</td>
<td>Introduction</td>
<td></td>
<td>249</td>
</tr>
<tr>
<td>14.2</td>
<td>Relationship Between Industrial Symbiosis and Sustainable Development</td>
<td></td>
<td>250</td>
</tr>
<tr>
<td>14.3</td>
<td>Challenges, Barriers, and Countermeasures in Exploration, Evaluation,</td>
<td></td>
<td>252</td>
</tr>
<tr>
<td></td>
<td>and Implementation of Industrial Symbiosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14.4</td>
<td>What By-Product Synergy Is and Is Not</td>
<td></td>
<td>253</td>
</tr>
<tr>
<td>14.5</td>
<td>Work Process and Successful Cases of Industrial Symbiosis</td>
<td></td>
<td>254</td>
</tr>
<tr>
<td>14.6</td>
<td>Conclusions and Recommendations</td>
<td></td>
<td>261</td>
</tr>
<tr>
<td></td>
<td>References</td>
<td></td>
<td>263</td>
</tr>
<tr>
<td></td>
<td>Index</td>
<td></td>
<td>265</td>
</tr>
</tbody>
</table>