

# CONTENTS

<b>Contributors</b>	<b>ix</b>
<b>Foreword</b>	<b>xi</b>
<b>Preface</b>	<b>xiii</b>
<b>1 Introduction</b>	<b>1</b>
<i>Jan Harmsen</i>	
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	
<b>2 Sustainability Metrics, Indicators, and Indices for the Process Industries</b>	<b>5</b>
<i>Joseph B. Powell</i>	
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	
<b>3 Resource Efficiency of Chemical Manufacturing Chains: Present and Future</b>	<b>23</b>
<i>Jean-Paul Lange</i>	
3.1 Introduction, 23	
3.2 Resource Efficiency, 24	
3.3 Economic Impact, 32	
3.4 Conclusions, 35	
References, 35	

<b>4</b>	<b>Regional Integration of Processes, Agriculture, and Society</b>	<b>39</b>
	<i>Michael Narodoslawsky</i>	
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	
<b>5</b>	<b>Eco-industrial Parks in The Netherlands: The Rotterdam Harbor and Industry Complex</b>	<b>59</b>
	<i>L. W. Baas and G. Korevaar</i>	
5.1	Introduction, 59	
5.2	Industrial Ecosystem Programs in Rotterdam, 60	
5.3	Conclusions, 76	
	References, 78	
<b>6</b>	<b>By-product Synergy Networks: Driving Innovation Through Waste Reduction and Carbon Mitigation</b>	<b>81</b>
	<i>Andrew Mangan and Elsa Olivetti</i>	
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	
<b>7</b>	<b>Fast Pyrolysis of Biomass For Energy and Chemicals: Technologies at Various Scales</b>	<b>109</b>
	<i>R. H. Venderbosch and W. Prins</i>	
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	

<b>8</b>	<b>Integrated Corn-Based Biorefinery: A Study in Sustainable Process Development</b>	<b>157</b>
	<i>Carina Maria Alles and Robin Jenkins</i>	
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	
<b>9</b>	<b>Cellulosic Biofuels: A Sustainable Option for Transportation</b>	<b>171</b>
	<i>Jean-Paul Lange, Iris Lewandowski, and Paul M. Ayoub</i>	
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	
<b>10</b>	<b>Integrated Urea–Melamine Process at DSM: Sustainable Product Development</b>	<b>199</b>
	<i>Tjien T. Tjioe and Johan T. Tinge</i>	
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	
<b>11</b>	<b>Sustainable Innovation in the Chemical Industry and Its Commercial Impacts</b>	<b>209</b>
	<i>Joseph B. Powell</i>	
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	

- 12 Implementation of Sustainable Strategies in Small and Medium-Sized Enterprises Based on the Concept of Cleaner Production 219**  
*Johannes Fresner and Jan Sage*
- 12.1 Overview, 219  
 12.2 Active Strategies for Sustainable Management, 220  
 12.3 Eloxieranstalt A. Heuberger GmbH: Sustainable Management in an Anodizing Plant, 221  
 12.4 Analysis of the Results, 226  
 12.5 Implementation of Sustainable Strategies, 230  
 Appendix: A Successful Regional Cleaner Production Project, 231  
 References, 236
- 13 Sustainable Concepts in Metals Recycling and Mineral Processing 237**  
*Nitosh Kumar Brahma*
- 13.1 Overview, 237  
 13.2 Bioleaching Process Design and Development, 238  
 13.3 Bioleaching Reactor Design: Applicability of the Core Particle Model, 241  
 13.4 Industrial Applications, 243  
 13.5 Conclusions, 245  
 References, 246
- 14 Industrial Ecosystem Principles in Industrial Symbiosis: By-product Synergy 249**  
*Qingzhong Wu*
- 14.1 Introduction, 249  
 14.2 Relationship Between Industrial Symbiosis and Sustainable Development, 250  
 14.3 Challenges, Barriers, and Countermeasures in Exploration, Evaluation, and Implementation of Industrial Symbiosis, 252  
 14.4 What By-Product Synergy Is and Is Not, 253  
 14.5 Work Process and Successful Cases of Industrial Symbiosis, 254  
 14.6 Conclusions and Recommendations, 261  
 References, 263