Contents

List of Contributors xiii
Preface xvii
Acknowledgments xxii

Part 1 Process Design Tools for Biomass Conversion Systems 1

1 Early-Stage Design and Analysis of Biorefinery Networks 3
Peam Cheali, Alberto Quaglia, Carina L. Gargalo, Krist V. Gernaey, Gürkan Sin, and Rafiqul Gani
1.1 Introduction 3
1.2 Framework 5
1.2.1 Sustainability Analysis 10
1.2.2 Environmental Impact Assessment 12
1.3 Application: Early-Stage Design and Analysis of a Lignocellulosic Biorefinery 15
1.3.1 Biorefinery Networks and Identification of the Optimal Processing Paths 15
1.3.2 Sustainability Analysis with Respect to Resource Consumption and Environmental Impact 29
1.4 Conclusion 34
Nomenclature 35
References 37

2 Application of a Hierarchical Approach for the Synthesis of Biorefineries 39
Carolina Conde-Mejía, Arturo Jiménez-Gutiérrez, and Mahmoud M. El-Halwagi
2.1 Introduction 39
2.2 Problem Statement 41
5 Synthesis of Biomass-Based Tri-generation Systems with Variations in Biomass Supply and Energy Demand
Viknesh Andiappan, Denny K. S. Ng, and Santanu Bandyopadhyay
5.1 Introduction 103
5.2 Problem Statement 106
5.3 Multi-period Optimization Formulation 107
5.3.1 Material Balance 108
5.3.2 Energy Balance 109
5.3.3 Economic Analysis 110
5.4 Case Study 112
5.5 Analysis of the Optimization Results 122
5.6 Conclusion and Future Work 123
Appendix A 124
Nomenclature 128
References 129

Part 2 Regional Biomass Supply Chains and Risk Management 133
6 Large-Scale Cultivation of Microalgae for Fuel Christina E. Canter, Luis F. Razon, and Paul Blowers
6.1 Introduction 135
6.2 Cultivation 137
6.2.1 Organisms for Growth 137
6.2.2 Selection of a Species for Growth 138
6.2.3 Types of Growth Systems 139
6.2.4 Nutrients, Water, and Carbon Dioxide for Growth 142
6.2.5 Large-Scale Commercial Microalgae Growth 143
6.3 Harvesting and Dewatering 144
6.3.1 Separation Characteristics of Various Species 144
6.3.2 Gravity Sedimentation 144
6.3.3 Flocculation 144
6.3.4 Dissolved Air Flotation 145
6.3.5 Centrifugation 145
6.3.6 Filtration 146
6.3.7 Electrocoagulation 146
6.4 Conversion to Products 146
6.4.1 Utilization of the Lipid Fraction (Biodiesel) 146
6.4.2 Utilization of the Carbohydrate Fraction (Bioethanol and Biogas) 151
6.4.3 Utilization of the Protein Fraction (Nitrogenous Compounds) 153
6.4.4 Thermochemical Conversion 154
## Contents

6.5 Conclusions 156  
Acknowledgments 157  
References 157  

7 Optimal Planning of Sustainable Supply Chains for the Production of *Ambrox* based on *Ageratina jocotepecana* in Mexico 161  
*Sergio I. Martínez-Guido, J. Betzabe González-Campos, Rosa E. Del Río, José M. Ponce-Ortega, Fabricio Nápoles-Rivera, and Medardo Serna-González*

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1 Introduction</td>
<td>161</td>
</tr>
<tr>
<td>7.2 <em>Ambrox</em> Supply Chain</td>
<td>162</td>
</tr>
<tr>
<td>7.3 Biomass Cultivation</td>
<td>163</td>
</tr>
<tr>
<td>7.4 Transportation System</td>
<td>165</td>
</tr>
<tr>
<td>7.5 <em>Ambrox</em> Production</td>
<td>165</td>
</tr>
<tr>
<td>7.6 Bioethanol Production</td>
<td>168</td>
</tr>
<tr>
<td>7.7 Supply Chain Optimization Model</td>
<td>168</td>
</tr>
<tr>
<td>7.8 Case Study</td>
<td>175</td>
</tr>
<tr>
<td>7.9 Conclusions</td>
<td>179</td>
</tr>
<tr>
<td>Acknowledgments</td>
<td>179</td>
</tr>
<tr>
<td>Nomenclature</td>
<td>179</td>
</tr>
<tr>
<td>References</td>
<td>181</td>
</tr>
</tbody>
</table>

8 Inoperability Input–Output Modeling Approach to Risk Analysis in Biomass Supply Chains 183  
*Krista Danielle S. Yu, Kathleen B. Aviso, Mustafa Kamal Abdul Azíz, Noor Azian Morad, Michael Angelo B. Promentilla, Joost R. Santos, and Raymond R. Tan*

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1 Introduction</td>
<td>183</td>
</tr>
<tr>
<td>8.2 Input–Output Model</td>
<td>186</td>
</tr>
<tr>
<td>8.3 Inoperability Input–Output Modeling</td>
<td>188</td>
</tr>
<tr>
<td>8.3.1 Inoperability</td>
<td>189</td>
</tr>
<tr>
<td>8.3.2 Interdependency Matrix</td>
<td>189</td>
</tr>
<tr>
<td>8.3.3 Perturbation</td>
<td>189</td>
</tr>
<tr>
<td>8.3.4 Economic Loss</td>
<td>189</td>
</tr>
<tr>
<td>8.4 Illustrative Example</td>
<td>190</td>
</tr>
<tr>
<td>8.5 Case Study 1</td>
<td>193</td>
</tr>
<tr>
<td>8.6 Case Study 2</td>
<td>195</td>
</tr>
<tr>
<td>8.7 Conclusions</td>
<td>203</td>
</tr>
<tr>
<td>8.8 Further Reading</td>
<td>204</td>
</tr>
<tr>
<td>Appendix A LINGO Code for Illustrative Example</td>
<td>204</td>
</tr>
<tr>
<td>Appendix B LINGO Code for Case Study 1</td>
<td>206</td>
</tr>
<tr>
<td>Appendix C Interval Arithmetic</td>
<td>208</td>
</tr>
<tr>
<td>Appendix D Analytic Hierarchy Process</td>
<td>208</td>
</tr>
<tr>
<td>Nomenclature</td>
<td>210</td>
</tr>
<tr>
<td>References</td>
<td>210</td>
</tr>
</tbody>
</table>
Part 3 Other Applications of Biomass Conversion Systems

9 Process Systems Engineering Tools for Biomass Polygeneration Systems with Carbon Capture and Reuse
Jhuma Sadhukhan, Kok Siew Ng, and Elias Martinez-Hernandez

9.1 Introduction

9.2 Production Using Carbon Dioxide
9.2.1 Chemical Production from Carbon Dioxide
9.2.2 Material Production from Carbon Dioxide

9.3 Process Systems Engineering Tools for Carbon Dioxide Capture and Reuse
9.3.1 Techno-economic Analysis Tools for Carbon Dioxide Capture and Reuse in Integrated Flowsheet

9.4 CO₂ Pinch Analysis Tool for Carbon Dioxide Capture and Reuse in Integrated Flowsheet
9.4.1 Overview of the Methodology for CO₂ Integration
9.4.2 Case Study: CO₂ Utilisation and Integration in an Algae-Based Biorefinery

9.5 Conclusions

References

10 Biomass-Fueled Organic Rankine Cycle-Based Cogeneration System
Nishith B. Desai and Santanu Bandyopadhyay

10.1 Introduction

10.2 Working Fluids for ORC

10.3 Expanders for ORC

10.4 Existing Biomass-Fueled ORC-Based Cogeneration Plants

10.5 Different Configurations of ORC
10.5.1 Regeneration Using an Internal Heat Exchanger
10.5.2 Turbine Bleeding
10.5.3 Turbine Bleeding and Regeneration
10.5.4 Thermodynamic Analysis of the ORC with Turbine Bleeding and Regeneration

10.6 Process Description

10.7 Illustrative Example

10.8 Conclusions

References

11 Novel Methodologies for Optimal Product Design from Biomass
Lik Yin Ng, Nishanth G. Chemmangattuvalappil, and Denny K. S. Ng

11.1 Introduction

11.2 CAMD
11.2.1 Signature-Based Molecular Design
11.2.2 Multi-objective Chemical Product Design with Consideration of Property Prediction Uncertainty
11.3 Two-Stage Optimisation Approach for Optimal Product Design from Biomass
11.3.1 Stage 1: Product Design
11.3.2 Stage 2: Integrated Biorefinery Design
11.4 Case Study
11.4.1 Design of Optimal Product
11.4.2 Selection of Optimal Conversion Pathway
11.5 Conclusions
11.6 Future Opportunities
Nomenclature
Appendix
References

12 The Role of Process Integration in Reviewing and Comparing Biorefinery Processing Routes: The Case of Xylitol
Aikaterini D. Mountraki, Konstantinos R. Koutsospyros, and Antonis C. Kokossis
12.1 Introduction
12.2 Motivating Example
12.3 The Three-Layer Approach
12.4 Production Paths to Xylitol
12.4.1 Catalytic Process
12.4.2 Biotechnological Process
12.5 Scope for Process and Energy Integration
12.5.1 Catalytic Process
12.5.2 Biotechnological Process
12.5.3 Summarizing Results
12.6 Conclusion
Acknowledgment
References

13 Determination of Optimum Condition for the Production of Rice Husk-Derived Bio-oil by Slow Pyrolysis Process
Suzana Yusup, Chung Loong Yiin, Chiang Jinn Tan, and Bawadi Abdullah
13.1 Introduction
13.2 Experimental Study
13.2.1 Biomass Preparation and Characterization
13.2.2 Experimental Procedure
13.2.3 Equipment
13.2.4 Characterization of Bio-oil
13.3 Results and Discussion
13.3.1 Characterization of RH
13.3.2 Characterization of Bio-oil
13.3.3 Parametric Analysis
13.3.4 Field Emission Scanning Electron Microscope
13.3.5 Chemical Composition (GC–MS) Analysis
\section*{14 Overview of Safety and Health Assessment for Biofuel Production Technologies}

\emph{Mimi H. Hassim, Weng Hui Liew, and Denny K. S. Ng}

14.1 Introduction \hspace{1cm} 341
14.2 Inherent Safety in Process Design \hspace{1cm} 343
14.3 Inherent Occupational Health in Process Design \hspace{1cm} 344
14.4 Design Paradox \hspace{1cm} 345
14.5 Introduction to Biofuel Technologies \hspace{1cm} 347
14.6 Safety Assessment of Biofuel Production Technologies \hspace{1cm} 348
14.7 Health Assessment of Biofuel Production Technologies \hspace{1cm} 350
14.8 Proposed Ideas for Future Safety and Health Assessment in Biofuel Production Technologies \hspace{1cm} 351
14.9 Conclusions \hspace{1cm} 354
References \hspace{1cm} 354

Index \hspace{1cm} 359