

# Contents

<b>1</b>	<b>Biomass Conversion to Energy</b> . . . . .	1
1.1	Introduction . . . . .	1
1.2	Biomass and Energy Generation . . . . .	4
1.2.1	Methods of Biomass Conversion . . . . .	7
1.2.2	Conversion of Biomass to Biofuels: The Biorefinery Concept . . . . .	56
1.2.3	Biomass Conversion into Electricity . . . . .	79
1.3	Economics and Modeling of Biomass Conversion Processes to Energy . . . . .	84
1.4	Future of Biomass Conversion into Energy . . . . .	87
	References . . . . .	88
<b>2</b>	<b>Biomass Energy</b> . . . . .	91
2.1	Introduction . . . . .	91
2.2	Energy Plantation . . . . .	93
2.3	Biomass Production Techniques . . . . .	94
2.4	Biomass Conversion Processes . . . . .	95
2.4.1	Direct Combustion Processes . . . . .	96
2.4.2	Thermochemical Process . . . . .	97
2.5	Types of Gasifiers . . . . .	102
2.5.1	Updraught or Counter Current Gasifier . . . . .	102
2.5.2	Downdraught or Co-Current Gasifiers . . . . .	102
2.5.3	Cross-Draught Gasifier . . . . .	103
2.5.4	Fluidized Bed Gasifier . . . . .	103
2.5.5	Other Types of Gasifiers . . . . .	104
2.6	Briquetting . . . . .	104
2.6.1	Screw Press and Piston Press Technologies . . . . .	104
2.6.2	Compaction Characteristics of Biomass and Their Significance . . . . .	107

2.7	Anaerobic Digestion . . . . .	109
2.7.1	Batch or Continuous . . . . .	112
2.7.2	Temperature. . . . .	113
2.7.3	Solids . . . . .	113
2.7.4	Number of Stages. . . . .	114
2.7.5	Residence . . . . .	115
2.7.6	Feedstocks. . . . .	115
2.8	Methane Production in Landfills. . . . .	116
2.9	Ethanol Fermentation . . . . .	117
2.10	Biodiesel . . . . .	119
2.11	First-Generation Versus Second-Generation Technologies . . . . .	120
2.12	Conclusion. . . . .	121
	References . . . . .	122
<b>3</b>	<b>Lignocellulose Pretreatment by Ionic Liquids: A Promising Start Point for Bio-energy Production . . . . .</b>	<b>123</b>
3.1	Introduction . . . . .	123
3.2	Ionic Liquids: Good Solvents for Biomass. . . . .	124
3.2.1	Relationship Between Ionic Liquids' Structure and Solubility. . . . .	125
3.2.2	Molecular Level Understanding of the Interaction of Ionic Liquids and Lignocellulose: The Key for Lignocellulose Pretreatment . . . . .	126
3.3	Toward Better Understanding of the Wood Chemistry in Ionic Liquids . . . . .	128
3.4	Ionic Liquids Pretreatment Technology for Enzymatic Production of Monosugars. . . . .	130
3.5	Ionic Liquids Pretreatment Technology for Chemical Production of Monosugars. . . . .	132
3.6	Enzymatic Compatible Ionic Liquids for Biomass Pretreatment. . . . .	138
3.7	Conclusions and Prospects. . . . .	140
	References . . . . .	140
<b>4</b>	<b>Application of Ionic Liquids in the Conversion of Native Lignocellulosic Biomass to Biofuels . . . . .</b>	<b>145</b>
4.1	Introduction . . . . .	145
4.2	Pretreatment of Native Biomass . . . . .	146
4.2.1	Cellulose and Lignin Composition in Biomass. . . . .	146
4.2.2	Dissolution of Biomass in Ionic Liquids . . . . .	147
4.2.3	Effect of Ionic Liquid Chemical Composition . . . . .	149
4.2.4	Effect of Temperature . . . . .	150
4.2.5	Effect of Density . . . . .	151
4.2.6	Viscosity . . . . .	151

4.2.7	Acid Hydrolysis . . . . .	152
4.2.8	Catalysts . . . . .	153
4.2.9	Pretreatment with Ammonia . . . . .	153
4.2.10	Microwave Heating and Ultrasounds . . . . .	154
4.2.11	Biomass Size Reduction . . . . .	154
4.2.12	Comparison with Other Pretreatments . . . . .	155
4.2.13	Water Adsorption as an Issue . . . . .	155
4.2.14	Presence of Impurities . . . . .	156
4.3	Mechanism of Delignification and Cellulose Dissolution . . . . .	157
4.3.1	Analytical Techniques . . . . .	157
4.3.2	Purified Cellulose Substrates and Lignin Models . . . . .	159
4.3.3	Swelling . . . . .	160
4.3.4	Regeneration and Reduction of Cellulose Crystallinity . . . . .	160
4.3.5	Hydrogen Bonding . . . . .	161
4.3.6	Empirical Solvent Polarity Scales . . . . .	163
4.4	Compatibility with Cellulases . . . . .	165
4.4.1	General Toxicity of Ionic Liquids . . . . .	165
4.4.2	Deactivation of Cellulases in ILs . . . . .	165
4.4.3	Temperature and pH Dependence of Cellulase Activity . . . . .	167
4.4.4	Effect of High Pressure . . . . .	168
4.4.5	Identification of Cellulases Resistant to Ionic Liquids . . . . .	169
4.4.6	Designing New Ionic Liquids Suitable for Cellulose Dissolution and Cellulase Activity . . . . .	169
4.4.7	Stabilization of Cellulases in Microemulsions and by Immobilization . . . . .	170
4.5	Recycling . . . . .	171
4.5.1	How Green are ILs? . . . . .	171
4.5.2	Recycling Attempts . . . . .	171
4.5.3	Biodegradability . . . . .	173
4.6	Applications . . . . .	173
4.6.1	Applications of Purified Cellulose Substrates . . . . .	173
4.6.2	Applications of Native Biomass . . . . .	174
4.7	Conclusions . . . . .	177
	References . . . . .	177
<b>5</b>	<b>Catalysts in Thermochemical Biomass Conversion . . . . .</b>	<b>187</b>
5.1	Thermochemical Biomass Conversion . . . . .	187
5.2	Types of Catalysts in the Thermochemical Biomass Conversion . . . . .	188
5.2.1	Known Catalyst Types for Biomass Gasification . . . . .	188
5.2.2	Catalyst Types for Biomass Pyrolysis . . . . .	191

5.2.3	Nanocatalysts for Biomass Conversion . . . . .	194
5.3	Conclusion. . . . .	196
	References . . . . .	196
<b>6</b>	<b>Fatty Acids-Derived Fuels from Biomass via Catalytic Deoxygenation . . . . .</b>	<b>199</b>
6.1	Introduction . . . . .	199
6.2	Deoxygenation Processes. . . . .	201
6.2.1	Hydrodeoxygenation of Fatty Acids . . . . .	201
6.2.2	Decarboxylation/Decarbonylation of Fatty Acids . . . . .	207
6.2.3	Deoxygenation of Fatty Acids via Catalytic Cracking . . . . .	214
6.2.4	Comparison of Deoxygenation Methods . . . . .	215
6.3	Conclusions . . . . .	217
	References . . . . .	218
<b>7</b>	<b>Biobutanol: The Future Biofuel. . . . .</b>	<b>221</b>
7.1	Introduction . . . . .	221
7.2	Microbiology of ABE Fermentation . . . . .	223
7.3	Biomass as Feedstock . . . . .	223
7.4	Improvements in Fermentation Processes. . . . .	225
7.4.1	Batch and Fed-Batch Fermentation Processes. . . . .	226
7.4.2	Continuous Fermentation Process . . . . .	229
7.5	Recovery Techniques Integrated with Fermentation Process. . . . .	229
7.6	Economic Aspects . . . . .	231
7.7	Prospective . . . . .	232
	References . . . . .	232
<b>8</b>	<b>Molecular Genetic Strategies for Enhancing Plant Biomass for Cellulosic Ethanol Production . . . . .</b>	<b>237</b>
8.1	Introduction . . . . .	237
8.2	Strategies for Enhancement of Biomass. . . . .	239
8.2.1	Genetic Basis of Plant Architecture . . . . .	239
8.2.2	Phytohormone-Related Genes and Developmental Regulation. . . . .	241
8.2.3	Functional Genomics Approaches for Identification of Useful Genes . . . . .	244
8.2.4	Plant Breeding . . . . .	244
8.2.5	Biotechnological Approaches to Further Improve Biofuel Crops. . . . .	245
8.3	Conclusions and Future Perspectives. . . . .	246
	References . . . . .	247

<b>9</b>	<b>Production of Bioethanol from Food Industry Waste: Microbiology, Biochemistry and Technology</b>	251
9.1	Introduction	251
9.2	Raw Materials	254
9.2.1	Wheat Straw	254
9.2.2	Sugarcane Bagasse	255
9.2.3	Rice Straw	256
9.2.4	Fruit and Vegetable Waste	256
9.2.5	Coffee Waste	259
9.2.6	Cheese Whey	259
9.2.7	Spent Sulfite Liquor	259
9.2.8	Bioethanol from Algae	260
9.3	Microorganisms for Bioethanol Production	260
9.3.1	Microorganisms and Their Characteristics	260
9.3.2	Substrate and Microorganisms	260
9.3.3	Lignocellulosic Material for Ethanolic Fermentation	261
9.3.4	Fermentation of Syngas into Ethanol	263
9.4	Biochemistry of Fermentation	263
9.4.1	Fermentation of Carbohydrates	263
9.4.2	Efficiency of Ethanol Formation	271
9.4.3	Metabolic Engineering for the Production of Advanced Fuels	272
9.5	Genetically Modified Microorganisms for Bioethanol Production	275
9.5.1	<i>Escherichia coli</i>	276
9.5.2	<i>Zymomonas mobilis</i>	276
9.5.3	<i>Pichia stipitis</i>	277
9.5.4	<i>Kloeckera oxytoca</i>	277
9.5.5	<i>Saccharomyces cerevisiae</i>	278
9.6	Fermentation	279
9.6.1	Fermentation Kinetics	279
9.6.2	Fermentation Process for Bioethanol	283
9.7	Technology of Bioethanol Production	286
9.7.1	Sugar Molasses	286
9.7.2	Apple Pomace	287
9.7.3	Orange Waste	289
9.7.4	Banana Waste	290
9.7.5	Potato Waste	291
9.7.6	Wheat Straw	291
9.7.7	Rice Straw	291
9.7.8	Rice Husk	292
9.7.9	Barley	292
9.7.10	Whey	292

9.7.11	Cassava Roots . . . . .	293
9.7.12	Hydrolysed Cellulosic Biomass . . . . .	293
9.7.13	Recent Advances in Bioethanol Production Process . . .	300
9.7.14	Boiethanol Refinery . . . . .	300
9.8	Future Perspectives and Conclusions. . . . .	301
	References . . . . .	302
<b>10</b>	<b>Enhancement of Biohydrogen Production by Two-Stage Systems: Dark and Photofermentation. . . . .</b>	<b>313</b>
10.1	Introduction . . . . .	313
10.2	Dark Fermentation . . . . .	314
10.2.1	Dark Fermentation with Pure Cultures . . . . .	317
10.2.2	Dark Fermentation with Mixed Cultures . . . . .	318
10.2.3	Substrates for Dark Fermentation . . . . .	320
10.2.4	Factors Influencing Dark Fermentation . . . . .	321
10.2.5	Pre-treatment of Mixed Culture . . . . .	322
10.2.6	pH and Temperature . . . . .	322
10.2.7	Partial Pressure of Produced Hydrogen . . . . .	323
10.2.8	Reactor Configuration . . . . .	323
10.3	Photofermentation. . . . .	324
10.3.1	Substrates for Photofermentation . . . . .	326
10.3.2	Factors Influencing Photofermentation . . . . .	327
10.3.3	C/N Ratio . . . . .	327
10.3.4	Inoculum Age . . . . .	328
10.3.5	Light Source and Light Intensity . . . . .	328
10.3.6	pH and Temperature . . . . .	329
10.3.7	Reactor Configuration . . . . .	329
10.4	Two-Stage Systems. . . . .	330
10.5	Conclusion. . . . .	332
	References . . . . .	333
<b>11</b>	<b>Organosolv Fractionation of Lignocelluloses for Fuels, Chemicals and Materials: A Biorefinery Processing Perspective . . . . .</b>	<b>341</b>
11.1	Introduction . . . . .	341
11.2	Overview of Organosolv Fractionation . . . . .	342
11.3	Ethanol Fractionation . . . . .	343
11.3.1	Effect of Treatment on the Structure of Lignocellulosic Material . . . . .	343
11.3.2	Process of Ethanol Fractionation and Lignin Recovery . . . . .	347
11.3.3	Applications of the Products . . . . .	350
11.4	Organic Acid Fractionation . . . . .	355

11.4.1	Effect of Treatment on the Structure of Lignocellulosic Material . . . . .	355
11.4.2	Process of Organic Acid Fractionation and Lignin Recovery . . . . .	358
11.4.3	Applications of the Products . . . . .	360
11.5	Other Fractionation Processes Using Organic Solvents . . . . .	364
11.5.1	Methanol . . . . .	364
11.5.2	Ethylene Glycol . . . . .	367
11.5.3	Ethanolamine . . . . .	367
11.5.4	Acetone . . . . .	368
11.5.5	Dimethyl Formamide . . . . .	369
11.6	Concluding Remarks . . . . .	370
	References . . . . .	370
<b>12</b>	<b>Lignin as Source of Fine Chemicals: Vanillin and Syringaldehyde . . . . .</b>	<b>381</b>
12.1	Lignin, a Fascinating Complex Polymer . . . . .	381
12.2	Main Lignin Types: Origin, Producers, End Users and Characteristics . . . . .	383
12.2.1	Kraft Lignins . . . . .	384
12.2.2	Lignosulfonates . . . . .	385
12.2.3	Organosolv Lignins . . . . .	388
12.2.4	Other Lignins . . . . .	390
12.3	Lignin as Source of Monomeric Compounds . . . . .	390
12.3.1	General Overview . . . . .	390
12.3.2	Industrial Vanillin Production . . . . .	390
12.4	Production of Vanillin and Syringaldehyde by Lignin Oxidation . . . . .	394
12.4.1	Reaction Conditions . . . . .	394
12.4.2	Evolution of Products and Temperature During Lignin Oxidation . . . . .	399
12.4.3	Influence of the Parameters in Lignin Oxidation and Vanillin Oxidation . . . . .	400
12.4.4	Catalysts . . . . .	405
12.4.5	The Continuous Process of Lignin Oxidation . . . . .	406
12.4.6	Perspectives . . . . .	408
12.5	Separation Processes for Oxidation Products of Lignin . . . . .	408
12.5.1	Conventional Process of Extraction . . . . .	409
12.5.2	Ion Exchange Processes . . . . .	409
12.5.3	Membrane Processes . . . . .	410
12.5.4	Supercritical Extraction and Crystallization . . . . .	410
12.5.5	The Integrated Process for Vanillin Production . . . . .	411
	References . . . . .	413

<b>13 Liquefaction of Softwoods and Hardwoods in Supercritical Methanol: A Novel Approach to Bio-Oil Production</b> . . . . .	421
13.1 Introduction . . . . .	421
13.2 Materials and Methods . . . . .	423
13.2.1 Supercritical Fluid Processing . . . . .	423
13.2.2 Chemical Characterization . . . . .	424
13.3 Results and Discussion . . . . .	424
13.3.1 Biochar Characterization . . . . .	425
13.3.2 Bio-Oil Characterization . . . . .	427
13.4 Conclusion. . . . .	431
References . . . . .	432
<b>14 Bioextraction: The Interface of Biotechnology and Green Chemistry</b> . . . . .	435
14.1 Disadvantages of Metal Extraction Process, its Environmental Concerns and Need of Bioextraction. . . . .	436
14.2 Brief Description of Bioextraction Process . . . . .	436
14.2.1 Phytoextraction . . . . .	437
14.2.2 Biomining . . . . .	441
14.3 Contribution of Microbes/Microorganisms in Bioextraction . . . . .	444
14.3.1 Role of Microbes in Biomining . . . . .	445
14.3.2 Role of Fungi in Biomining. . . . .	446
14.4 Various Chemical Processes for Extraction of Heavy Metals. . . . .	447
14.4.1 Concentration of the Ore (Removal of Unwanted Metals and Gangue to Purify the Ore). . . . .	447
14.4.2 Conversion into Metal Oxide. . . . .	447
14.4.3 Reduction of Metal Oxide to Metal . . . . .	448
14.4.4 Refining of Impure Metal into Pure Metals . . . . .	449
14.5 Development of Metal Specific Chelating Resins to Extract Metal Ions . . . . .	451
14.6 Applications of Bioextraction. . . . .	451
14.7 Economization of Bioextraction . . . . .	454
14.8 Flow Diagram to Summarize the Chapter and the Process of Bioextraction . . . . .	455
14.9 Conclusion. . . . .	456
References . . . . .	456
<b>About the Editors</b> . . . . .	459
<b>Index</b> . . . . .	461