

Contents

1	Introduction	1
1.1	Introduction	1
1.2	Energy Demand and Availability	2
1.2.1	Fossil Energy Sources	3
1.2.2	Renewable Energy Sources	10
1.3	Present Energy Situation	12
1.3.1	Energy Production and Future Energy Scenarios	12
1.3.2	Future Energy Scenarios	13
	References	26
2	Green Energy Facilities	29
2.1	Introduction	29
2.2	Biomass Feedstocks	30
2.3	Green Energy	31
2.4	Importance of Biomass	32
2.5	Production of Fuels and Chemicals from Biomass	36
	References	46
3	Biofuels	49
3.1	Introduction	49
3.2	Importance of Biofuels	51
3.3	Bioethanol	54
3.4	Biodiesel	56
3.5	Bio-oil	59
3.6	Biogas	61
3.7	Fischer–Tropsh Liquids from Biorenewable Feedstocks	64
3.8	Biohydrogen	69
3.9	Other Liquid Biofuels	70
3.9.1	Glycerol-based Fuel Oxygenates for Biodiesel and Diesel Fuel Blends	70
3.9.2	P-series Fuels	71

3.9.3	Dimethyl Ether	71
3.9.4	Other Bio-oxygenated Liquid Fuels	72
	References	72
4	Algae Technology	75
4.1	Introduction	75
4.1.1	Definition of Algal Terms	76
4.2	Production Systems	77
4.2.1	Harvesting Microalgae	79
4.2.2	Photobioreactors	80
4.2.3	Open-pond Systems	83
4.2.4	Closed and Hybrid Systems	87
4.3	Production Costs	89
	References	93
5	Energy from Algae	97
5.1	Introduction	97
5.1.1	Historical Perspective	99
5.2	Biofuels	99
5.2.1	Biodiesel	102
5.2.2	Bioalcohol	104
5.2.3	Costs, Prices, and Economic Impacts of Biofuels	106
5.2.4	Environmental Impacts of Biofuels	110
5.2.5	Combustion Efficiencies of Biofuels	113
5.2.6	Bio-oil	117
5.2.7	Biomethane	119
5.2.8	Production of Bio-oil and Hydrogen by Pyrolysis	120
5.2.9	Anaerobic Biohydrogen Production	125
5.3	Liquefaction of Algal Cells	127
5.3.1	Liquefaction of Algal Cells by Hexane Extraction	129
5.4	High-value-added Products from Algae	131
5.4.1	Small Molecules	131
5.4.2	Polymers	132
5.4.3	High-value Oils	132
	References	133
6	Biodiesel from Algae	139
6.1	Introduction	139
6.2	Biodiesel from Algal Oil	140
6.2.1	Production of Biodiesel from Algal Oils	144
6.3	Potential of Microalgal Biodiesel	147
6.4	Acceptability of Microalgal Biodiesel	150
6.5	Economics of Biodiesel Production	151
6.6	Improving Economics of Microalgal Biodiesel	153
6.7	Advantages and Disadvantages of Biodiesel from Algal Oil	153
	References	154

7	Biorefineries	159
7.1	Introduction	159
7.2	Definitions of Biorefinery	162
7.2.1	Main Technical and Nontechnical Gaps and Barriers to Biorefineries	164
7.3	Historical Perspective	164
7.4	Petroleum Refinery and Biorefinery	168
7.5	Refining of Upgraded Products	174
7.6	Opportunities for Refining Pyrolysis Products	178
	References	180
8	Future Developments	183
8.1	Introduction	183
8.1.1	World Theoretical Limit of Biomass Supply	184
8.1.2	High-yield Energy Crops	185
8.1.3	Food Versus Fuel Delineation	186
8.1.4	Thermodynamic Efficiency (Exergy Analysis)	187
8.1.5	Biofuel Upgradation	187
8.1.6	Carbon Credits	188
8.2	Social and Political Issues	189
8.2.1	The Promise of Algae: Energy Security	190
8.3	Environmental Impacts of Biomass Production	191
	References	193
	Index	195