

Contents

<i>List of figures and tables</i>	<i>xi</i>
<i>Preface</i>	<i>xx</i>
<i>List of contributors</i>	<i>xxi</i>
1 Introduction	1
1.1 Current status of bioenergy	3
1.2 Combustion as main bioenergy technology	4
1.3 This handbook	5
1.4 References	6
2 Biomass Fuel Properties and Basic Principles of Biomass Combustion	7
2.1 Introduction	7
2.2 The process of biomass combustion	8
2.2.1 Drying, pyrolysis, gasification and combustion	9
2.2.2 Operational and design variables affecting the combustion process	11
2.2.3 Principles of medium- to large-scale combustion applications	22
2.2.4 Thermodynamics and gas phase kinetics	23
2.2.5 Solid fuel kinetics and gas phase interaction	23
2.2.6 Basic engineering calculations	23
2.2.7 Basic emission conversion calculations	29
2.2.8 Batch versus continuous combustion	31
2.2.9 Modelling biomass combustion	33
2.2.10 Ash formation	34
2.3 Physical and chemical characteristics of biomass fuels	38
2.3.1 Overview	38
2.3.2 Fuel characteristics and interaction with the combustion system	38
2.3.3 Databases on biomass fuel characteristics	48
2.3.4 Standardization of biomass fuels	49
2.4 References	50
3 Biomass Fuel Supply and Pre-treatment	54
3.1 Quality-related influences along the supply chain of biomass fuels	56
3.1.1 Influences on the fuel quality during the growing phase	57
3.1.2 Influences on the fuel quality during the supply phase	58
3.1.3 Fuel quality control and price calculations	59
3.2 Biomass production	60
3.2.1 Forest residues	60
3.2.2 Herbaceous biomass fuels	61
3.2.3 Short rotation woody crops	62

3.3	Fuel pre-treatment	64
3.3.1	Comminution of woody biomass	64
3.3.2	Pre-treatment of waste wood	69
3.3.3	Baling and bundling of biomass fuels	72
3.3.4	Pellets and briquettes	74
3.3.5	Drying of biomass	78
3.4	Storage, handling and transport systems	83
3.4.1	Storage of biomass	83
3.4.2	Fuel-feeding and handling systems	89
3.4.3	Transport systems for biomass fuels	95
3.5	System perspectives on bioenergy	96
3.5.1	Case 1 Multifunctional bioenergy systems (MBS)	98
3.5.2	Case 2 Co-firing opportunities in Poland	102
3.5.3	Conclusions from the two cases	108
3.6	References	108
4	Domestic Wood-Burning Appliances	112
4.1	Introduction	112
4.2	Design considerations	112
4.3	Residential batch-fired wood-burning appliances	113
4.3.1	Wood-stoves	113
4.3.2	Fireplace inserts and zero clearance fireplaces	115
4.3.3	Heat-storing stoves	116
4.3.4	Wood log boilers	118
4.4	Wood pellet appliances and burners	122
4.4.1	Background	122
4.4.2	Technical features	122
4.4.3	Safety requirements regarding back-burning	123
4.4.4	Emissions	123
4.4.5	Efficiency	124
4.4.6	Certification	124
4.4.7	Pellet burners for central heating systems	125
4.4.8	Wood pellet stoves	127
4.5	Woodchip appliances	128
4.5.1	Pre-ovens	128
4.5.2	Under-fire boilers	129
4.5.3	Stoker burners	129
4.6	Certification and testing standards	129
4.6.1	European standards	130
4.6.2	North American standards	132
4.7	References	133
5	Combustion Technologies for Industrial and District Heating Systems	134
5.1	Introduction	134
5.2	Fixed-bed combustion	135
5.2.1	Grate furnaces	135
5.2.2	Underfeed stokers	146

5.3	Fluidized bed combustion	147
5.3.1	Bubbling fluidized bed (BFB) combustion	148
5.3.2	Circulating fluidized bed (CFB) combustion	149
5.4	Pulverized fuel combustion	150
5.5	Summary of combustion technologies	154
5.6	Heat recovery systems and possibilities for increasing plant efficiency	155
5.7	Process control systems for biomass combustion installations	161
5.7.1	Control objectives	161
5.7.2	Process dynamics	161
5.7.3	State-of-the-art process control	163
5.7.4	Advanced process control	164
5.8	Techno-economic aspects of biomass combustion plant design	167
5.8.1	Technical and economic standards for biomass combustion and district heating plants	168
5.8.2	Plant dimensioning/boiler size	169
5.8.3	Annual utilization rate of the biomass system	170
5.8.4	Size of the fuel storage unit	170
5.8.5	Construction and civil engineering costs	171
5.8.6	Heat distribution network	171
5.8.7	Heat generation costs and economic optimization	171
5.9	References	173
6	Power Generation and Co-generation	175
6.1	Overview of power generation processes	175
6.2	Closed thermal cycles for power production	175
6.3	Steam turbines	177
6.3.1	Working principle	177
6.3.2	Rankine cycle	179
6.3.3	Economic aspects	182
6.4	Steam piston engines	183
6.5	Steam screw engines	187
6.6	Organic Rankine cycle (ORC)	189
6.7	Closed gas turbines	192
6.8	Stirling engines	193
6.9	Comparison of heat, power and CHP production	197
6.10	Summary	200
6.11	References	201
7	Co-combustion	203
7.1	Introduction	203
7.2	Operational experience	203
7.3	Co-firing concepts	206
7.3.1	Direct co-firing	207
7.3.2	Indirect co-firing	207
7.3.3	Parallel co-firing	207
7.4	Examples of biomass co-firing in pulverized coal-fired boilers	208
7.4.1	Direct co-firing of demolition wood waste with coal, Gelderland Power Station, Nijmegen, the Netherlands	208

7.4.2	Direct co-firing of sawdust and woodchips with coal, Wallerawang Power Station, NSW, Australia	209
7.4.3	Direct co-firing of straw with coal, Studstrup, Denmark	212
7.4.4	Direct co-firing of wood fuels with coals, St Andrea, Austria	215
7.4.5	Indirect co-firing of biomass fuel gas with coal, Zeltweg Power Plant, Austria	216
7.4.6	Indirect co-firing of biomass fuel gas with coal, Amer Power Plant, the Netherlands	218
7.4.7	Parallel co-firing of biomass and fossil fuels, Avedøre Power Plant, Denmark	219
7.4.8	Summary of experience of biomass co-firing in pulverized coal-fired boilers	220
7.5	Fuel preparation, processing and handling issues	223
7.5.1	Preliminary size reduction	224
7.5.2	Bulk handling	225
7.5.3	Long-term storage	226
7.5.4	Drying	228
7.5.5	Secondary size reduction	228
7.6	Operational and environmental issues	232
7.6.1	General fuel characteristics of coals and biomass	232
7.6.2	Particle size and residence time	233
7.6.3	Boiler efficiency	235
7.6.4	Rate of combustion and char burnout	235
7.6.5	Flame stability	237
7.6.6	System integration and control issues	237
7.6.7	Ash deposition	237
7.6.8	Gas-side corrosion of boiler components	239
7.6.9	Impact on emissions	239
7.6.10	Performance of NO _x and SO _x emissions abatement equipment	243
7.6.11	Efficiency of particulate emissions abatement equipment	244
7.6.12	Flyash utilization	245
7.7	References	247
8	Biomass Ash Characteristics and Behaviour in Combustion Systems	249
8.1	Introduction	249
8.2	Biomass ash characteristics	250
8.2.1	Introduction	250
8.2.2	Laboratory characterization techniques for biomass ashes	251
8.3	High temperature behaviour of inorganic constituents of biomass in combustion systems	258
8.3.1	Introduction	258
8.3.2	Grate-fired combustors	260
8.3.3	Fluidized bed combustors	263
8.3.4	Pulverized fuel combustion systems	264
8.4	Formation and nature of ash deposits on the surfaces of combustors and boilers firing or co-firing biomass materials	266
8.4.1	Introduction to ash deposition	266
8.4.2	Slag formation processes	267

8.4.3	Convective section fouling processes	269
8.4.4	Deposit growth, shedding and online cleaning	271
8.5	Impact of ash on the flue gas cleaning equipment in biomass-firing systems	272
8.5.1	Introduction	272
8.5.2	The impact of co-firing on electrostatic precipitators	273
8.5.3	The impact of biomass co-firing on SCR catalysts	273
8.5.4	The impact of biomass co-firing on FGD plants	275
8.6	Impact of biomass ash on boiler tube corrosion, and on erosive and abrasive wear of boiler components	276
8.6.1	Technical background to gas-side corrosion processes in boilers	276
8.6.2	Corrosion mechanisms	277
8.6.3	Plant experience and boiler probing trials with biomass firing and biomass-coal co-firing	278
8.6.4	Preventive and remedial measures for fire side corrosion	283
8.6.5	Erosion and abrasion of boiler components and other equipment	285
8.7	Biomass ash utilization and disposal	286
8.8	References	288
9	Environmental Aspects of Biomass Combustion	291
9.1	Introduction	291
9.2	Environmental impacts of biomass combustion	292
9.2.1	Emission components and their main influencing factors	294
9.2.2	Measuring emissions from biomass combustion	304
9.2.3	Emissions data	304
9.2.4	Primary emission reduction measures	309
9.2.5	Secondary emission reduction measures	318
9.2.6	Emission limits in selected IEA member countries	339
9.3	Options for ash disposal and utilization	348
9.3.1	Introduction: General, ecological and technological limitations	348
9.3.2	Physical and chemical properties of biomass ashes	350
9.3.3	Material fluxes of ash-forming elements during combustion of biomass	359
9.3.4	Conclusions	361
9.4	Treatment technologies and logistics for biomass ashes	362
9.4.1	Combustion technology	362
9.4.2	Downstream processes: Ash pre-treatment and utilization	363
9.4.3	Examples of guidelines for the utilization of biomass ashes in Austria	365
9.4.4	Recommended procedure and quantitative limits for biomass ash-to-soil recycling in Austria	365
9.5	Waste-water handling from flue gas condensation	367
9.6	References	372

10	Policies	379
10.1	Introduction	379
10.2	Global expansion of biomass combustion	379
10.2.1	Trends in selected OECD member countries	381
10.2.2	Trends in selected non-OECD member countries	385
10.2.3	Relevant policy issues	385
10.3	Financial support instruments	387
10.3.1	Fixed feed-in tariffs and fixed premiums	387
10.3.2	Green certificate systems	387
10.3.3	Tendering	387
10.3.4	Investment subsidies	387
10.3.5	Tax deduction	388
10.4	Other policies that influence the establishment of biomass combustion	389
10.5	References	390
11	Research and Development: Needs and Ongoing Activities	391
11.1	Investigation of potentials of biomass resources	391
11.2	Development of improved combustion technologies	392
11.3	Gaseous (especially NO _x) reduction technologies	392
11.4	Ash and aerosol-related problems during biomass combustion including dust (fine particulate) reduction technologies	393
11.5	Innovative micro-, small- and medium-scale CHP technologies based on biomass combustion	394
11.6	Technology development and unsolved problems concerning co-firing of biomass in large-scale power plants	394
11.7	Fuel pre-treatment technologies	395
11.8	CFD modelling and simulation of thermochemical processes	395
11.9	References	396
<i>Annex 1</i>	<i>Mass Balance Equations and Emission Calculation</i>	<i>408</i>
<i>Annex 2</i>	<i>Abbreviations</i>	<i>413</i>
<i>Annex 3</i>	<i>European and National Standards or Guidelines for Solid Biofuels and Solid Biofuel Analysis</i>	<i>417</i>
<i>Annex 4</i>	<i>Members of IEA Bioenergy Task 32: Biomass Combustion and Cofiring</i>	<i>423</i>
<i>Index</i>		<i>426</i>