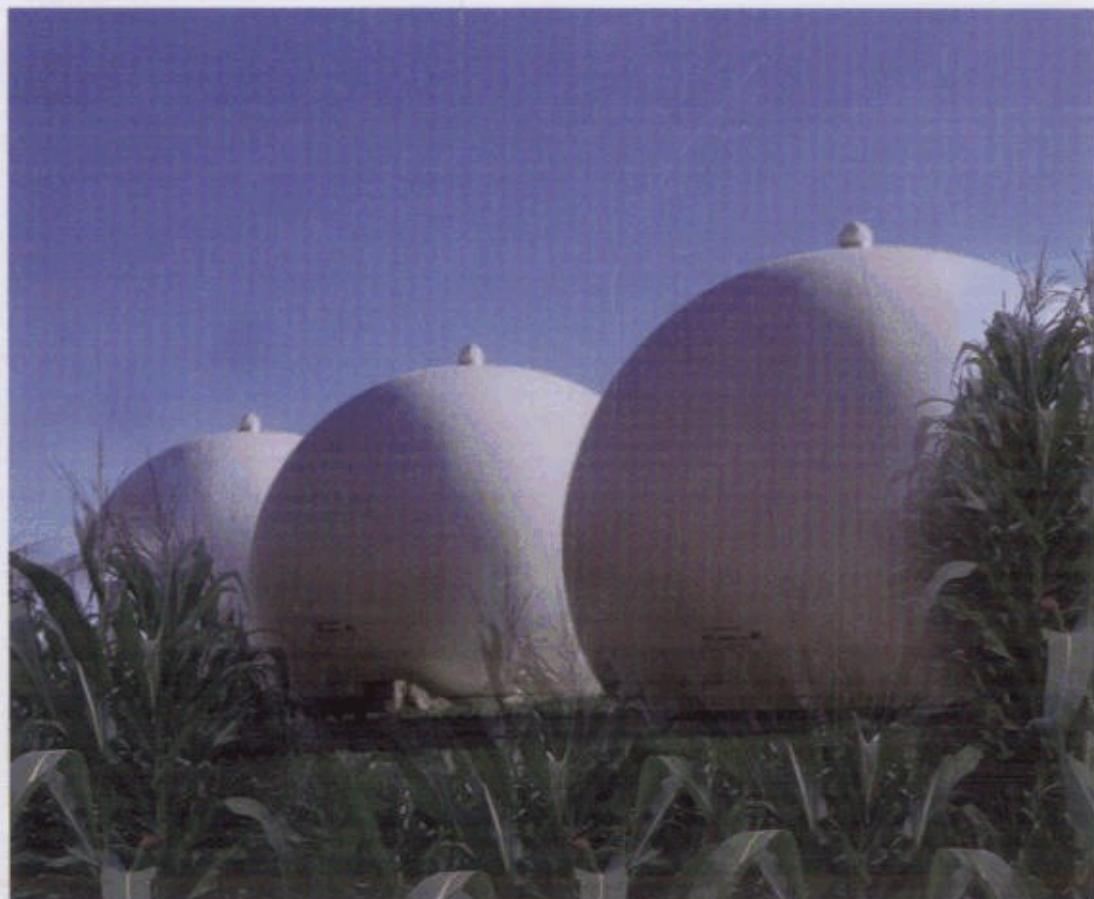


Dieter Deublein
and Angelika Steinhauser

WILEY-VCH

Biogas from Waste and Renewable Resources

An Introduction



Contents

Preface XV
Abbreviations XVII
Acknowledgement XXIII

Part I General thoughts about energy supply 1

- 1 Energy supply – today and in the future 3**
 - 1.1 Primary energy sources 3
 - 1.2 Secondary energy sources 5
 - 1.3 End-point energy sources 6
 - 1.4 Effective energy 6
- 2 Energy supply in the future – scenarios 7**
 - 2.1 Amount of space 11
 - 2.2 Potential yield from biomass 13
 - 2.2.1 Theoretical potential 13
 - 2.2.1.1 C3 plants (energy plants) 15
 - 2.2.1.2 C4 plants and CAM plants 17
 - 2.2.1.3 Micro-algae 20
 - 2.3 Technical potential 21
 - 2.4 Economic potential 23
 - 2.5 Realizable potential 23
- 3 History and status to date in Europe 27**
 - 3.1 First attempts at using biogas 28
 - 3.2 Second attempts at using biogas 30
 - 3.3 Third attempts at applying biogas 32
 - 3.4 Status to date and perspective in Europe 32
- 4 History and status to date in other countries 35**
 - 4.1 History and status to date in China 36

4.1.1	Period from 1970 to 1983	37
4.1.2	Period from 1984 to 1991	38
4.1.3	Period from 1992 to 1998	38
4.1.3.1	"A pit with three rebuildings"	38
4.1.3.2	"4 in 1"	39
4.1.3.3	"Pig-biogas-fruits"	39
4.1.4	Period from the year 1999 onwards	39
4.2	History and status to date in India	40
4.3	Status to date in Latin America	42
4.4	Status to date in the CIS states	42
5	General aspects of the recovery of biomass in the future	45
Part II	Substrate and biogas	47
1	Biogas	49
1.1	Biogas compared to other methane-containing gases	49
1.2	Detailed overview of biogas components	52
1.2.1	Methane and carbon dioxide	53
1.2.2	Nitrogen and oxygen	54
1.2.3	Carbon monoxide	55
1.2.4	Ammonia	55
1.2.5	Hydrogen sulfide	55
1.2.6	Chlorine, fluorine, mercaptans	56
1.2.7	BTX, PAK, etc.	56
1.2.8	Siloxanes	56
2	Substrates	57
2.1	Liquid manure and co-substrates	57
2.2	Bio waste from collections of residual waste and trade waste similar to domestic waste	66
2.3	Landfill for residual waste	66
2.4	Sewage sludge and co-substrate	70
2.5	Industrial waste water	74
2.6	Waste grease or fat	74
2.7	Cultivation of algae	74
2.8	Plankton	75
2.9	Sediments in the sea	76
2.10	Wood, straw	77
3	Evaluation of substrates for biogas production	79
4	Benefits of a biogas plant	83

Part III Formation of biogas 87**1 Biochemical reaction 89****2 Biology 93**

2.1 Bioreactions 93

2.1.1 Hydrolysis 94

2.1.2 Acidogenic phase 94

2.1.3 Acetogenic phase 96

2.1.4 Methanogenic phase 98

2.2 Process parameters 100

2.2.1 Parameter: hydrogen partial pressure 101

2.2.2 Parameter: concentration of the microorganisms 102

2.2.3 Parameter: type of substrate 102

2.2.4 Parameter: specific surface of material 103

2.2.5 Parameter: disintegration 106

2.2.6 Parameter: cultivation, mixing, and volume load 110

2.2.7 Parameter: light 112

2.2.8 Parameter: temperature 112

2.2.9 Parameter: pH 113

2.2.10 Parameter: redox potential 116

2.2.11 Parameter: nutrients (C/N/P-ratio) 116

2.2.12 Parameter: trace elements 116

2.2.13 Parameter: precipitants (calcium carbonate, MAP, apatite) 117

2.2.14 Parameter: biogas removal 117

2.2.15 Parameter: inhibitors 118

2.2.15.1 Oxygen 119

2.2.15.2 Sulfur compounds 119

2.2.15.3 Organic acids (fatty acids and amino acids) 121

2.2.15.4 Nitrate (NO_3^-) 1222.2.15.5 Ammonium (NH_4^+) and ammonia (NH_3) 123

2.2.15.6 Heavy metals 125

2.2.15.7 Tannins 125

2.2.15.8 Other inhibiting thresholds 125

2.2.16 Parameter: degree of decomposition 127

2.2.17 Parameter: foaming 127

2.2.18 Parameter: scum 127

3 Bacteria participating in the process of degradation 129

3.1 Hydrolyzing genera 131

3.2 Acidogenic genera 131

3.3 Acetogenic genera 134

3.4 Methanogenics 135

3.5 Methanotropic species 137

Part IV Laws and guidelines concerning biogas plants 149

1	Guidelines and regulations 151
1.1	Construction of plants 152
1.1.1	Corresponding regulations 152
1.1.2	Checklist of regulations concerning the plant 154
1.2	Utilized biomass 155
1.3	Biomass to be used preferentially 159
1.4	Distribution of the residues 160
1.5	Feeding biogas to the gas network 161
1.6	Risk of explosion 161
1.6.1	Explosion-endangered areas – ex-zones 162
1.6.2	Checklist of measures for explosion protection 164
1.7	Risk of fire 171
1.7.1	Fire protection sectors 171
1.7.2	Checklist for fire protection measures 172
1.8	Harmful exhaust gases 173
1.8.1	Prescriptions and guidelines 173
1.8.1.1	Germs 175
1.8.1.2	Emissions of smells 175
1.8.2	Checklist for immission prevention measures 179
1.9	Noise protection 183
1.9.1	Regulations and guidelines 184
1.9.2	Checklist for noise protection measures 185
1.10	Prevention of injuries 185
1.11	Protection from water 186
1.11.1	Regulations and guidelines 186
1.11.2	Checklist for water protection measures 186
2	Building a biogas plant 189
2.1	Feasibility study 189
2.2	Preliminary planning 189
2.3	The construction process 192
3	Financing 195

Part V Process engineering 197

1	Parts of biogas plants 199
1.1	Tanks and reactors 199
1.1.1	Brick tanks 199
1.1.2	Reinforced concrete tanks 200
1.1.3	Tanks of normal steel sheet metals with enamel layer or plastic coating 205
1.1.4	Tanks of stainless steel 206

1.1.5	Ground basin with plastic foil lining	206
1.2	Equipment for tempering the substrate	207
1.3	Thermal insulation	209
1.4	Piping system	209
1.5	Pump system	210
1.6	Measurement, control, and automation technology	211
1.6.1	Mechanisms for monitoring and regulation	211
1.6.1.1	Dry matter concentration in the substrate	213
1.6.1.2	Organic dry matter content and/or total organic carbon (TOC)	213
1.6.1.3	Biochemical oxygen demand (BOD)	213
1.6.1.4	Chemical oxygen demand (COD)	214
1.6.1.5	Degree of decomposition	215
1.6.1.6	Acid value	216
1.6.1.7	Determination of nutrients (nitrogen and phosphorus compounds)	216
1.6.1.8	Sludge (volume) index (I_{sv})	217
1.6.1.9	Ignition loss	217
1.6.1.10	Biogas yield and quality	217
1.6.2	Equipment to secure the operatability	217
1.6.2.1	Foaming	218
1.6.2.2	Blockage	218
1.6.3	Safety devices for humans and the environment	218
1.6.3.1	Safety device before the gas flare	218
1.6.3.2	Overpressure and negative pressure safety device	218
1.7	Exhaust air cleaning	220
2	Area for the delivery and equipment for storage of the delivered biomass	221
3	Process technology for the upstream processing	223
3.1	Adjustment of the water content	224
3.2	Removal of disturbing/harmful substances	224
3.3	Comminution	226
3.4	Hygienization	226
3.4.1	Direct inspection	227
3.4.1.1	Salmonella	227
3.4.1.2	Plasmodiophora brassicae	229
3.4.1.3	Tobacco mosaic virus	229
3.4.1.4	Tomato seeds	229
3.4.2	Indirect process inspection	229
3.4.3	Control of the finished goods	230
3.5	Disintegration	231
3.5.1	Mechanical processes	235
3.5.2	Ultrasonic process	235
3.5.3	Chemical processes	236

3.5.4	Thermal processes	238
3.5.5	Biological processes	238
3.6	Feeding	239
4	Fermentation technology	243
4.1	Batchwise and continuous processes without separators	243
4.1.1	Systems engineering	244
4.1.2	Reactor technique	248
4.1.2.1	Reactor size	248
4.1.2.2	Reactor Designs	250
4.1.2.3	Covering of the bioreactor	251
4.1.2.4	Access door and inlet	252
4.1.2.5	Drainage layer below the bioreactor	253
4.1.2.6	Heat insulation	254
4.1.2.7	Agitators	254
4.1.2.8	Heating	257
4.1.3	Efficiency	258
4.2	Existing installations by different suppliers	259
4.2.1	WABIO-Vaasa process	260
4.2.2	DUT process	261
4.2.3	WABIO process	261
4.2.4	Farmatic™ biotech energy installation	262
4.2.5	Bigadan™ process (formerly Krüger process)	263
4.2.6	Valorga™ process	263
4.3	Installation with substrate dilution and subsequent water separation	264
4.3.1	Equipment	265
4.3.2	Implemented installations of different manufacturers	268
4.4	Installation with biomass accumulation	269
4.4.1	Sewage sludge digestion tower installation	269
4.4.1.1	Equipment	270
4.4.1.2	Operation of the digestion tower	285
4.4.2	Industrial purification of sewage	286
4.4.2.1	Process engineering and equipment construction	287
4.4.2.2	Plant installations	299
4.5	Plants with separation of non-hydrolyzable biomass	301
4.5.1	Process of suspension	302
4.5.1.1	Process engineering and equipment construction	302
4.5.1.2	Efficiency	303
4.5.1.3	Plant installations	303
4.5.2	Percolation process	305
4.5.2.1	Process engineering and equipment construction	305
4.5.2.2	Plant installations	306
4.6	Residue storage tank and distribution	311

5	Special plant installations	313
5.1	Combined fermentation of sewage sludge and bio waste	313
5.2	Bio waste plants	315
5.3	Purification of industrial waste water	322
5.3.1	Process engineering and equipment construction	322
5.3.2	Plants for industrial waste water fermentation	322

Part VI Biogas to energy 323

1	Gas pipelines	325
2	Biogasholder	327
2.1	Biogasholder types	327
2.1.1	Low-pressure biogasholder	327
2.1.2	Medium- and high-pressure biogasholders	330
2.2	Gas flares	330
3	Gas preparation	333
3.1	Removal of hydrogen sulfide	335
3.1.1	Biological desulfurization	335
3.1.2	Sulfide precipitation	339
3.1.3	Absorption in a ferric chelate solution	340
3.1.4	Adsorption at iron-containing masses	341
3.1.5	Adsorption on activated charcoal	342
3.1.6	Chemical binding to zinc	343
3.1.7	Surfactants	343
3.1.8	Passing the biogas through an algae reactor or addition of sodium alginate	344
3.1.9	Direct oxidation	344
3.1.10	Compressed gas scrubbing	344
3.1.11	Molecular sieves	344
3.2	Removal of the carbon dioxide	345
3.2.1	Absorption	345
3.2.2	Absorbents based on glycol and ethanolamines	348
3.2.3	Adsorption with pressure swing technology (PSA)	349
3.2.4	Adsorption with pressure swing technology (VPSA) under vacuum	351
3.2.5	Diaphragm technology	351
3.2.6	Mineralization and biomineralization	353
3.2.7	Cryogenic biogas purification	353
3.3	Removal of oxygen	354
3.4	Removal of water	354
3.5	Removal of ammonia	355
3.6	Removal of siloxanes	355

4	Liquefaction or compression of the biogas	357
4.1	Liquefaction	357
4.2	Compression	358
5	Utilization of biogas for the generation of electric power and heat	361
5.1	Supply of current to the public electricity network	361
5.1.1	Generators	363
5.1.2	Current-measuring instruments	363
5.1.3	Control of the synchronization	363
5.1.4	Switching devices	364
5.1.5	Network failure registration	364
5.1.6	Short-circuit protection	365
5.1.7	Wattless current compensation	365
5.2	Heat	365
5.3	Combined heat and power generator (CHP)	367
5.3.1	Engines	367
5.3.1.1	Generation of electricity in a four-stroke gas engine and a Diesel engine	367
5.3.1.2	Generation of electricity in a Stirling engine	372
5.3.1.3	Generation of electricity in a fuel cell	373
5.3.1.4	Generation of electricity in a gas turbine	378
5.3.1.5	Generation of electricity in a micro gas turbine	379
5.3.2	Controlling the CHP	381
5.3.3	Emission control	382
5.3.3.1	Regulations	382
5.3.3.2	Measures for the reduction of emissions	383
5.4	Lessons learnt from experience	386
5.5	Economy	388
5.6	CHP manufacturers	388
6	Biogas for feeding into the natural gas network	389
6.1	Biogas for feeding into the natural gas network in Switzerland	392
6.2	Biogas for feeding into the natural gas network in Sweden	393
6.3	Biogas for feeding into the natural gas network in Germany	394
7	Biogas as fuel for vehicles	397
7.1	Example project: "chain of restaurants in Switzerland"	397
7.2	Example projects in Sweden	398
Part VII	Residues and waste water	401
1	Residues	403
2	Waste water	405

- Attachment I Typical design calculation for an agricultural biogas plant 407**
- Attachment II Economy of biogas plants for the year 2007
(Calculation on the basis of the example of
Attachment I) 415**
- Literature 419**
- Index 429**