

TECHNOLOGY & COSTS**Biorenewable Insights****Municipal Solid Waste as a Sustainable Feedstock**

Table of Contents

A Report by **NexantECA, the Energy and Chemical Advisory company**

Published Date: December 2021

www.nexanteca.com/subscriptions-and-reports**Contents**

1	Executive Summary	1
1.1	Overview	1
1.2	Introduction	1
1.3	Waste Disposal Methods	2
1.4	Collection and Sorting	3
1.5	Waste Management Technologies	4
1.6	Economics	5
1.6.1	Tipping Fees	5
1.6.2	Disposal Economics	5
1.7	Municipal Solid Waste Market Analysis.....	7
2	Introduction.....	9
2.1	Overview	9
2.2	Types of Municipal Solid Waste.....	10
2.3	Waste Disposal Methods	13
2.3.1	Landfilling	14
2.3.2	Recycling.....	32
2.3.3	Incineration.....	32
2.4	Municipal Solid Waste as an Important Resource	32
2.4.1	Environmental Drivers	34
2.4.2	Economic Drivers.....	35
2.4.3	Policy Drivers	37
3	Municipal Solid Waste Collection and Sorting Technologies	43
3.1	Collection	43
3.2	Pre-Sorting.....	44
3.3	Sorting.....	44
3.3.1	Manual Sorting.....	44
3.3.2	Screens	45

3.3.3	Ballistic Separators	45
3.3.4	Air Separation	45
3.3.5	Electromagnetic Separation	45
3.3.6	Eddy Currents	45
3.3.7	Optical Sorting	45
3.3.8	Post-Sorting	45
4	Municipal Solid Waste as a Feedstock	46
4.1	Introduction	46
4.2	Gasification	48
4.2.1	Overview	48
4.2.2	Gasification Product.....	49
4.2.3	Process Description.....	50
4.2.4	Gasification Technology Developers	53
4.3	Pyrolysis.....	53
4.3.1	Overview	53
4.3.2	Pyrolysis Products	54
4.3.3	Process Description.....	55
4.3.4	Pyrolysis Technology Developers	59
4.4	Mass Burn/RDF Incineration/Waste-to-Energy	60
4.4.1	Overview	60
4.4.2	Waste-to-Energy Products	62
4.4.3	Process Description.....	62
4.4.4	Waste-to-Energy Plants.....	66
4.5	Anaerobic Digestion	72
4.5.1	Overview	72
4.5.2	Anaerobic Digestion Products	73
4.5.3	Process Description.....	75
4.5.4	Anaerobic Digestion Technology Developers.....	78
4.5.5	Biogas Plants	78
4.6	Aerobic Composting	90
4.6.1	Overview	90
4.6.2	Aerobic Composting Product.....	91
4.6.3	Process Description.....	91
4.6.4	Aerated Static Pile Composting	94
4.6.5	In-Vessel Composting	95
4.6.6	Aerated Windrow Composting	96
4.6.7	Aerobic Composters	96
5	Economics	98
5.1	Methodology	98
5.1.1	Sources	98
5.1.2	Capital Cost Elements	98
5.1.3	Operating Cost Elements	102

5.2	5.1.4 Model Limitations and Material Balance	104
5.2	Costing Basis.....	106
5.2.1	Location Basis.....	106
5.2.2	Investment Basis.....	106
5.3	Cost of Production Estimates.....	106
5.3.1	Regional Overview.....	107
5.3.2	Material Recovery Facility	111
5.3.3	Material Recovery Facility with a Green Waste Composting Center on Site	114
5.3.4	Material Recovery Facility with Refuse-Derived Fuel Recovery and Incineration (for Energy Generation).....	117
5.3.5	Material Recovery Facility with Green Waste Composting and Energy Generation from Refuse-Derived Fuel.....	120
5.3.6	Mass Burn Incineration Facility with Energy Recovery	123
5.3.7	Composting of Source Separated Green Waste.....	126
6	Municipal Solid Waste Market Analysis	128
6.1	United States	130
6.2	Europe	135
6.3	Asia Pacific	138

Appendices

A	Cost of Production Estimates	144
B	References	168

Figures

Figure 1	Waste Management Hierarchy	2
Figure 2	Typical Material Recovery Facility Configuration	3
Figure 3	Waste Conversion Technologies	4
Figure 4	Global Economic Competitiveness of Various Waste Disposal Configurations	5
Figure 5	Global Waste Generation, 2016-2050	7
Figure 6	Selected Global Municipal Waste Generation per Capita, 2010-2019	8
Figure 7	Typical Global Waste Composition	11
Figure 8	Waste Management Hierarchy	13
Figure 9	Waste Disposal Method in Selected Countries, 2019	14
Figure 10	Landfills in the United States	15
Figure 11	Municipal Waste Management in the United States, 1960-2018	16
Figure 12	Municipal Waste Management in the European Union, 1995-2019	17
Figure 13	Municipal Waste Management in the European Union and Several Non-Member Countries, 2019	17
Figure 14	Landfills in Europe, 2018	18
Figure 15	Municipal Waste Management in China, 2002-2018	20
Figure 16	Landfills in China's Main Cities, 2002-2018	20
Figure 17	Sanitary Landfill	22
Figure 18	Landfill Design Steps	23
Figure 19	U.S. MSW Landfill Tipping Fees by Year	25
Figure 20	Landfill Organic Bans in the United States by State, 2021	27
Figure 21	Landfill Electronic Devices Bans in the United States by State, 2021	28
Figure 22	Inputs and Outputs of Waste Management Process	33
Figure 23	Solid Waste Management System	34
Figure 24	Greenhouse Gas Sources Associated with the Material Life Cycle	35
Figure 25	Greenhouse Gas Emissions Reductions per Ton of Material Recycled	35
Figure 26	Global Municipal Solid Waste Generation versus Population	36
Figure 27	Fastest Growing Cities in the World	37
Figure 28	Typical Material Recovery Facility Configuration	43
Figure 29	SWOT Analysis of Municipal Solid Waste as a Feedstock	46
Figure 30	Waste Conversion Technologies	47
Figure 31	Chemicals and Fuels from Syngas	50
Figure 32	Generic Municipal Solid Waste-based Gasification Process	51
Figure 33	Main Pyrolysis Products at Different Temperatures	54
Figure 34	Plastics to Liquid Fuel Recycling Process	56
Figure 35	Mass Burn and RDF Boilers	60
Figure 36	Schematic of WTE Mass Burn Facility	63
Figure 37	Schematic of WTE Refuse-Derived Facility	65
Figure 38	Global Waste Capacity for Waste-to-Energy Plants, 2019	66
Figure 39	Waste-to-Energy Plants in the United States, 2018	67
Figure 40	Waste-to-Energy Plants in Europe, 2018	68

Figure 41	China's Planned Capacity for Treating Municipal Solid Waste, 2020	69
Figure 42	Chinese Waste Incineration Plants, 2011-2018	70
Figure 43	Waste-to-Energy Plants in Southeast Asia	70
Figure 44	Basic Anaerobic Digestion System Flow Diagram	73
Figure 45	Material Flow in an Anaerobic Digestion System	74
Figure 46	Energy Flow in an Anaerobic Digestion System	75
Figure 47	Typical Anaerobic Digestion Process Flow Diagram.....	76
Figure 48	Food Waste-based Digesters in the United States	79
Figure 49	Operational Biogas Systems in the United States, 2018	80
Figure 50	Biogas Plants in Europe, 2018	81
Figure 51	UK Biogas Production Facilities	82
Figure 52	Scandinavia Biogas Production Facilities.....	83
Figure 53	Germany and Netherlands Biogas Production Facilities	84
Figure 54	Switzerland, Austria, and Hungary Biogas Production Facilities.....	85
Figure 55	France Biogas Production Facilities	86
Figure 56	Italy Biogas Production Facilities.....	87
Figure 57	Biogas Systems in Europe, 2009- 2019	88
Figure 58	Production Potential for Biogas and Biomethane, 2018.....	88
Figure 59	Evolution of Biogas Systems in China.....	89
Figure 60	Phases of Thermophilic Composting.....	92
Figure 61	Catabolic Pathway of Aerobic Digestion	93
Figure 62	Aerated Static Pile Composting.....	95
Figure 63	In-Vessel Composting	95
Figure 64	Windrow Composting	96
Figure 65	Material Balance for a Dirty MRF	105
Figure 66	Waste Management Economics in the United States	107
Figure 67	Waste Management Economics in China	108
Figure 68	Waste Management Economics in Brazil.....	109
Figure 69	Waste Management Economics in Western Europe.....	110
Figure 70	Regional MRF Economics	111
Figure 71	Sensitivity of MRF Economics to Tipping Fee.....	112
Figure 72	Sensitivity of MRF Economics to Byproduct Credit	112
Figure 73	Sensitivity of MRF Economics to Byproduct Credit- Required Tipping Fees	113
Figure 74	Regional MRF Economics with Green Waste Composting	114
Figure 75	Sensitivity of MRF Economics with Green Waste Composting to Tipping Fee.....	115
Figure 76	Sensitivity of MRF Economics with Green Waste Composting to Byproduct Credit.....	115
Figure 77	Sensitivity of MRF Economics with Green Waste Composting to Byproduct Credit – Required Tipping Fees	116
Figure 78	Regional MRF with Energy Generation from RDF Economics	117
Figure 79	Sensitivity of MRF with Energy Generation from RDF Economics to Tipping Fee	118
Figure 80	Sensitivity of MRF with Energy Generation from RDF Economics to Byproduct Credit	118

Figure 81	Sensitivity of MRF with Energy Generation from RDF Economics to Byproduct Credit- Required Tipping Fees	119
Figure 82	Regional MRF with Green Waste Composting and Energy Generation from RDF Economics	120
Figure 83	Sensitivity of MRF with Green Waste Composting and Energy Generation from RDF Economics to Tipping Fee.....	121
Figure 84	Sensitivity of MRF with Green Waste Composting and Energy Generation from RDF Economics to Byproduct Credit.....	121
Figure 85	Sensitivity of MRF with Green Waste Composting and Energy Generation from RDF Economics to Byproduct Credit – Required Tipping Fees	122
Figure 86	Regional Mass Burn Incineration with Energy Recovery Economics.....	123
Figure 87	Sensitivity of Mass Burn Incineration with Energy Recovery Economics to Tipping Fee.....	124
Figure 88	Sensitivity of Mass Burn Incineration with Energy Recovery Economics to Byproduct Credit.....	124
Figure 89	Sensitivity of Mass Burn Incineration with Energy Recovery Economics to Byproduct Credit – Required Tipping Fees	125
Figure 90	Regional Composting of Source Separated Green Waste Economics.....	126
Figure 91	Sensitivity of Composting of Source Separated Green Waste Economics to Tipping Fee.....	127
Figure 92	Global Waste Generation, 2016-2050	128
Figure 93	Selected Global Municipal Waste Generation per Capita, 2010-2019.....	129
Figure 94	Municipal Solid Waste per Capita versus Income Level	130
Figure 95	United States Municipal Solid Waste Generated by Material Type, 2018	130
Figure 96	United States Municipal Solid Waste Generation Over Time.....	131
Figure 97	United States Municipal Solid Waste Stream by Type, 2020.....	131
Figure 98	United States Municipal Solid Waste Stream by Source, 2019	132
Figure 99	European Union Municipal Solid Waste Generation Over Time	135
Figure 100	Western Europe MSW Composition.....	136
Figure 101	European Union Waste Generation by Economic Activities and Households	138
Figure 102	Asia Pacific MSW Generation by Country, 2016.....	139
Figure 103	China MSW Generation, 2001-2018	139
Figure 104	Asia Pacific MSW Generation by Material Type, 2016.....	140

Tables

Table 1	Sources and Types of Municipal Solid Waste	10
Table 2	Waste Types and Typical Components.....	11
Table 3	Waste Type by Origin	12
Table 4	Recycling Comparison of Different Materials	12
Table 5	Waste and Recycling Data - China, Hong Kong, Singapore, and Taiwan	19
Table 6	Typical Asia Pacific Landfill Tipping Fees, 2013	21
Table 7	Landfill Main Classifications	21
Table 8	Differences of Open Dumps and Sanitary Landfills.....	24
Table 9	Average U.S. Landfill Tipping Fees by Region.....	26
Table 10	Landfill Taxes and Gate Fees in Europe by Country, 2017	30
Table 11	Current Energy Investment Tax Credit.....	38
Table 12	GREEN Act Investment Tax Credit Rates for Solar Projects	38
Table 13	Current Energy Production Tax Credit	39
Table 14	GREEN Act Tax Credit Rates for Wind Projects	39
Table 15	Typical Metrics of Various Gasifier Types	52
Table 16	Characteristics of Pyrolysis Processes	57
Table 17	Advantages and Disadvantages of Selected Pyrolysis Reactors.....	59
Table 18	Advantages and Disadvantages of Waste Incineration.....	61
Table 19	Biogas Potential of Different Feedstocks	75
Table 20	Advantages and Disadvantages of Dry High Solids Anaerobic Digestion	77
Table 21	Advantages and Disadvantages of Wet High Solids Anaerobic Digestion	77
Table 22	Advantages and Disadvantages of High Solids Multi-Stage Anaerobic Digestion.....	78
Table 23	Differences between Aerobic Composting and Anaerobic Digestion.....	90
Table 24	Example Single-Stream Waste Composition	133
Table 25	United States Waste Generation per Capita by States, 2019	134
Table 26	European Union and several Non-Member Countries Waste Generation per Capita by Country, 2019	136
Table 27	Material Recovery Facility Waste Stream Composition in the United Kingdom.....	137
Table 28	MSW Generation Rates in China, 2019	140
Table 29	Composition of MSW in China, 2016	141
Table 30	Cost of Production Estimate for: Material Recovery Facility Basis: 2021, USGC	144
Table 31	Cost of Production Estimate for: Material Recovery Facility Basis: 2021, China	145
Table 32	Cost of Production Estimate for: Material Recovery Facility Basis: 2021, Brazil.....	146
Table 33	Cost of Production Estimate for: Material Recovery Facility Basis: 2021, Western Europe.....	147
Table 34	Cost of Production Estimate for: MRF with Green Waste Composting Basis: 2021, USGC	148
Table 35	Cost of Production Estimate for: MRF with Green Waste Composting Basis: 2021, China	149

Table 36	Cost of Production Estimate for: MRF with Green Waste Composting Basis: 2021, Brazil.....	150
Table 37	Cost of Production Estimate for: MRF with Green Waste Composting Basis: 2021, Western Europe.....	151
Table 38	Cost of Production Estimate for: MRF with Energy Generation from RDF Basis: 2021, USGC	152
Table 39	Cost of Production Estimate for: MRF with Energy Generation from RDF Basis: 2021, China	153
Table 40	Cost of Production Estimate for: MRF with Energy Generation from RDF Basis: 2021, Brazil.....	154
Table 41	Cost of Production Estimate for: MRF with Energy Generation from RDF Basis: 2021, Western Europe.....	155
Table 42	Cost of Production Estimate for MRF with Green Waste Composting and Energy Generation from RDF Basis: 2021, USGC	156
Table 43	Cost of Production Estimate for: MRF with Green Waste Composting and Energy Generation from RDF Basis: 2021, China	157
Table 44	Cost of Production Estimate for: MRF with Green Waste Composting and Energy Generation from RDF Basis: 2021, Brazil.....	158
Table 45	Cost of Production Estimate for: MRF with Green Waste Composting and Energy Generation from RDF Basis: 2021, Western Europe.....	159
Table 46	Cost of Production Estimate for: Mass Burn Incineration with Energy Recovery Basis: 2021, USGC	160
Table 47	Cost of Production Estimate for: Mass Burn Incineration with Energy Recovery Basis: 2021, China	161
Table 48	Cost of Production Estimate for: Mass Burn Incineration with Energy Recovery Basis: 2021, Brazil.....	162
Table 49	Cost of Production Estimate for: Mass Burn Incineration with Energy Recovery Basis: 2021, Western Europe.....	163
Table 50	Cost of Production Estimate for: Composting of Source Separated Green Waste Basis: 2021, USGC	164
Table 51	Cost of Production Estimate for: Composting of Source Separated Green Waste Basis: 2021, China	165
Table 52	Cost of Production Estimate for: Composting of Source Separated Green Waste Basis: 2021, Brazil.....	166
Table 53	Cost of Production Estimate for: Composting of Source Separated Green Waste Basis: 2021, Western Europe.....	167



TECHNOLOGY & COSTS

Biorenewable Insights

The NexantECA Subscriptions' Biorenewable Insights program is recognized globally as the industry standard source for information relevant to the chemical process and refining industries. Biorenewable Insights reports are available as a subscription program or on a single report basis.

Contact Details:

Americas:

Marcos Nogueira Cesar, Vice President, Global Subscriptions and Reports
Phone: + 1-914-609-0324, e-mail: mcesar@NexantECA.com

Erica Hill, Client Services Coordinator, Subscriptions and Reports
Phone: + 1-914-609-0386, e-mail: ehill@NexantECA.com

EMEA:

Anna Ibbotson, Vice President, Sales and Marketing
Phone: +44-207-950-1528, aibbotson@NexantECA.com

Asia:

Chommanad Thammanayakatip, Managing Consultant
Phone: +66-2793-4606, email: chommanadt@NexantECA.com

NexantECA Subscriptions and Reports provide clients with comprehensive analytics, forecasts and insights for the chemicals, polymers, energy and cleantech industries. Using a combination of business and technical expertise, with deep and broad understanding of markets, technologies and economics, NexantECA provides solutions that our clients have relied upon for over 50 years.

Copyright © 2000-2021 NexantECA (BVI) Limited. All rights reserved