

**TECHNOLOGY & COSTS****Technoeconomics - Energy & Chemicals (TECH)****TECH 2022S11 Advances in Mechanical  
Recycling of Plastics**

## Table of Contents

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

Published Date: April 2022

[www.nexanteca.com/subscriptions-and-reports](http://www.nexanteca.com/subscriptions-and-reports)**Contents**

1	Executive Summary .....	1
1.1	Introduction.....	1
1.2	Polyethylene Terephthalate .....	3
1.2.1	Introduction.....	3
1.2.2	Mechanical Recycling Technology Analysis .....	3
1.2.3	Economic Analysis .....	4
1.2.4	Market Analysis .....	4
1.3	High Density Polyethylene .....	5
1.3.1	Introduction.....	5
1.3.2	Mechanical Recycling Technology Analysis .....	6
1.3.3	Economic Analysis .....	6
1.3.4	Market Analysis .....	7
1.4	Polypropylene.....	7
1.4.1	Introduction.....	7
1.4.2	Mechanical Recycling Technology Analysis .....	8
1.4.3	Economic Analysis .....	8
1.4.4	Market Analysis .....	9
1.5	Profitability Overview.....	10
2	Introduction.....	11
2.1	Overview.....	11
2.2	Plastic Waste Stream Composition .....	14
2.2.1	Municipal Solid Waste .....	14
2.2.2	Packaging Overview.....	17
2.2.3	Types of Plastics in a Plastic Waste Stream.....	19
2.3	Plastic Waste Streams .....	23
2.3.1	Post-industrial Plastic Waste.....	23
2.3.2	Post-consumer Plastic Waste .....	24

2.3.3	Differences Between Post-industrial and Post-consumer.....	24
2.4	Plastic Recycling Rates .....	26
2.4.1	United States .....	26
2.4.2	Europe.....	29
2.4.3	Asia Pacific.....	32
2.5	Understanding Mechanical Recycling .....	35
2.5.1	Mechanical Recycling Process - Steps .....	35
2.5.2	Benefits and Limitations of Mechanical Recycling .....	40
2.5.3	Superclean (or Physical): Secondary Recycling .....	42
2.5.4	Mechanical Washing Process .....	43
2.6	Recycling Legislation/Regulation .....	47
2.6.1	United States .....	47
2.6.2	Europe .....	55
2.6.3	Asia Pacific.....	61
3	Polyethylene Terephthalate.....	63
3.1	Introduction.....	63
3.1.1	Superclean PET Recycling .....	64
3.2	Polyethylene Terephthalate Mechanical Recycling Technologies .....	66
3.2.1	Bühler .....	66
3.2.2	DAK Americas .....	68
3.2.3	EREMA.....	69
3.2.4	Evergreen.....	73
3.2.5	Far Eastern New Century.....	74
3.2.6	Gneuss Kunststofftechnik .....	74
3.2.7	Krones .....	80
3.2.8	Plastic Technologies, Inc. .....	82
3.2.9	ProTech Polymer Processing.....	83
3.2.10	Next Generation Recycling .....	84
3.2.11	PolyQuest.....	87
3.2.12	Starlinger .....	89
3.2.13	Viscotec .....	94
3.2.14	Others.....	107
3.3	Economic Analysis .....	107
3.3.1	Investment Basis .....	107
3.3.2	Pricing Basis.....	108
3.3.3	Cost of Production Basis .....	109
3.3.4	Production Cost Estimates .....	109
3.4	Market Analysis .....	114
3.4.1	Global .....	114
3.4.2	North America .....	115
3.4.3	Western and Central Europe.....	115
3.4.4	Asia Pacific.....	116

4	High Density Polyethylene .....	118
4.1	Introduction.....	118
4.2	High Density Polyethylene Mechanical Recycling Technologies.....	122
4.2.1	Envision Plastics .....	122
4.2.2	EREMA.....	122
4.2.3	Krones .....	123
4.2.4	KW Plastics Recycling.....	125
4.2.5	Starlinger .....	125
4.2.6	Waste & Resources Action Programme.....	127
4.2.7	Others.....	128
4.3	Economic Analysis .....	128
4.3.1	Investment Basis .....	128
4.3.2	Pricing Basis.....	129
4.3.3	Cost of Production Basis .....	129
4.3.4	Production Cost Estimates .....	130
4.4	Market Analysis .....	135
4.4.1	Global .....	135
4.4.2	North America .....	136
4.4.3	Western and Central Europe.....	137
4.4.4	Asia Pacific.....	138
5	Polypropylene Technologies .....	139
5.1	Introduction.....	139
5.2	Polypropylene Mechanical Recycling Technologies .....	142
5.2.1	KW Plastics Recycling.....	142
5.2.2	Starlinger .....	142
5.2.3	Others.....	145
5.3	Economic Analysis .....	145
5.3.1	Investment Basis .....	145
5.3.2	Pricing Basis.....	146
5.3.3	Cost of Production Basis .....	147
5.3.4	Production Cost Estimates .....	147
5.4	Market Analysis .....	152
5.4.1	Global .....	152
5.4.2	North America .....	153
5.4.3	Western and Central Europe.....	154
5.4.4	Asia Pacific.....	155
6	Glossary .....	156

## Appendices

A	Cost of Production Estimates .....	159
B	Definitions of Capital Cost Terms Used in Process Economics.....	183
C	Definitions of Operating Cost Terms Used in Process Economics .....	188
D	TECH Program Title Index (2012-2022) .....	191
E	References .....	194

## Figures

Figure 1	SWOT Analysis of Mechanical Recycling .....	2
Figure 2	Key Drivers of Mechanical Recycling .....	2
Figure 3	Cost of Production Summary for Recycled PET Flakes.....	4
Figure 4	Global Recycled Polyethylene Terephthalate Outlook .....	5
Figure 5	Cost of Production Summary for Recycled HDPE Flakes.....	6
Figure 6	Global Recycled High Density Polyethylene Outlook .....	7
Figure 7	Cost of Production Summary for Recycled PP Flakes .....	9
Figure 8	Global Recycled Polypropylene Outlook .....	9
Figure 9	Plastics Main Markets.....	11
Figure 10	Global Plastics Industry Value.....	12
Figure 11	Plastic Industry Structure.....	13
Figure 12	United States Plastic Waste Generation Over Time .....	15
Figure 13	United States Municipal Solid Waste Composition by Material Type, 2018.....	15
Figure 14	Western Europe Municipal Solid Waste Composition by Material Type, 2019 .....	16
Figure 15	Asia Pacific Municipal Solid Waste Composition by Material Type, 2016.....	16
Figure 16	Global Packaging Market by End Use, 2019.....	18
Figure 17	Typical Composition of Plastic Waste in MSW.....	19
Figure 18	Global Plastics Consumption by Sector, 2020 .....	20
Figure 19	Global Plastic Demand by Type of Plastic, 2021-e .....	20
Figure 20	Global Polyethylene Terephthalate Demand by Application, 2021-e.....	21
Figure 21	Global Polyethylene Demand by Application, 2021-e .....	22
Figure 22	Global Polypropylene Demand by Application, 2021-e .....	22
Figure 23	Plastic Waste Streams .....	23
Figure 24	Types of Solid Plastic Waste .....	25
Figure 25	United States Plastic Packaging and Food-Service Plastic Demand by Type of Plastic .....	26
Figure 26	Plastic Recycling Rates, 1980-2018 .....	27
Figure 27	United States Plastic Containers and Packaging Generated, 1960-2018.....	27
Figure 28	United States Post-consumer Bottles Recovered for Recycling, 2015-2019 .....	28
Figure 29	United States Post-consumer Bottles Recovered for Recycling by Category, 2019 .....	28
Figure 30	EU28+NO/CH Post-consumer Plastic Waste Management .....	30
Figure 31	European Union Plastic Post-consumer Plastic Waste Disposal Management, 2018 .....	30

Figure 32	European Union Plastic Demand by Type of Plastic, 2019 .....	31
Figure 33	European Union Plastic Packaging Waste Generation and Recycled, 2009-2019.....	31
Figure 34	Plastic Packaging Recycling Rate per Country, 2019 .....	32
Figure 35	China and Southeast Asia Plastic Packaging Consumption per Capita, 2016 .....	34
Figure 36	China and Southeast Asia Household Packaging Consumption, 2016 .....	34
Figure 37	Typical Mechanical Recycling Scheme .....	35
Figure 38	Climate Change - Net Impact .....	40
Figure 39	Photochemical Ozone Formation - Net Impact .....	41
Figure 40	AMUT PET Washing Line.....	44
Figure 41	AMUT HDPE Washing Line.....	46
Figure 42	Policies in the United States .....	48
Figure 43	States with Mandatory Recycling Laws .....	49
Figure 44	United States Refund and PET Recycling Rates by State .....	53
Figure 45	European EPR Schemes for Packaging Waste .....	56
Figure 46	Global Number of People Covered by Container Deposit Systems.....	60
Figure 47	Refund and PET Return Rates in European Countries.....	61
Figure 48	Color Shift of Recycled PET Bottles .....	64
Figure 49	No Objection Letters Granted to PET Physical Processes by Year.....	65
Figure 50	No Objection Letters Granted to PET Physical Processes by Company .....	65
Figure 51	Buhler Bottle to Bottle Process.....	67
Figure 52	EREMA VACUNITE® Recycling Machinery .....	71
Figure 53	EREMA VACUREMA® Recycling Machinery.....	73
Figure 54	Extruder MRSjump with Vacuum Recycling Machinery .....	76
Figure 55	Tray-to-Tray Recycling Sheet Line with MRSjump Recycling Machinery .....	76
Figure 56	Scheme of the Polyreactor Jump .....	77
Figure 57	Vacuum for Polyreactor Jump Process .....	78
Figure 58	Vacuum for Polyreaction Extruder MRSjump Process .....	79
Figure 59	Krones MetaPure W-PET Washing Module .....	81
Figure 60	Krones MetaPure S Decontamination Module .....	82
Figure 61	ProTec Polymer Processing Tumble Reactor Machinery.....	84
Figure 62	NGR P:REACT Recycling Machinery .....	86
Figure 63	PolyQuest Recycling Scheme .....	88
Figure 64	Starlinger recoSTAR PET FG Process .....	91
Figure 65	Starlinger recoSTAR PET (HC) IV+ Process .....	93
Figure 66	Viscotec viscoSHEET Recycling Process .....	96
Figure 67	Viscotec viscoSHEET <sup>one</sup> Recycling Process .....	98
Figure 68	Viscotec viscoSTAR Recycling Process.....	100
Figure 69	Viscotec deCON iV+ Recycling Process .....	102
Figure 70	Viscotec deCON Recycling Process .....	104
Figure 71	Viscotec deCON20 Recycling Machinery .....	106
Figure 72	Cost of Production Summary for Recycled PET Flakes.....	111
Figure 73	Cost of Production Summary for Recycled PET Pellets.....	112

Figure 74	Effect of Changes in PET Scrap Price on Recycled PET Flake Economics .....	113
Figure 75	Effect of Changes in Recycled PET Flake Price on Recycled PET Pellet Economics .....	113
Figure 76	Global Recycled Polyethylene Terephthalate Outlook .....	114
Figure 77	North America Recycled Polyethylene Terephthalate Outlook .....	115
Figure 78	Western and Central Europe Recycled Polyethylene Terephthalate Outlook .....	116
Figure 79	Asia Pacific Recycled Polyethylene Terephthalate Outlook.....	117
Figure 80	Days of Embrittlement of Recycled HDPE Bottles .....	120
Figure 81	No Objection Letters Granted to HDPE Physical Processes by Year.....	121
Figure 82	No Objection Letters Granted to HDPE Physical Processes by Company .....	121
Figure 83	EREMA HDPE Recycling Machinery.....	123
Figure 84	Krones MetaPure W-PO Washing Module.....	124
Figure 85	Starlinger recoSTAR HDPE FG+ Recycling Machinery .....	126
Figure 86	Starlinger recoSTAR Dynamic with C-VAC Degassing Module and Downstream Odor Reduction Technology Recycling Machinery .....	127
Figure 87	Cost of Production Summary for Recycled HDPE Flakes.....	131
Figure 88	Cost of Production Summary for Recycled HDPE Pellets .....	133
Figure 89	Effect of Changes in HDPE Scrap Price on Recycled HDPE Flake Economics .....	134
Figure 90	Effect of Changes in Recycled HDPE Flake Price on Recycled HDPE Pellet Economics .....	135
Figure 91	Global Recycled High Density Polyethylene Outlook.....	136
Figure 92	North America Recycled High Density Polyethylene Outlook .....	137
Figure 93	Western and Central Europe Recycled High Density Polyethylene Outlook .....	137
Figure 94	Asia Pacific Recycled High Density Polyethylene Outlook .....	138
Figure 95	No Objection Letters Granted to PP Physical Processes by Year .....	141
Figure 96	No Objection Letters Granted to PP Physical Processes by Company .....	141
Figure 97	Starlinger recoSTAR Dynamic Process .....	144
Figure 98	Cost of Production Summary for Recycled PP Flakes .....	149
Figure 99	Cost of Production Summary for Recycled PP Pellets.....	150
Figure 100	Effect of Changes in PP Scrap Price on Recycled PP Flake Economics .....	151
Figure 101	Effect of Changes in Recycled PP Flake Price on Recycled PP Pellet Economics .....	152
Figure 102	Global Recycled Polypropylene Outlook .....	153
Figure 103	North America Recycled Polypropylene Outlook .....	154
Figure 104	Western and Central Europe Recycled Polypropylene Outlook.....	155
Figure 105	Asia Pacific Recycled Polypropylene Outlook.....	155

## Tables

Table 1	Global Plastic Recycling Contribution.....	1
Table 2	Mechanical Recycling of Polyethylene Terephthalate Technology Developers Profiled .....	3
Table 3	Mechanical Recycling of High Density Polyethylene Technology Developers Profiled .....	6
Table 4	Mechanical Recycling of Polypropylene Technology Developers Profiled.....	8
Table 5	Margins and Return on Investment for Mechanically Recycled Plastics, USGC .....	10
Table 6	Global Plastic Recycling Contribution.....	13
Table 7	Global Plastic Waste Per Capita .....	14
Table 8	Global Single-Use Plastic Waste Per Capita.....	14
Table 9	Packaging Segments and Sub-segments .....	17
Table 10	United States Post-consumer PET Bottle Recycling Rate, 2015-2019.....	28
Table 11	United States Post-consumer HDPE Bottle Recycling Rate, 2015-2019.....	29
Table 12	United States Post-consumer PP Bottle Recycling Rate, 2015-2019.....	29
Table 13	Composition of Municipal Solid Waste in China, 2016 .....	33
Table 14	Country Share Plastic Waste Imports, 1988-2016 .....	35
Table 15	Sorting Techniques by Type of Plastics .....	37
Table 16	Sorting Methods for Plastics.....	38
Table 17	Mechanical Recycling Advantages and Disadvantages.....	41
Table 18	AMUT PET Specifications .....	45
Table 19	States with Bottle Bill Laws.....	51
Table 20	Deposit Refund Mandates in European Countries .....	61
Table 21	Krones PET Recycling Systems .....	80
Table 22	P:REACT Specifications .....	87
Table 23	PolyQuest rPET Characteristics .....	88
Table 24	Starlinger Food-Contact rPET Systems .....	89
Table 25	Prices of Raw Materials, Products, Utilities, and Labor – Polyethylene Terephthalate Recycling .....	108
Table 26	Cost of Production Summary for Recycled PET Flakes.....	110
Table 27	Cost of Production Summary for Recycled PET Pellets.....	112
Table 28	Krones Polyolefins Recycling Systems .....	123
Table 29	Starlinger recoSTAR HDPE FG+ Specifications .....	125
Table 30	Prices of Raw Materials, Products, Utilities, and Labor – High Density Polyethylene Recycling .....	129
Table 31	Cost of Production Summary for Recycled HDPE Flakes.....	131
Table 32	Cost of Production Summary for Recycled HDPE Pellets .....	133
Table 33	Prices of Raw Materials, Products, Utilities, and Labor – Polypropylene Recycling.....	146
Table 34	Cost of Production Summary for Recycled PP Flakes .....	148
Table 35	Cost of Production Summary for Recycled PP Pellets .....	150
Table 36	Cost of Production Estimate for: Recycled PET Flakes Process: Sort/Wash/Grind/Separate; USGC Basis .....	159
Table 37	Cost of Production Estimate for: Recycled PET Flakes Process: Sort/Wash/Grind/Separate; Western Europe Basis .....	160

Table 38	Cost of Production Estimate for: Recycled PET Flakes Process: Sort/Wash/Grind/Separate; China Basis .....	161
Table 39	Cost of Production Estimate for: Recycled PET Flakes Process: Sort/Wash/Grind/Separate; Japan Basis.....	162
Table 40	Cost of Production Estimate for: Recycled PET Pellets Process: Solid State Phase Polymerization of Recycled PET Flakes; USGC Basis .....	163
Table 41	Cost of Production Estimate for: Recycled PET Pellets Process: Solid State Phase Polymerization of Recycled PET Flakes; Western Europe Basis .....	164
Table 42	Cost of Production Estimate for: Recycled PET Pellets Process: Solid State Phase Polymerization of Recycled PET Flakes; China Basis .....	165
Table 43	Cost of Production Estimate for: Recycled PET Pellets Process: Solid State Phase Polymerization of Recycled PET Flakes; Japan Basis .....	166
Table 44	Cost of Production Estimate for: Recycled HDPE Flakes Process: Sort/Wash/Grind/Separate; USGC Basis .....	167
Table 45	Cost of Production Estimate for: Recycled HDPE Flakes Process: Sort/Wash/Grind/Separate; Western Europe Basis .....	168
Table 46	Cost of Production Estimate for: Recycled HDPE Flakes Process: Sort/Wash/Grind/Separate; China Basis .....	169
Table 47	Cost of Production Estimate for: Recycled HDPE Flakes Process: Sort/Wash/Grind/Separate; Japan Basis.....	170
Table 48	Cost of Production Estimate for: Recycled HDPE Pellets Process: Pelletization of Recycled HDPE Flakes; USGC Basis .....	171
Table 49	Cost of Production Estimate for: Recycled HDPE Pellets Process: Pelletization of Recycled HDPE Flakes; Western Europe Basis.....	172
Table 50	Cost of Production Estimate for: Recycled HDPE Pellets Process: Pelletization of Recycled HDPE Flakes; China Basis .....	173
Table 51	Cost of Production Estimate for: Recycled HDPE Pellets Process: Pelletization of Recycled HDPE Flakes; Japan Basis .....	174
Table 52	Cost of Production Estimate for: Recycled PP Flakes Process: Sort/Wash/Grind/Separate; USGC Basis .....	175
Table 53	Cost of Production Estimate for: Recycled PP Flakes Process: Sort/Wash/Grind/Separate; Western Europe Basis .....	176
Table 54	Cost of Production Estimate for: Recycled PP Flakes Process: Sort/Wash/Grind/Separate; China Basis .....	177
Table 55	Cost of Production Estimate for: Recycled PP Flakes Process: Sort/Wash/Grind/Separate; Japan Basis.....	178
Table 56	Cost of Production Estimate for: Recycled PP Pellets Process: Pelletization of Recycled PP Flakes; USGC Basis .....	179
Table 57	Cost of Production Estimate for: Recycled PP Pellets Process: Pelletization of Recycled PP Flakes; Western Europe Basis .....	180
Table 58	Cost of Production Estimate for: Recycled PP Pellets Process: Pelletization of Recycled PP Flakes; China Basis .....	181
Table 59	Cost of Production Estimate for: Recycled PP Pellets Process: Pelletization of Recycled PP Flakes; Japan Basis .....	182



## TECHNOLOGY & COSTS

# Technoeconomics - Energy & Chemicals (TECH)

The NexantECA Subscriptions' Technoeconomics - Energy & Chemicals (TECH) program is recognized globally as the industry standard source for information relevant to the chemical process and refining industries. Technoeconomics - Energy & Chemicals (TECH) 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](mailto:mcesar@NexantECA.com)

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

#### EMEA:

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

#### Asia:

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