

**TECHNOLOGY & COSTS****Biorenewable Insights****Commercial Bioplastics in 2020**

## Table of Contents

A Report by **NexantECA, Inc.**

Published Date: December 2020

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

1	Executive Summary .....	1
1.1	Overview.....	1
1.2	Technologies .....	1
1.2.1	Cost of Production Models .....	5
1.3	Capacity and Implications .....	20
1.3.1	By Polymer Type.....	20
1.3.2	By Region.....	21
1.3.3	By Polymer/Monomer.....	22
2	Introduction.....	23
2.1	Overview.....	23
2.1.1	Biobased versus Renewable versus Sustainable .....	24
2.1.2	Commercial Bioplastics in 2020 .....	25
2.1.3	Biopolymers not included: .....	29
2.2	Industry Trends and Drivers .....	30
2.2.1	Climate Change and Resource Depletion.....	30
2.2.2	Waste Accumulation.....	30
2.2.3	Other Drivers .....	31
3	Olefins for Polyolefins.....	32
3.1	Ethylene.....	32
3.1.1	Ethanol to Ethylene .....	32
3.1.2	Steam Cracking of Bio-Naphtha.....	36
3.2	Cost of Production.....	70
3.3	Propylene .....	71
3.3.1	Propane Dehydrogenation (PDH) .....	71
3.3.2	Steam Cracking Byproduct .....	73
3.3.3	Cost of Production.....	75
4	Difunctional, Diols and Polyols for Polyesters and Polyurethanes.....	77
4.1	Ethylene Glycol .....	77
4.1.1	Ethanol to Ethylene .....	78

4.1.2	Ethylene to Ethylene Glycol .....	80
4.1.3	Cost of Production.....	90
4.2	PDO and PTT .....	91
4.2.1	PDO.....	91
4.2.2	Polytrimethylene Terephthalate (PTT) .....	100
4.3	1,4-BDO.....	110
4.3.1	Existing Commercial Capacity .....	110
4.3.2	Genomatica .....	110
4.3.3	Cost of Production.....	121
4.4	Difunctional Molecules for Polyesters .....	122
4.4.1	Lactic Acid and PLA .....	122
4.4.2	PLA.....	138
4.5	Polyols .....	154
4.5.1	Polyol Supply.....	155
4.5.2	Polyester Polyols.....	156
4.5.3	Renewable Polyol Technology.....	167
4.5.4	Cost of Production Estimates .....	176
5	Difunctional, Diacids, Diamines, and Amino Acids for Polyesters and Polyamides.....	178
5.1	Difunctional Molecules for Polyamides .....	178
5.1.1	11-Aminoundecanoic Acid .....	178
5.2	Diacids.....	180
5.2.1	Succinic Acid .....	180
5.2.2	Azelaic Acid .....	191
5.2.3	Sebacic Acid.....	196
5.3	Diamines.....	201
5.3.1	1,5-Pentadiamine .....	201
6	Diisocyanates and Non-Isocyanate Routes to Polyurethanes .....	205
6.1	PDI.....	205
6.1.1	Existing Capacity.....	205
6.1.2	PDI Process Chemistry .....	205
6.1.3	PDI Process Description .....	207
6.1.4	Cost of Production Estimate.....	216
6.2	Non-Isocyanate Derived Polyurethanes.....	216
6.2.1	Existing Capacity.....	216
6.2.2	Process Chemistry .....	216
6.2.3	Process Description .....	217
6.2.4	Technology Developers.....	218
6.2.5	Production Costs .....	218
7	Non-Conventional Polymers.....	219
7.1	PHA .....	219
7.1.1	Existing Capacity.....	219
7.1.2	Sugar Fermentation Based Routes.....	220

7.1.3	Vegetable Oil Based Fermentation .....	234
7.1.4	Cost of Production Estimate.....	241
7.2	Thermoplastic Starch (TPS).....	242
7.2.1	Existing Capacity.....	242
7.2.2	Thermoplastic Starch Production .....	243
7.2.3	Producers .....	249
7.2.4	Cost of Production Estimates.....	256
7.3	Cellulosic Plastics.....	258
7.3.1	Cellulose Acetate .....	259
7.3.2	Regenerated Cellulose.....	262
8	Capacity Analysis and Impacts on Conventional Industry .....	269
8.1	Global Overview .....	270
8.1.1	By Polymer Type .....	270
8.1.2	By Region.....	271
8.1.3	By Polymer/Monomer.....	272
8.2	Biopolymers by Region .....	273
8.2.1	North America .....	273
8.2.2	South America.....	275
8.2.3	Europe.....	276
8.2.4	Asia.....	278
8.3	Biopolymers by Polymer Type .....	280
8.3.1	Polyolefin .....	280
8.3.2	Polyesters.....	280
8.3.3	Polyamides.....	281
8.3.4	Polyurethanes .....	282
8.3.5	Regenerated Cellulose.....	283
A	Appendices .....	
A	References .....	286

## Figures

Figure 1	Commercial Bioplastics in 2020 .....	4
Figure 2	Cost of Production Estimate, Bio-Ethylene .....	5
Figure 3	Cost of Production Estimate, Bio-Propylene .....	6
Figure 4	Cost of Production Estimate, Bio-Ethylene Glycol .....	6
Figure 5	Cost of Production Estimate, PDO .....	7
Figure 6	Cost of Production Estimate, PTT .....	8
Figure 7	Cost of Production Estimate, BDO .....	8
Figure 8	Cost of Production Estimate, Lactic Acid .....	9
Figure 9	Cost of Production Estimate, PLA .....	10
Figure 10	Cost of Production Estimates, Bio-Based Polyols in the United States .....	11
Figure 11	Cost of Production Estimate, Succinic Acid .....	12
Figure 12	Cost of Production Estimate, Azelaic Acid .....	13
Figure 13	Cost of Production Estimate, Sebacic Acid .....	14
Figure 14	Cost of Production Estimate, PDI .....	15
Figure 15	Cost of Production Estimate, PHA .....	16
Figure 16	Cost of Production Estimate, TPS .....	17
Figure 17	Cost of Production Estimate, TPS Blends in the United States .....	18
Figure 18	Cost of Production Estimate, Cellulose Acetate Flake .....	19
Figure 19	Global Biopolymer Capacity by Polymer Type .....	20
Figure 20	Global Biopolymer Capacity by Polymer Type—excluding Regenerated Cellulose .....	20
Figure 21	Global Biopolymer Capacity by Region .....	21
Figure 22	Global Biopolymer Capacity by Region—excluding Regenerated Cellulose .....	21
Figure 23	Global Biopolymer Capacity by Polymer/Monomer .....	22
Figure 24	Global Biopolymer Capacity by Polymer/Monomer—excluding Regenerated Cellulose .....	22
Figure 25	Biodegradability and Renewability .....	24
Figure 26	Commercial Bioplastics in 2020 .....	26
Figure 27	Bio-Ethanol to Green Ethylene: Conceptual Process Flow .....	33
Figure 28	Braskem Ethanol Dehydration Process .....	35
Figure 29	Steam Cracking Process Overview .....	38
Figure 30	NGL Cracking (Cracking and Compression) Simplified Process Flow Diagram .....	39
Figure 31	NGL Cracking (Fractionation and Recovery) Simplified Process Flow Diagram .....	40
Figure 32	Typical Cracking Furnace Process Flow .....	45
Figure 33	Typical Dual Radiant Cell Cracking Furnace Design .....	46
Figure 34	Water Quench System Simplified Process Flow Diagram .....	49
Figure 35	Oil and Water Quench System Simplified Process Flow Diagram .....	50
Figure 36	Demethanizer-First Simplified Process Flow Diagram .....	59
Figure 37	Deethanizer-First Simplified Process Flow Diagram .....	60
Figure 38	Depropanizer-First Simplified Process Flow Diagram .....	61
Figure 39	Cost of Production Estimate, Bio-Ethylene .....	71
Figure 40	Paraffin Dehydrogenation: Thermodynamic Conversion at 1.0 Bara .....	72

Figure 41	Cost of Production Estimate, Bio-Propylene .....	76
Figure 42	Ethylene from Ethanol .....	79
Figure 43	Dow METEOR™ Glycol Reaction and Evaporation System .....	83
Figure 44	Glycol Reaction and Separation via SD Process .....	85
Figure 45	Shell OMEGA Process .....	88
Figure 46	Shell OMEGA Ethylene Glycol .....	89
Figure 47	Cost of Production Estimate, Bio-Ethylene Glycol .....	90
Figure 48	Metabolic Pathway for Glucose to 1,3-Propanediol .....	93
Figure 49	DuPont Bio-based PDO Process, Fermentation .....	95
Figure 50	DuPont Bio-based PDO Process, Downstream Purification .....	98
Figure 51	Cost of Production Estimate, PDO .....	99
Figure 52	Esterification of Terephthalic Acid .....	100
Figure 53	Melt-Phase Polycondensation of bis-HPT .....	100
Figure 54	Shell/Lurgi Esterification of PTA and 1,3-PDO to Bis-HPT .....	103
Figure 55	Shell/Lurgi: Polycondensation of Bis-HPT .....	105
Figure 56	1,3-PDO Recovery .....	107
Figure 57	Cost of Production Estimate, PTT .....	109
Figure 58	Engineered Metabolic Pathways to 4-HB and BDO in <i>E. coli</i> .....	112
Figure 59	Genomatica's BDO Fermentation Process (Simple Flow Diagram) .....	117
Figure 60	Genomatica's BDO Recovery Process (Simple Flow Diagram) .....	119
Figure 61	Cost of Production Estimate, BDO .....	121
Figure 62	Global Lactic Acid Capacity by Region .....	123
Figure 63	Global Lactic Acid Capacity by Producer .....	123
Figure 64	Block Flow Diagram – Cargill Lactic Acid Production Process .....	127
Figure 65	Plaxica's Optipure® Technology Integrated with PLA Production .....	128
Figure 66	Block Flow Diagram Corbion's Lactic Acid Purification .....	132
Figure 67	Uhde Inventa Fischer and Thyssenkrupp Industrial Solutions Lactic Acid and PLA Integrated Process .....	135
Figure 68	Thyssenkrupp Lactic Acid Production Process .....	136
Figure 69	Cost of Production Estimate, Lactic Acid .....	137
Figure 70	Global PLA Capacity by Region .....	138
Figure 71	Global PLA Capacity by Producer .....	139
Figure 72	NatureWorks Lactic and PLA Production Process .....	141
Figure 73	Block Flow Diagram: NatureWorks Ring Opening Polymerization of Lactide .....	143
Figure 74	Total and Corbion Integration for PLA Production .....	145
Figure 75	Total Corbion PLA Production Facility in Rayong, Thailand .....	145
Figure 76	Block Flow Diagram: Uhde Inventa Fischer PLAneo® Process .....	148
Figure 77	Block Flow Diagram: Futerro PLA Production Process .....	151
Figure 78	Hitachi's PLA Production Process .....	152
Figure 79	Block Flow Diagram: Hitachi Ring Opening Polymerization of Lactide .....	153
Figure 80	Cost of Production Estimate, PLA .....	154
Figure 81	Polyester Polyol Production via Esterification .....	160
Figure 82	Polyester Polyol Production via Transesterification .....	162

Figure 83	Emery Oleochemicals EMEROX Ozonolysis Process .....	172
Figure 84	Emery Oleochemicals INFIGREEN Process.....	172
Figure 85	Cost of Production Estimates, Bio-Based Polyols in the United States .....	177
Figure 86	Sebacic Acid from Castor Oil.....	183
Figure 87	Reverdia's Assumed Pathways to Succinic Acid .....	186
Figure 88	Reverdia Fermentation Simple Flow Diagram.....	190
Figure 89	Cost of Production Estimate, Succinic Acid .....	191
Figure 90	Azelaic Acid from Oleic Acid.....	195
Figure 91	Cost of Production Estimate, Azelaic Acid .....	196
Figure 92	Formation of Sebacic Acid from Ricinoleic Acid.....	199
Figure 93	Cost of Production Estimate, Sebacic Acid .....	200
Figure 94	PDI Production Chemistry .....	206
Figure 95	Simplified Block Flow Diagram of PDI Production.....	207
Figure 96	Glycolysis Pathway.....	209
Figure 97	TCA Cycle.....	210
Figure 98	Metabolic Pathway to Lysine from Oxaloacetate in <i>Corynebacterium glutamicum</i> .....	211
Figure 99	Generic PDA Two-Step Fermentation Process Flow Diagram .....	212
Figure 100	Generic Diisocyanate Process .....	215
Figure 101	Cost of Production Estimate, PDI .....	216
Figure 102	Non-Isocyanate Polyurethane Chemistry .....	217
Figure 103	Simplified Block Flow Diagram of Non-Isocyanate Derived Polyurethane Technology .....	217
Figure 104	Biosynthetic Pathway Sugar and Fatty Acid Fermentation .....	220
Figure 105	PHA Production Process Flow Diagram.....	228
Figure 106	PHA Fermentation Process Block Diagram .....	229
Figure 107	Full Cycle Bioplastics Process.....	232
Figure 108	Biomer Sugar Fermentation Process .....	238
Figure 109	Biomer Extraction Process .....	240
Figure 110	Cost of Production Estimate, PHA.....	241
Figure 111	Existing Capacity by Producer, Thermoplastic Starch Blends .....	242
Figure 112	Existing Capacity by Region, Thermoplastic Starch Blends .....	243
Figure 113	Starch Production via Extruder.....	244
Figure 114	Mechanical Properties of TPS/PBAT Blends Before and After Storage .....	247
Figure 115	Novamont Facilities .....	250
Figure 116	BioLogiQ Production Process.....	252
Figure 117	Plantic TPS Barrier System .....	254
Figure 118	BIOPAR® Technology.....	256
Figure 119	Cost of Production Estimate, TPS .....	257
Figure 120	Cost of Production Estimate, TPS Blends in the United States .....	258
Figure 121	Cost of Production Estimate, Cellulose Acetate Flake .....	262
Figure 122	Map of Dissolving Pulp Mills.....	262
Figure 123	Rayon Manufacturing Process .....	265
Figure 124	Identification of Cotton Linter.....	267

Figure 125	Global Biopolymer Capacity by Polymer Type .....	270
Figure 126	Global Biopolymer Capacity by Polymer Type—excluding Regenerated Cellulose .....	270
Figure 127	Global Biopolymer Capacity by Region.....	271
Figure 128	Global Biopolymer Capacity by Region—excluding Regenerated Cellulose .....	271
Figure 129	Global Biopolymer Capacity by Polymer/Monomer.....	272
Figure 130	Global Biopolymer Capacity by Polymer/Monomer—excluding Regenerated Cellulose .....	272
Figure 131	North American Biopolymer Capacity by Polymer Type .....	273
Figure 132	North American Biopolymer Capacity by Polymer Type—excluding Regenerated Cellulose .....	273
Figure 133	North American Biopolymer Capacity by Country .....	274
Figure 134	North American Biopolymer Capacity by Country—excluding Regenerated Cellulose .....	274
Figure 135	South American Biopolymer Capacity by Polymer Type.....	275
Figure 136	European Biopolymer Capacity by Polymer Type.....	276
Figure 137	European Biopolymer Capacity by Polymer Type—excluding Regenerated Cellulose .....	276
Figure 138	European Biopolymer Capacity by Country .....	277
Figure 139	European Biopolymer Capacity by Country—excluding Regenerated Cellulose.....	277
Figure 140	Asian Biopolymer Capacity by Polymer Type .....	278
Figure 141	Asian Biopolymer Capacity by Polymer Type—excluding Regenerated Cellulose.....	278
Figure 142	Asian Biopolymer Capacity by Country .....	279
Figure 143	Asian Biopolymer Capacity by Country—excluding Regenerated Cellulose .....	279
Figure 144	Biopolyester Capacity by Region.....	280
Figure 145	Biopolyolefin Capacity by Polymer/Monomer.....	281
Figure 146	Biopolyamide Capacity by Region.....	281
Figure 147	Biopolyamide Capacity by Polymer/Monomer.....	282
Figure 148	Biopolyurethane Capacity by Region .....	282
Figure 149	Biopolyurethane Capacity by Polymer/Monomer .....	283
Figure 150	Regenerated Cellulose Capacity by Region.....	283
Figure 151	Biopolyurethane Capacity by Polymer/Monomer .....	284

## Tables

Table 1	Bioethylene Capacity .....	32
Table 2	Steam Cracking of Naphtha – Once Through Yields .....	42
Table 3	Steam Cracking of Naphtha – Effect of Variables on Once-Through Yields.....	43
Table 4	Typical Pyrolysis Heater Characteristics .....	47
Table 5	Comparison of Ethylene Cracking Tube Alloys .....	56
Table 6	Licensors and Technology Holders for Steam Cracking Routes to Ethylene .....	70
Table 7	Propylene Yield from Representative Cracker Feedstocks.....	74
Table 8	Bioethylene Glycol Capacity.....	78
Table 9	Genomatica's Assumed Biocatalyst Genetic Modifications .....	112
Table 10	Existing Lactic Acid Capacity.....	124
Table 11	Existing PLA Capacity .....	139
Table 12	NatureWorks LLC Product Range, Properties and Applications.....	140
Table 13	Total Corbion PLA Grades .....	146
Table 14	UIF PLA Properties .....	146
Table 15	Important Diols and Triols Used for Polyester Polyols .....	156
Table 16	Important Dicarboxylic Acids and Derivatives Used for Polyester Polyols.....	157
Table 17	Properties of Commonly used Starters for the Production of Polyurethane Polyols.....	163
Table 18	Typical Properties of Glycerin-PO adduct with MW of 2,900 to 3,300 .....	165
Table 19	Physical Properties of 11-Aminoundecanoic Acid.....	179
Table 20	Properties of Succinic Acid.....	184
Table 21	Physical Properties of Azelaic Acid .....	193
Table 22	Physical Properties of Sebacic Acid.....	197
Table 23	Properties of 1,5-Pentanediamine .....	201
Table 24	PHA Capacity Table .....	219
Table 25	Comparison of Solvent Extraction Methods.....	227
Table 26	Typical Oil Content of Commodity Oilseeds.....	234
Table 27	Thermoplastic Starch Capacity Listing, Blends .....	243
Table 28	Polymer Properties .....	245
Table 29	Cellulose Acetate Flake Capacity.....	259
Table 30	Properties of Cellulose Acetate .....	259
Table 31	NatureFlex Regenerated Cellulose Properties.....	268



## 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 Products, E&CA: NexantECA Subscriptions  
Phone: + 1-914-609-0324, e-mail: [mcesar@nexantECA.com](mailto:mcesar@nexantECA.com)

Erica Hill, Client Services Coordinator, E&CA-Products  
Phone: + 1-914-609-0386, e-mail: [ehill@nexantECA.com](mailto:ehill@nexantECA.com)

#### EMEA:

Anna Ibbotson, Director, NexantECA Subscriptions  
Phone: +44-207-950-1528, [aibbotson@nexantECA.com](mailto:aibbotson@nexantECA.com)

#### Asia:

Chommanad Thammanayakatip, Managing Consultant, Energy & Chemicals Advisory  
Phone: +66-2793-4606, email: [chommanadt@nexantECA.com](mailto:chommanadt@nexantECA.com)

NexantECA ([www.nexantECA.com](http://www.nexantECA.com)) is a leading management consultancy to the global energy, chemical, and related industries. For over 38 years, NexantECA has helped clients increase business value through assistance in all aspects of business strategy, including business intelligence, project feasibility and implementation, operational improvement, portfolio planning, and growth through M&A activities. NexantECA has its main offices in White Plains (New York), and London (UK), and satellite offices worldwide.

Copyright © by NexantECA 2020. All Rights Reserved.