

BIOREFINERY TECHNOLOGIES: GLOBAL MARKETS



EGY054C
July 2016

Edward Gobina
Project Analyst

ISBN: 1-62296-326-1



BCC Research
49 Walnut Park, Building 2
Wellesley, MA 02481 USA
866-285-7215 (toll-free within the USA),
or (+1) 781-489-7301
www.bccresearch.com
information@bccresearch.com

TABLE OF CONTENTS

TOPIC	PAGE NO.
CHAPTER 1 INTRODUCTION	2
STUDY GOAL AND OBJECTIVES	2
REASONS FOR DOING THE STUDY	3
INTENDED AUDIENCE	5
ANALYST'S CREDENTIALS	6
RELATED BCC RESEARCH REPORTS	6
METHODOLOGY	7
SCOPE OF THE REPORT	8
BCC RESEARCH WEBSITE	9
DISCLAIMER	9
CHAPTER 2 SUMMARY	11
<i>SUMMARY TABLE GLOBAL MARKET FOR BIOREFINERY TECHNOLOGIES BY TYPE OF PLATFORM, THROUGH 2021 (\$ BILLIONS)</i>	12
<i>SUMMARY FIGURE GLOBAL MARKET FOR BIOREFINERY TECHNOLOGIES BY TYPE OF PLATFORM, 2013-2021 (\$ BILLIONS)</i>	12
CHAPTER 3 OVERVIEW	14
INTRODUCTION	14
<i>TABLE 1 GENERALIZED BIOREFINERY TECHNOLOGY CONFIGURATIONS</i>	15
INDUSTRY DEFINITION	15
<i>TABLE 2 BIOREFINERY SYSTEM CLASSIFICATION USING CURRENT METHODS</i>	16
<i>TABLE 3 GENERALIZED BIOREFINERY OUTLINE USING CURRENT METHODS</i>	17
GLOBAL MARKET FOR BIOREFINERY APPLICATIONS	17
<i>TABLE 4 GLOBAL MARKET FOR APPLICATIONS OF BIOREFINERY TECHNOLOGIES BY PRODUCT TYPE, THROUGH 2021 (\$ BILLIONS)</i>	17
ENERGY PRODUCTS BY INDUSTRY APPLICATION	18
Global Petroleum Demand	18
Global Natural Gas Demand	18
Global Power/Heat Demand	18
Global Coal Demand	18
<i>TABLE 5 GLOBAL MARKET FOR BIOREFINERY TECHNOLOGIES USED TO PROCESS ENERGY PRODUCTS BY INDUSTRY APPLICATION, THROUGH 2021 (\$ BILLIONS)</i>	19
NON-ENERGY PRODUCTS BY INDUSTRY APPLICATION	19
Global Chemical Demand	19
Global Plastics/Polymers Demand	19
Global Composite Materials Demand	19
Global Pharmaceutical Demand	20
<i>TABLE 6 GLOBAL MARKET FOR BIOREFINERY TECHNOLOGIES USED TO PROCESS NON-ENERGY PRODUCTS BY INDUSTRY APPLICATION, THROUGH 2021 (\$ BILLIONS)</i>	20
MARKET PENETRATION	20
<i>TABLE 7 GLOBAL BIOREFINERY TECHNOLOGIES MARKET PENETRATION, THROUGH 2021 (\$ BILLIONS)</i>	21
<i>TABLE 8 MAJOR BIOREFINERY TECHNOLOGY PLATFORM ACTIVITIES AND PRODUCTS</i>	22
OVERVIEW OF THE BIOREFINERY TECHNOLOGY SUPPLY CHAIN	23
<i>TABLE 9 ENERGETIC AND NON-ENERGETIC FOREST BIOREFINERY SUPPLY CHAIN</i>	23

TOPIC	PAGE NO.
OVERVIEW OF THE BIOMASS VALUE CHAIN CONVERSION PROCESS	24
<i>TABLE 10 OVERVIEW OF THE BIOMASS VALUE CHAIN CONVERSION PROCESS</i>	25
<i>TABLE 11 LIGNOCELLULOSIC BIOMASS VALUE CHAIN CONVERSION PROCESS</i>	26
<i>TABLE 12 PROCESSES USED AND PRODUCTS EXTRACTED FROM PLANTS</i>	27
LARGE-VOLUME OILS	27
SMALL-VOLUME OILS	28
<i>FIGURE 1 VALUE CHAIN OF THE NATURAL INGREDIENT INDUSTRY</i>	28
OVERVIEW OF INDUSTRY AND MATERIAL USES	28
<i>TABLE 13 OVERVIEW OF INDUSTRIAL AND MATERIAL USE OF BIO-BASED RAW MATERIALS</i>	29
OVERVIEW OF BIOREFINERY TECHNOLOGY CONVERSION ROUTES	31
<i>TABLE 14 BIOREFINERY TECHNOLOGY CONVERSION ROUTES OF PLANT BIOMASS</i>	32
BIOREFINERY TECHNOLOGY MARKET FEATURES AND RELATIVE SUBGROUPS	32
<i>TABLE 15 BIOREFINERY TECHNOLOGIES APPROACHES: MARKET FEATURES AND RELATIVE SUBGROUPS</i>	33
IMPORTANCE OF BIOREFINERY TECHNOLOGIES	34
<i>TABLE 16 PRIMARY BIOREFINERY CONVERSION TECHNOLOGIES TO CRUDE PRODUCTS</i>	35
SECONDARY AND TERTIARY BIOREFINERY TRANSFORMATION TECHNOLOGY TO PRODUCT	35
<i>TABLE 17 SECONDARY AND TERTIARY BIOREFINERY TRANSFORMATION TECHNOLOGIES TO PRODUCT</i>	36
VALUE-ADDED BIOREFINERY TECHNOLOGY OPPORTUNITIES	37
<i>TABLE 18 EFFECTIVE H/C RATIO IN RELATION TO THE BIOCHEMICAL TECHNOLOGY PLATFORM AND ITS INTERMEDIATES</i>	38
<i>TABLE 19 HYDROGEN TO CARBON RATIO STAIRCASE FOR FOSSIL FUEL FEEDSTOCKS</i>	39
SELECTED JOBS IN ADVANCED BIOREFINERY TECHNOLOGIES	39
<i>TABLE 20 SELECTED EMPLOYMENT OPPORTUNITIES AMONG ADVANCED BIOREFINERY COMPANIES</i>	40
PROFESSIONS, OCCUPATIONS, CAREERS AND WAGES IN BIOREFINERY TECHNOLOGY	41
<i>TABLE 21 STAFFING AND SALARY PROJECTIONS FOR A PROTOTYPE 10-MILLION-GALLON-PER-YEAR RURAL BIOREFINERY, THROUGH 2020 (\$ THOUSANDS)</i>	42
Science Professions: Occupations, Careers and Wages	42
<i>TABLE 22 SELECTED SCIENCE OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)</i>	43
Engineering and Mapping Professions: Occupations, Careers and Wages	43
<i>TABLE 23 SELECTED ENGINEERING AND MAPPING OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)</i>	44
Construction and Material-Moving Professions: Occupations, Careers and Wages	44
<i>TABLE 24 SELECTED CONSTRUCTION AND MATERIAL-MOVING OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)</i>	45
Industrial Microbiology Professions: Occupations, Careers and Wages	45
<i>TABLE 25 SELECTED INDUSTRIAL MICROBIOLOGY OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)</i>	47
Agriculture Professions: Occupations, Careers and Wages	47

TOPIC	PAGE NO.
<i>TABLE 26 SELECTED AGRICULTURE OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)</i>	48
Production Professions: Occupations, Careers and Wages	48
<i>TABLE 27 SELECTED PRODUCTION OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)</i>	48
Sales Professions: Occupations, Careers and Wages	49
<i>TABLE 28 SELECTED SALES OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)</i>	49
Management and Business Specialist Professions: Occupations, Careers and Wages	49
<i>TABLE 29 SELECTED MANAGEMENT AND BUSINESS SPECIALIST OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)</i>	50
Mechanics and Maintenance Professions: Occupations, Careers and Wages	50
<i>TABLE 30 SELECTED MECHANIC AND MAINTENANCE OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)</i>	50
HISTORY OF BIOREFINERY TECHNOLOGIES AND MATURITY STATUS	51
<i>TABLE 31 RFS2 DATA, CONVENTIONAL BIOFUEL AND ADVANCED BIOFUEL (BILLION GALLONS)</i>	51
<i>TABLE 32 BIOMASS CONVERSION TECHNOLOGY MATURITY STATUS</i>	52
ANTICIPATED CHEMICAL AND MATERIAL DEVELOPMENT PATHWAY BY KEY FEEDSTOCK	52
<i>TABLE 33 ANTICIPATED CHEMICAL AND MATERIAL DEVELOPMENT PATHWAY BY KEY FEEDSTOCK</i>	53
U.S. GOVERNMENT SUPPORT FOR BIOREFINERY TECHNOLOGIES	53
<i>TABLE 34 U.S. FEDERAL FUNDING FOR ADVANCED BIOREFINERY TECHNOLOGIES, 2007-2014 (\$ MILLIONS)</i>	54
<i>TABLE 35 U.S. FEDERAL AND PUBLIC FUNDING FOR ADVANCED BIOREFINERY TECHNOLOGIES 2015-2016 (\$ MILLIONS)</i>	54
OVERVIEW OF IMPORTANT DEVELOPMENTS IN BIOREFINERY TECHNOLOGIES	55
<i>TABLE 36 IMPORTANT DEVELOPMENTS IN BIOREFINERY TECHNOLOGIES</i>	55
FUTURE OF BIOREFINERY TECHNOLOGIES	59
MACROECONOMIC OVERVIEW	59
<i>TABLE 37 REAL GDP AND INDUSTRIAL PRODUCTION GROWTH, THROUGH 2021 (% CHANGE ON PREVIOUS YEAR)</i>	60
OVERVIEW OF GLOBAL DEMAND FOR BIOREFINERY TECHNOLOGIES	60
<i>TABLE 38 GLOBAL MARKET FOR BIOREFINERY TECHNOLOGIES BY TYPE OF PLATFORM, THROUGH 2021 (%)</i>	61
CHAPTER 4 DEMAND FOR THE PHYSICOCHEMICAL PLATFORM	63
INTRODUCTION	63
<i>TABLE 39 PHYSICOCHEMICAL CONVERSION OF BUILDING-BLOCK CHEMICALS, THEIR DERIVATIVES AND POTENTIAL APPLICATIONS</i>	63
<i>FIGURE 2 BASIC OLEOCHEMICAL, DOWNSTREAM OLEOCHEMICAL AND DERIVATIVE PRODUCTION TECHNOLOGY</i>	65
<i>FIGURE 3 TRANSESTERIFICATION AND EPOXIDATION, HYDROFORMYLATION AND METATHESIS REACTIONS</i>	65
<i>FIGURE 4 BASIC OLEOCHEMICAL AND DOWNSTREAM OLEOCHEMICAL PRODUCTION TECHNOLOGY</i>	66
DEMAND FOR THE PHYSICOCHEMICAL TECHNOLOGY PLATFORM BY PRODUCT SEGMENT	67

TOPIC	PAGE NO.
<i>TABLE 40 GLOBAL MARKET FOR THE PHYSICOCHEMICAL TECHNOLOGY PLATFORM BY PRODUCT SEGMENT, THROUGH 2021 (\$ BILLIONS)</i>	67
SPECIALTY/FINE CHEMICALS PRODUCTION BY PHYSICOCHEMICAL TRANSFORMATION	67
Biopesticides	68
Glycerol	68
Biosolvents	68
Biolubricants	68
Lignin and Specialty Cellulose	68
Antioxidants	69
Detergent Alcohols and Fatty Acids	69
<i>TABLE 41 GLOBAL MARKET FOR BIO-DERIVED FINE CHEMICALS PRODUCED BY PHYSICOCHEMICAL CONVERSION TYPE, THROUGH 2021 (\$ MILLIONS)</i>	70
BIOPOLYMERS AND BIOPLASTICS PRODUCTION BY PHYSICOCHEMICAL TECHNOLOGY	70
Caustic Oxidation Technology	70
Oleic Acid and Ozonolysis Technology	70
Oleic Acid and Dimerization Technology	70
Oxidation and Epoxidation Epoxy Ring Opening Technology	70
<i>TABLE 42 GLOBAL MARKET FOR LIPID CONVERSION BIOPOLYMER/ BIOPLASTIC BUILDING-BLOCK TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)</i>	71
BIOCOMPOSITE PRODUCTION TECHNOLOGY	71
<i>TABLE 43 BIOCOMPOSITE TECHNOLOGY VALUE ADDITION</i>	72
Natural Fiber Process Techniques and Applications	72
<i>TABLE 44 NATURAL FIBER PROCESS TECHNIQUES AND APPLICATIONS</i>	73
Biocomposite Structure	73
<i>TABLE 45 BIOCOMPOSITE PRODUCT STRUCTURE</i>	74
Biocomposites by Processing Technology	74
<i>TABLE 46 BIOCOMPOSITE PROCESSING TECHNOLOGY</i>	74
Processing Techniques	74
Resin Transfer Molding and Vacuum Injection Technology	74
Sheet Molding Compound Technology	75
Vacuum Pressing Technology	75
Sandwich Technology	75
<i>TABLE 47 GLOBAL MARKET FOR BIOCOMPOSITE TECHNOLOGY BY TYPE, THROUGH 2021 (\$ BILLIONS)</i>	76
Biocomposites by Type of Production Technology	76
Thermoset	76
Thermoplastic	76
<i>TABLE 48 GLOBAL MARKET FOR BIOCOMPOSITE PRODUCTION TECHNOLOGY BY TYPE, THROUGH 2021 (\$ BILLIONS)</i>	77
VEGETABLE OIL FUEL TECHNOLOGY	77
<i>TABLE 49 GLOBAL MARKET FOR VEGETABLE OIL FUEL TECHNOLOGY BY TYPE, THROUGH 2021 (\$ BILLIONS)</i>	77
Straight Vegetable Oil Technology	78
Single-Tank System Technology	78
Two-Tank System Technology	78
<i>TABLE 50 GLOBAL MARKET FOR STRAIGHT VEGETABLE OIL ENGINE TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)</i>	78

TOPIC	PAGE NO.
Hydrogenated Vegetable Oil Technology	79
<i>TABLE 51 CURRENT GLOBAL ANNUAL PRODUCTION CAPACITY OF HVO DROP-IN BIOFUELS</i>	79
Diesel Technology	79
Jet Technology	79
<i>TABLE 52 GLOBAL MARKET FOR HYDROGENATED VEGETABLE OIL FUEL BY TYPE OF ENGINE TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)</i>	80
BIODIESEL TECHNOLOGY	80
<i>FIGURE 5 CHEMICAL PROCESSES FOR METHYL OR ETHYL ESTER BIODIESEL PRODUCTION AND PRODUCT YIELDS</i>	81
<i>TABLE 53 BIODIESEL BY ESTERIFICATION OF VEGETABLE OIL PRODUCTION</i>	82
Biodiesel Technology by Type of Feedstock	82
<i>TABLE 54 FLOW CHART OF PHYSICOCHEMICAL PRODUCTION OF BIODIESEL</i>	82
Alcohol and Catalyst Mixing Technology	83
Chemical Reaction Technology	83
Separation Technology	83
Alcohol Removal Technology	83
Glycerin Neutralization Technology	83
Methyl Ester Wash Technology	84
Product Quality Technology	84
<i>TABLE 55 GLOBAL MARKET FOR VEGETABLE OIL IN BIODIESEL PRODUCTION BY TYPE OF FEEDSTOCK TECHNOLOGY, THROUGH 2021 (THOUSAND METRIC TONS)</i>	84
Biodiesel Production by Type of Esterification Technology	85
<i>TABLE 56 GLOBAL MARKET FOR BIODIESEL BY TYPE OF ESTERIFICATION TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)</i>	85
Biodiesel Technology by Type of Catalyst	85
Base-Catalyzed Transesterification Technology	85
Acid-Catalyzed Transesterification Technology	86
Enzyme-Catalyzed Biodiesel Technology	86
Other Alternative Catalysts	86
Solid Heterogeneous Catalysts	86
Supercritical Methanol	87
<i>TABLE 57 GLOBAL MARKET FOR PHYSICOCHEMICAL CATALYSIS OF BIODIESEL BY TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)</i>	87
HERBS/BOTANICALS AND PHYTOCHEMICALS	87
<i>TABLE 58 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)</i>	88
Drugs Derived from Plant Root Technology	88
Aconite	88
Colchicum	88
Gentian	89
Goldenseal	89
Ginseng	89
Ipecac	89
Jalap	89
Licorice	90
Podophyllum	90
Rhubarb	90
Squills	91

TOPIC	PAGE NO.
Senega	91
Valerian	91
Lonchocarpus	91
Derris	92
Rotenone	92
<i>TABLE 59 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY BY TYPE OF PLANT ROOT, THROUGH 2021 (\$ BILLIONS)</i>	92
Drugs Derived from the Bark of Plant Technology	93
Sangre de Grado	93
Cascara	93
Curare	93
Quinine	94
Slippery Elm	94
<i>TABLE 60 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY BY TYPE OF PLANT BARK, THROUGH 2021 (\$ BILLIONS)</i>	95
Drugs Derived from Stem and Wood Technology	95
Ephedrine	95
Guaiacum	95
Quassia	96
<i>TABLE 61 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY BY TYPE OF STEM AND WOOD, THROUGH 2021 (\$ BILLIONS)</i>	96
Drugs Derived from Plant Leaf Technology	96
Aloe	96
Belladonna	97
Cocaine	97
Buchu	97
Digitalis	97
Eucalyptus	98
Hamamelis	98
Henbane	98
Hoarhound	98
Lobelia	99
Pennyroyal	99
Senna	99
Stramonium	99
Wormwood	99
<i>TABLE 62 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY BY TYPE OF PLANT LEAF, THROUGH 2021 (\$ BILLIONS)</i>	100
Drugs Derived from Flower Technology	100
Pyrethrum	100
Chamomile	101
Hops	101
Santonin	101
Red Squill	102
<i>TABLE 63 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY BY TYPE OF PLANT FLOWER, THROUGH 2021 (\$ BILLIONS)</i>	102
Drugs Derived from Fruit and Seed Technology	102
Chaulmoogra Oil	102

TOPIC	PAGE NO.
Colocynth	103
Cubebs	103
Croton Oil	103
Nux Vomica	103
Opium	103
Psyllium	104
Strophanthus	104
Wormseed	104
<i>TABLE 64 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY BY TYPE OF PLANT FRUIT AND SEED, THROUGH 2021 (\$ BILLIONS)</i>	105
Drugs Derived from Rhizome Technology	105
Gingerroot	105
Galangal	106
Galangal Varieties	106
Turmeric	106
<i>TABLE 65 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY BY TYPE OF PLANT RHIZOME, THROUGH 2021 (\$ BILLIONS)</i>	107
Drugs Derived from Lower Plant Technology	107
Antibiotics	107
Agar	107
Ergot	108
Kelp	108
Lycopodium	108
Male Fern	108
<i>TABLE 66 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY BY TYPE OF LOWER PLANT, THROUGH 2021 (\$ BILLIONS)</i>	109
HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY BY EXTRACTION METHOD	109
Cold Pressing Technology	109
Water-Extraction Technology	110
Water Maceration	110
Water/Steam Distillation	110
Enfleurage Technology	111
Low-Boiling Solvent Extraction Technology	111
Drying	112
<i>TABLE 67 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL COMPOUNDS BY EXTRACTION TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)</i>	112
CHAPTER 5 DEMAND FOR THE BIOLOGICAL PLATFORM	114
INTRODUCTION	114
<i>TABLE 68 GLOBAL MARKET FOR THE BIOLOGICAL PLATFORM BY TYPE OF TRANSFORMATION, THROUGH 2021 (\$ BILLIONS)</i>	114
<i>TABLE 69 BIOTECHNOLOGY SEGMENTS</i>	115
<i>TABLE 70 BIOLOGICAL CONVERSION FOR CHEMICAL BUILDING BLOCKS, THEIR DERIVATIVES AND THEIR POTENTIAL APPLICATIONS</i>	116
<i>FIGURE 6 BIOTECHNICAL SYNTHESIS OF END PRODUCTS AND INTERMEDIATES FOR THE CHEMICAL, MATERIAL, FUEL, AND ENERGY INDUSTRIES</i>	117
DEMAND FOR FERMENTATION TECHNOLOGY BY PRODUCT SEGMENT	118

TOPIC	PAGE NO.
<i>TABLE 71 GLOBAL MARKET FOR FERMENTATIVE TECHNOLOGY BY PRODUCT SEGMENT, THROUGH 2021 (\$ BILLIONS)</i>	119
BIOETHANOL PRODUCTION BY TECHNOLOGY	119
<i>TABLE 72 GLOBAL MARKET FOR FEEDSTOCK IN BIOETHANOL PRODUCTION, THROUGH 2021 (THOUSAND METRIC TONS)</i>	120
Bioethanol Production by Type of Malting Technology	120
Wheat Malting Technology	120
Barley Malting Technology	120
<i>TABLE 73 GLOBAL MARKET FOR BIOETHANOL PRODUCTION BY MALTING TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)</i>	121
Bioethanol Production by Type of Corn Milling Technology	121
Corn Wet Milling Technology	121
Corn Dry Milling Technology	122
<i>TABLE 74 GLOBAL MARKET FOR BIOETHANOL PRODUCTION BY TYPE OF CORN MILLING TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)</i>	122
Bioethanol Production by Type of Sugar Feedstock Technology	122
Sugarcane	123
Sugar Beet	123
Sorghum	123
<i>TABLE 75 GLOBAL MARKET FOR BIOETHANOL PRODUCTION BY TYPE OF SUGAR FEEDSTOCK TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)</i>	124
Bioethanol by Type of Cellulosic Feedstock Technology	124
Agricultural Residue Technology	124
Organic Landfill Waste Technology	124
Algae Technology	125
Grass Technology	125
Wood Technology	125
<i>TABLE 76 GLOBAL MARKET FOR BIOETHANOL PRODUCTION BY TYPE OF CELLULOSIC FEEDSTOCK TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)</i>	125
Bioethanol Production by Type of Cellulosic Hydrolysis Technology	126
Biochemical Cellulosic Hydrolysis	126
Chemical Cellulosic Hydrolysis	126
<i>TABLE 77 GLOBAL MARKET FOR BIOETHANOL PRODUCTION BY TYPE OF CELLULOSIC HYDROLYSIS TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)</i>	126
Bioethanol by Type of Dehydration Technology	127
Azeotropic Distillation Technology	127
Molecular Sieve Technology	127
Membrane Technology	128
<i>TABLE 78 GLOBAL MARKET FOR BIOETHANOL BY TYPE OF DEHYDRATION TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)</i>	128
FERMENTATIVE BIOGAS PRODUCTION TECHNOLOGY	128
<i>TABLE 79 GLOBAL MARKET FOR FERMENTATIVE BIOGAS PRODUCTION TECHNOLOGY BY TYPE OF ENVIRONMENT, THROUGH 2021 (\$ BILLIONS)</i>	128
<i>TABLE 80 MICROBIAL GROUPS INVOLVED IN ENVIRONMENTAL REMEDIATION</i>	129
Anaerobic Digestion Technology	132
<i>TABLE 81 ANAEROBIC DIGESTION TECHNOLOGY</i>	132
Manure Digestion Technology	133
Wastewater Treatment Technology	133

TOPIC	PAGE NO.
<i>TABLE 82 GLOBAL MARKET FOR ANAEROBIC DIGESTION TECHNOLOGY BY TYPE OF ENVIRONMENT, THROUGH 2021 (\$ BILLIONS)</i>	134
Landfill Technology	134
Anaerobic Technology	134
Aerobic Technology	135
<i>TABLE 83 GLOBAL MARKET FOR LANDFILL BIOGAS BY TYPE OF ENVIRONMENT, THROUGH 2021 (\$ BILLIONS)</i>	135
Biogas Recovery and Purification Technology	135
<i>TABLE 84 SULFUR REMOVAL TECHNOLOGY</i>	135
Amine Purification Technology	136
Adsorption Technology	136
Cryogenic Technology	137
Membrane Technology	137
Combined Process Technologies	137
<i>TABLE 85 GLOBAL MARKET FOR BIOGAS BY TYPE OF RECOVERY AND PURIFICATION TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)</i>	138
FERMENTATION-DERIVED PRODUCTS (EXCLUDING BIOETHANOL)	138
Crude Antibiotic Technology	138
Amino Acid Technology	139
Biocatalytic Technology	139
Organic Acid Technology	139
<i>TABLE 86 GLOBAL INDUSTRIAL PRODUCTION OF ORGANIC ACID FROM BIOMASS FEEDSTOCKS</i>	140
Xanthan Technology	141
Vitamin Technology	141
<i>TABLE 87 GLOBAL MARKET FOR FERMENTATION-DERIVED SPECIALTY/FINE CHEMICAL TECHNOLOGY BY TYPE, THROUGH 2021 (\$ MILLIONS)</i>	141
DEMAND FOR BIOTRANSFORMATION TECHNOLOGY BY CATEGORY	142
<i>TABLE 88 GLOBAL MARKET FOR BIOTRANSFORMATION TECHNOLOGY BY PRODUCT CATEGORY, THROUGH 2021 (\$ BILLIONS)*</i>	142
BIOTRANSFORMATION TECHNOLOGY BY CHEMICAL TYPE	142
<i>TABLE 89 VALUE-ADDED BIOCHEMICALS POTENTIALLY DERIVED FROM CELLULOSE, HEMICELLULOSE AND LIGNIN (LIGNOCELLULOSIC BIOMASS)</i>	143
Diacids	144
Levulinic Acid	144
2, 5-Furan Dicarboxylic Acid (FDCA)	144
Glucaric Acid	145
Aspartic Acid	145
Muconic Acid	145
Others	146
<i>TABLE 90 GLOBAL MARKET FOR BIOTRANSFORMATION TECHNOLOGY BY TYPE OF CHEMICAL, THROUGH 2021 (\$ MILLIONS)</i>	147
BIOTRANSFORMATION TECHNOLOGY BY TYPE OF ACTIVE PHARMACEUTICAL INGREDIENT	147
<i>TABLE 91 GLOBAL MARKET FOR BIOTRANSFORMATION TECHNOLOGY BY TYPE OF ACTIVE PHARMACEUTICAL INGREDIENT, THROUGH 2021 (\$ BILLIONS)</i>	148
BIOTRANSFORMATION TECHNOLOGY BY TYPE OF DRUG	148
First-Generation Biodrug Technology	148
Second-Generation Biodrug Technology	149

TOPIC	PAGE NO.
<i>TABLE 92 GLOBAL MARKET FOR BIOTRANSFORMATION TECHNOLOGY BY TYPE OF DRUG, THROUGH 2021 (\$ BILLIONS)</i>	149
BIOTRANSFORMATION TECHNOLOGY BY TYPE OF SPECIALTY/FINE CHEMICAL	149
Biosurfactants	149
Bioremediation	150
Biofertilizers	150
<i>TABLE 93 GLOBAL MARKET FOR BIOTRANSFORMATION TECHNOLOGY BY TYPE OF SPECIALTY/FINE CHEMICAL, THROUGH 2021 (\$ MILLIONS)</i>	151
BIOTRANSFORMATION TECHNOLOGY BY TYPE OF POLYMER	151
<i>TABLE 94 BIOTRANSFORMATION OF POLYMERS</i>	152
Polylactic Acid Production from Biomass	152
<i>FIGURE 7 POLYLACTIC ACID PRODUCTION FROM BIOMASS</i>	153
Production of 1, 3-Propanediol	154
<i>FIGURE 8 BIO-BASED ROUTES TO 1, 3-PROPANEDIOL</i>	154
Polyhydroxyalkanoates	154
Plastics Directly from Plants	155
Vinyl Polymers	155
<i>TABLE 95 GLOBAL MARKET FOR BIOTRANSFORMATION OF POLYMERS BY TYPE, THROUGH 2021 (\$ MILLIONS)</i>	155
Bio-based Polyethylene (PE)	155
Bio-based Polypropylene	156
Bio-based Polyvinyl Chloride	156
<i>TABLE 96 GLOBAL MARKET FOR BIOTRANSFORMATION OF VINYL POLYMER BY TYPE, THROUGH 2021 (\$ MILLIONS)</i>	157
BIOFUEL TECHNOLOGY	157
<i>TABLE 97 BIOFUEL PRODUCTION VIA BIOTRANSFORMATION TECHNOLOGY</i>	158
Biodiesel Technology	159
Bioethanol Technology	159
Biogas Technology	159
Biobutanol Technology	160
<i>TABLE 98 GLOBAL MARKET FOR BIOTRANSFORMATION TECHNOLOGY BY TYPE OF BIOFUEL, THROUGH 2021 (\$ MILLIONS)</i>	160
BIOFUEL PRODUCTION BY TYPE OF MICROALGAE POND DESIGN	160
Open Ponds	160
Enclosed Ponds	161
Plate Reactor	161
<i>TABLE 99 GLOBAL MARKET FOR BIOFUEL PRODUCTION TECHNOLOGY BY TYPE OF MICROALGAE POND DESIGN, THROUGH 2021 (\$ MILLIONS)</i>	162
BIOFUEL PRODUCTION TECHNOLOGY BY TYPE OF MICROALGAE MODE OF OPERATION	162
Continuous Mode	162
Batch Mode	163
<i>TABLE 100 GLOBAL MARKET FOR BIOTRANSFORMATION TECHNOLOGY BY TYPE OF MICROALGAE BY MODE OF OPERATION, THROUGH 2021 (\$ MILLIONS)</i>	163
BIOFUEL PRODUCTION TECHNOLOGY BY TYPE OF MICROALGAE EXTRACTION TECHNOLOGY	163
Solvent-Based Technology	163
Microwave-Assisted Extraction Technology	164

TOPIC	PAGE NO.
Ultrasound-Assisted Extraction Technology	164
Supercritical Extraction Technology	164
Autoclave Technology	164
Enzyme-Assisted Extraction Technology	164
Extraction-Assisted Mechanical Destruction Technology	165
<i>TABLE 101 GLOBAL MARKET FOR BIOFUEL PRODUCTION TECHNOLOGY BY TYPE OF MICROALGAE EXTRACTION TECHNOLOGY THROUGH 2021 (\$ MILLIONS)</i>	165
CHAPTER 6 DEMAND FOR THE THERMOCHEMICAL PLATFORM	167
INTRODUCTION	167
<i>TABLE 102 THERMOCHEMICAL CONVERSION FOR POWER, HEAT, CHEMICAL FEEDSTOCKS AND FUEL</i>	168
DEMAND FOR THE THERMOCHEMICAL PLATFORM BY TYPE OF CONVERSION	168
<i>TABLE 103 GLOBAL MARKET FOR THERMOCHEMICAL PLATFORM BY TYPE OF CONVERSION, THROUGH 2021 (\$ BILLIONS)</i>	169
INDUSTRIAL DIRECT BIOMASS COMBUSTION REACTOR TECHNOLOGY	169
Fixed-Bed Combustion Technology	170
Fluidized-Bed Combustion Technology	170
Pulverized Bed Combustion Technology	170
Incineration Technology	170
<i>TABLE 104 GLOBAL MARKET FOR BIOMASS INDUSTRIAL DIRECT COMBUSTION TECHNOLOGY BY TYPE OF REACTOR, THROUGH 2021 (\$ BILLIONS)</i>	171
BIOMASS GASIFICATION REACTOR TECHNOLOGY	171
Fixed-Bed Gasification Technology	171
Fluidized-Bed Gasification Technology	171
<i>TABLE 105 GLOBAL MARKET FOR BIOMASS GASIFICATION BY TYPE OF REACTOR TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)</i>	172
PYROLYSIS TECHNOLOGY	172
<i>TABLE 106 COMMERCIAL AND PRE-COMMERCIAL (≥50 TONS PER DAY) BIO-OIL FACILITIES</i>	172
Conventional Pyrolysis Technology	173
Fast Pyrolysis Technology	174
<i>TABLE 107 GLOBAL MARKET FOR BIOMASS PYROLYSIS TECHNOLOGY BY TYPE, THROUGH 2021 (\$ BILLIONS)</i>	174
HYDROTHERMAL LIQUEFACTION TECHNOLOGY	174
HTU Technology	175
High-Pressure (Hydrothermal) Liquefaction Technology	175
<i>TABLE 108 GLOBAL MARKET FOR BIOMASS HYDROTHERMAL LIQUEFACTION TECHNOLOGY BY TYPE, THROUGH 2021 (\$ BILLIONS)</i>	175
DEMAND FOR THERMOCHEMICAL PLATFORM BY TYPE OF ENERGY RECOVERY TECHNOLOGY	175
WASTE-TO-ENERGY	176
POWER GENERATION	176
<i>TABLE 109 GLOBAL MARKET FOR THERMOCHEMICAL TECHNOLOGY PLATFORM BY TYPE OF ENERGY RECOVERY TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)</i>	177
CHAPTER 7 DEMAND FOR THE HYBRID PLATFORM	179
INTRODUCTION	179
<i>TABLE 110 HYBRID BIOREFINERY PLATFORMS</i>	179

TOPIC	PAGE NO.
DEMAND FOR HYBRID TECHNOLOGY PLATFORM BY COMBINATION	179
SYNGAS FERMENTATION	180
ZEACHEM PROCESS	180
AQUEOUS PHASE REFORMING AND THE VIRENT PROCESS	180
ALCOHOL-TO-JET PROCESS	181
<i>TABLE 111 GLOBAL MARKET FOR HYBRID TECHNOLOGY PLATFORM BY TYPE OF COMBINATION, THROUGH 2021 (\$ BILLIONS)</i>	181
CHAPTER 8 TECHNOLOGICAL DEVELOPMENTS	183
INTRODUCTION	183
<i>TABLE 112 METHODS FOR CONVERTING DIFFERENT BIOMASS SOURCES INTO BIOPRODUCTS</i>	183
<i>TABLE 113 CONVERSION OF BIOMASS TO BIO-BASED PRODUCTS</i>	184
ADVANCED BIOREFINERY TECHNOLOGIES	184
<i>TABLE 114 DESCRIPTION OF AN ADVANCED BIOREFINERY PLANT</i>	185
SIZE RANGE OF ADVANCED BIOREFINERY PLANT	185
<i>TABLE 115 ADVANCED BIOREFINERY PLANTS BY PLANT SIZE RANGE SORTED BY TECHNOLOGY PLATFORM (NUMBER OF PLANTS)</i>	186
ADVANCED BIOREFINERY TECHNOLOGY DEVELOPMENT	186
<i>TABLE 116 ADVANCED BIOREFINERY TECHNOLOGY DEVELOPMENT</i>	186
BIOREFINERY TECHNOLOGY WITHIN THE GLOBAL ECONOMY	188
<i>TABLE 117 BIO-DERIVED PRODUCTS WITHIN THE ECONOMY</i>	188
BIOREFINERY TECHNOLOGIES DEVELOPMENT AND SIGNIFICANCE	189
<i>TABLE 118 BIOREFINERY TECHNOLOGIES DEVELOPMENT AND SIGNIFICANCE</i>	189
BIOLOGICAL PLATFORM DEVELOPMENTS	203
<i>TABLE 119 BIOLOGICAL PLATFORM DEVELOPMENTS (TONS PER YEAR)</i>	203
CELLULOSIC TECHNOLOGY DEVELOPMENT	207
<i>TABLE 120 INTEGRATED CELLULOSIC ETHANOL BIOREFINERY</i>	207
BIOETHANOL FROM WOOD OR STRAW BY ENZYMATIC HYDROLYSIS AND FERMENTATION PRODUCTION TECHNOLOGY	208
<i>TABLE 121 BIOETHANOL FROM WOOD STRAW BY ACID HYDROLYSIS AND FERMENTATION TECHNOLOGY</i>	208
MOST PROMISING PRETREATMENT TECHNOLOGIES	208
Pretreatment	209
Hydrolysis	209
<i>TABLE 122 MOST PROMISING PRETREATMENT TECHNOLOGIES BY METHOD OF PRETREATMENT</i>	209
THERMOCHEMICAL PLATFORM DEVELOPMENTS	210
<i>TABLE 123 THERMOCHEMICAL PLATFORM DEVELOPMENTS</i>	211
PHYSICOCHEMICAL PLATFORM DEVELOPMENTS	213
<i>TABLE 124 PHYSICOCHEMICAL PLATFORM DEVELOPMENTS (TONS PER YEAR)</i>	214
HYBRID PLATFORM DEVELOPMENTS	214
<i>TABLE 125 HYBRID PLATFORM DEVELOPMENTS</i>	215
PATENT EVALUATION AND ANALYSIS	215
CHAPTER 9 INDUSTRY STRUCTURE AND COMPETITIVE ENVIRONMENT	218
INTRODUCTION	218
<i>TABLE 126 MAJOR BIOMASS CONVERSION BY TECHNOLOGY</i>	218
COMPARISON OF BIOREFINERIES TO PETRO-REFINERIES	220

TOPIC	PAGE NO.
<i>TABLE 127 PETROREFINERY SUPPLY CHAIN</i>	220
TECHNOLOGY VALUE CHAIN	220
<i>TABLE 128 NECESSARY VALUE CHAINS AND CAPITAL INVESTMENTS BY TYPE OF BIOREFINERY</i>	221
VALUE ADDITION OF BIO-DERIVED PRODUCTS	221
<i>TABLE 129 ADDED VALUE OF BIO-DERIVED PRODUCTS THROUGH PROCESSING AND STANDARDIZATION</i>	222
<i>TABLE 130 VALUE ADDITION OF BIO-BASED PRODUCTS</i>	223
COMMERCIALIZATION OF ADVANCED BIOREFINERIES	223
<i>TABLE 131 GEOGRAPHICAL COMMERCIALIZATION OF ADVANCED BIOREFINERIES</i>	224
EUROPEAN UNION HORIZON 2020 ENERGY EFFICIENCY CALL 2016-2017	224
<i>TABLE 132 HORIZON 2020 ENERGY EFFICIENCY CALL 2015-2016 (€ MILLIONS)</i>	224
TITLE IX OF THE AGRICULTURE ACT OF 2014	224
<i>TABLE 133 TITLE IX OF THE AGRICULTURE ACT OF 2014, THROUGH 2018 (\$ MILLIONS)</i>	225
COMMERCIALIZATION STAGES OF VARIOUS BIOPRODUCTS AND TECHNOLOGIES	225
<i>TABLE 134 COMMERCIALIZATION STAGE OF BIOPRODUCTS AND TECHNOLOGIES</i>	226
PATH TO COMMERCIAL DEPLOYMENT OF BIOREFINERIES	227
<i>TABLE 135 PATH TO COMMERCIAL DEPLOYMENT OF ADVANCED BIOREFINERIES BY COMPANY, 2003-2021</i>	228
BIOREFINERY PLANT SCALE OF OPERATION	236
<i>TABLE 136 TYPICAL SCALE OF OPERATION FOR VARIOUS SECOND-GENERATION BIOFUEL PLANTS USING ENERGY CROP-BASED LIGNOCELLULOSIC FEEDSTOCKS</i>	237
<i>TABLE 137 CAPITAL COSTS AND EFFICIENCIES OF PRINCIPAL BIOELECTRICITY AND COMPETITIVE CONVERSION TECHNOLOGIES</i>	238
INTEGRATED BIOREFINERY DEMONSTRATION COFUNDED BY THE U.S. DEPARTMENT OF ENERGY	238
<i>TABLE 138 U.S. DEPARTMENT OF ENERGY COFUNDED INTEGRATED BIOREFINERIES</i>	239
CHAPTER 10 INTERNATIONAL CONSIDERATIONS	241
INTRODUCTION	241
<i>TABLE 139 GEOGRAPHIC DISTRIBUTION OF BIOREFINERY JOBS</i>	241
GEOGRAPHIC TRENDS IN BIOREFINERY TECHNOLOGIES	242
<i>TABLE 140 GEOGRAPHIC TRENDS IN BIOREFINERY TECHNOLOGY PRODUCTS BY COUNTRY</i>	243
GLOBAL COMMODITY PRICES	245
CRUDE OIL	246
BIOFUELS FEEDSTOCK	246
NATURAL GAS	246
LNG	247
METALS AND MINERALS	247
<i>TABLE 141 GLOBAL COMMODITY PRICES, THROUGH 2021 (NOMINAL \$ U.S.)</i>	248
GLOBAL POPULATION	249
UNITED STATES AND CANADA	250
SOUTH ASIA	250
SUB-SAHARAN AFRICA	250
OTHER	250
<i>TABLE 142 GLOBAL POPULATION BY REGION, THROUGH 2020 (MILLION PEOPLE)</i>	250

TOPIC	PAGE NO.
GLOBAL GDP AND R&D SPENDING	251
<i>TABLE 143 GLOBAL TRENDS IN R&D SPENDING, 2014-2016 (\$ BILLIONS)</i>	251
GLOBAL ENERGY CONSUMPTION BY FEEDSTOCK	252
PETROLEUM	252
NATURAL GAS	252
COAL	252
NUCLEAR	253
HYDROELECTRIC	253
RENEWABLES	253
<i>TABLE 144 GLOBAL ENERGY CONSUMPTION BY FEEDSTOCK, THROUGH 2021 (MILLION METRIC TONNES OF OIL EQUIVALENT)</i>	253
INTERNATIONAL TRADE IN VEGETABLE OILS BY COUNTRY	254
PRODUCTION	254
DOMESTIC CONSUMPTION	254
IMPORTS	254
EXPORTS	254
<i>TABLE 145 GLOBAL SUPPLY AND DISTRIBUTION OF MAJOR VEGETABLE OILS BY TYPE OF OIL, THROUGH 2021 (MILLION METRIC TONS PER YEAR)</i>	255
INTERNATIONAL CURRENCY EXCHANGE RATES	256
<i>TABLE 146 YEARLY AVERAGE EXCHANGE RATES FOR CONVERTING FOREIGN CURRENCIES INTO U.S. DOLLARS*</i>	257
CHAPTER 11 REGULATIONS AND LEGISLATION	260
INTRODUCTION	260
<i>TABLE 147 IMPORTANT UPCOMING ENVIRONMENTAL REGULATIONS BY ACTIVITY</i>	260
CHAPTER 12 COMPANY PROFILES	264
BIOLOGICAL TECHNOLOGY PLATFORM COMPANIES	264
ABENGOA	264
ALFA AESAR (PART OF JOHNSON MATTHEY GROUP)	264
ALEXION PHARMACEUTICALS	264
ALKERMES	265
ALKOL BIOTECH	265
ALPHA CHEMIKA	265
AMGEN	266
AMYLIN PHARMACEUTICALS	266
AMYRIS	266
AMYRIS INC.	266
ANQING HEXING CHEMICAL CO. LTD.	267
ARCADIA BIOSCIENCES INC.	267
ARCHER DANIELS MIDLAND	267
ARIAD PHARMACEUTICALS	268
AVANTIUM	268
BASF SA	268
BAXTER INTERNATIONAL	269
BETA RENEWABLES	269
BIOAMBER INC.	270
Bioamber Inc.	270

TOPIC	PAGE NO.
BIOGEN	270
BIOGEN IDEC	270
BIOGASOL	271
BIOMARIN PHARMACEUTICALS INC.	271
BP BIOFUELS	271
BRASKEM	272
BUTAMAX	272
CATHAY INDUSTRIAL BIOTECH LTD.	272
CARGILL	273
CELGENE	273
CERES INC.	273
BLADE SEEDS	274
CHEMTEX	274
CHENGDU JINKAI BIOLOGY ENGINEERING CO. LTD.	274
CHROMATIN INC.	274
Seed Operations	275
CELGENE	275
CLARIENT	275
CODEXIS INC.	276
COPERSUCAR SA	276
CSL BEHRING	276
DUPONT	277
EARTH ENERGY RENEWABLES	277
EVOLVA	277
FIBERIGHT	278
GENENTECH	278
GF BIOCHEMICALS	278
GILEAD SCIENCES	279
GLENMARK PHARMACEUTICALS	279
DIASSORIN	279
DR. REDDY'S LABORATORIES	279
GEVO	280
ELEVANCE	280
GADIV PETROCHEMICAL INDUSTRIES ISRAEL	280
GENOME COMPILER CORP.	281
GILEAD SCIENCES	281
ITACONIX CORP.	281
JIANGSU HIGH HOPE INTERNATIONAL GROUP CORP.	282
Nanjing Huajin Biologicals Co. Ltd.	282
JINAN HUAMING BIOCHEMISTRY CO. LTD.	282
KAWASAKI KASEI CHEMICALS LTD.	283
KEMIN	283
LUCITE INTERNATIONAL GROUP LTD.	283
MENDOTA BIOENERGY LLC	283
MERCK KGAA	284
MITSUBISHI CHEMICAL JAPAN	284
MITSUBISHI RAYON	284

TOPIC	PAGE NO.
MITSUI & CO. LTD.	284
MODULAR GENETICS INC.	285
MYRIANT CORP.	285
NEXSTEPPE	285
NIPPON SHOKUBAI CO. LTD.	286
NOVO NORDISK	286
ODEBRECHT AGROINDUSTRIAL (ETH)	286
PACIFIC ETHANOL INC.	287
POET BIOREFINING	287
PURAC	287
QINGDAO ABEL TECHNOLOGY CO. LTD.	288
QINGDAO KEHAI BIOCHEMISTRY CO. LTD.	288
RAIZEN NORTH AMERICA INC.	288
REGENERON	289
RENEWABLE ENERGY GROUP	289
REVERDIA (DSM - ROQUETTE)	289
RENMATRIX INC.	290
ROQUETTE FRERES SA	290
ROYAL DSM	290
RONAS CHEMICALS IND. CO. LTD.	291
SEATTLE GENETICS	291
SEVENTH GENERATION	291
SHIRE PLC	292
SOLUTIONS4CO2	292
SOUTHEAST RENEWABLE FUELS LLC	292
STORA ENSO	293
SUCCINITY	293
SYNBIAS LTD.	293
TEVA PHARMACEUTICAL INDUSTRIES	293
TOKYO CHEMICAL INDUSTRY CO. LTD.	294
UNITED THERAPEUTICS	294
V & V PHARMA INDUSTRIES	294
VALERO RENEWABLE FUELS	294
VERDEZYME	295
VERTEX PHARMACEUTICALS	295
WACKER CHEMIE	295
ZOOSHARE BIOGAS CO-OPERATIVE INC.	296
ZERO WASTE ENERGY SYSTEMS LTD.	296
ZHEJIANG KEDAO CHEMICALS CO. LTD.	296
PHYSICOCHEMICAL TECHNOLOGY PLATFORM COMPANIES	297
ABENGOA BIOENERGIA	297
ALGAE DYNAMICS (FORMERLY CONVERTED CARBON TECHNOLOGIES)	297
BORREGAARD	298
CARBONA	298
CHEMREC	298
CONOCOPHILLIPS	299
DIAMOND GREEN DIESEL	299

TOPIC	PAGE NO.
DYNAMIC FUELS LLC	299
EMERALD BIOFUELS	300
HONEYWELL-UOP	300
NESTE OIL	300
POND BIOFUELS	301
SUN PINE	301
VIRENT	302
WILMAR INTERNATIONAL LTD.	302
THERMOCHEMICAL TECHNOLOGY PLATFORM COMPANIES	303
ALTRANEX	303
AMEC FOSTER WHEELER	303
CHEMREC	303
CHOREN	304
DYNAMOTIVE LTD.	304
ECN	305
ENERGY RESEARCH CENTER OF THE NETHERLANDS	305
ENSYN	305
EVERGENT	306
FORTUM	306
GAS TECHNOLOGY INSTITUTE	306
GOTEBORG ENERGI	307
GREASOLINE	307
GREEN FUEL NORDIC OY	308
LICELLA	308
RED ARROW	308
RENTECH	309
REPOTEC	309
SUNDROP FUELS	309
THYSSEN KRUP UHDE	310
UPM	310
VARMLANDSMETANOL AB	310
WOODLAND BIOFUELS	311
HYBRID TECHNOLOGY PLATFORM COMPANIES	311
ENERKEM	311
INEOS BIO	311
LANZATECH	312
VIRENT ENERGY SYSTEMS	312
ZEACHEM	312
BIOREFINERY TECHNOLOGY INTEGRATORS	313
AIR PRODUCTS & CHEMICALS	313
AKZO NOBEL INC.	313
ARKEMA	313
ASAHI KASEI	314
BASF	314
BAYER	315
BOREALIS	315
CHEVRON PHILLIPS CHEMICAL	315

TOPIC	PAGE NO.
DUPONT	316
EASTMAN CHEMICAL	316
ECOLAB	317
EVONIK INDUSTRIES	317
EXXONMOBIL	317
FORMOSA PLASTICS CORP.	318
HANWHA CHEMICAL	318
HUNTSMAN CORP.	318
INDORAMA	319
LANXESS	319
LOTTE CHEMICAL	320
LYONDELLBASELL INDUSTRIES	320
MITSUBISHI CHEMICAL	320
MIITSUI CHEMICALS	321
MOSAIC	321
PPG INDUSTRIES	321
PRAXAIR	322
PTT GLOBAL CHEMICAL	322
RELIANCE INDUSTRIES	323
SASOL	323
SHELL	323
SHI-ETSU CHEMICAL	324
SIAM CEMENT	324
SK INNOVATION	324
SOLVAY	325
SUMITOMO CHEMICAL	325
SYNGENTA	326
TORAY INDUSTRIES	326
TOSOH	326
YARA	327

LIST OF TABLES

TABLE HEADING	PAGE NO.
SUMMARY TABLE GLOBAL MARKET FOR BIOREFINERY TECHNOLOGIES BY TYPE OF PLATFORM, THROUGH 2021 (\$ BILLIONS)	12
TABLE 1 GENERALIZED BIOREFINERY TECHNOLOGY CONFIGURATIONS	15
TABLE 2 BIOREFINERY SYSTEM CLASSIFICATION USING CURRENT METHODS	16
TABLE 3 GENERALIZED BIOREFINERY OUTLINE USING CURRENT METHODS	17
TABLE 4 GLOBAL MARKET FOR APPLICATIONS OF BIOREFINERY TECHNOLOGIES BY PRODUCT TYPE, THROUGH 2021 (\$ BILLIONS)	17
TABLE 5 GLOBAL MARKET FOR BIOREFINERY TECHNOLOGIES USED TO PROCESS ENERGY PRODUCTS BY INDUSTRY APPLICATION, THROUGH 2021 (\$ BILLIONS)	19
TABLE 6 GLOBAL MARKET FOR BIOREFINERY TECHNOLOGIES USED TO PROCESS NON-ENERGY PRODUCTS BY INDUSTRY APPLICATION, THROUGH 2021 (\$ BILLIONS)	20
TABLE 7 GLOBAL BIOREFINERY TECHNOLOGIES MARKET PENETRATION, THROUGH 2021 (\$ BILLIONS)	21
TABLE 8 MAJOR BIOREFINERY TECHNOLOGY PLATFORM ACTIVITIES AND PRODUCTS	22
TABLE 9 ENERGETIC AND NON-ENERGETIC FOREST BIOREFINERY SUPPLY CHAIN	23
TABLE 10 OVERVIEW OF THE BIOMASS VALUE CHAIN CONVERSION PROCESS	25
TABLE 11 LIGNOCELLULOSIC BIOMASS VALUE CHAIN CONVERSION PROCESS	26
TABLE 12 PROCESSES USED AND PRODUCTS EXTRACTED FROM PLANTS	27
TABLE 13 OVERVIEW OF INDUSTRIAL AND MATERIAL USE OF BIO-BASED RAW MATERIALS	29
TABLE 14 BIOREFINERY TECHNOLOGY CONVERSION ROUTES OF PLANT BIOMASS	32
TABLE 15 BIOREFINERY TECHNOLOGIES APPROACHES: MARKET FEATURES AND RELATIVE SUBGROUPS	33
TABLE 16 PRIMARY BIOREFINERY CONVERSION TECHNOLOGIES TO CRUDE PRODUCTS	35
TABLE 17 SECONDARY AND TERTIARY BIOREFINERY TRANSFORMATION TECHNOLOGIES TO PRODUCT	36
TABLE 18 EFFECTIVE H/C RATIO IN RELATION TO THE BIOCHEMICAL TECHNOLOGY PLATFORM AND ITS INTERMEDIATES	38
TABLE 19 HYDROGEN TO CARBON RATIO STAIRCASE FOR FOSSIL FUEL FEEDSTOCKS	39
TABLE 20 SELECTED EMPLOYMENT OPPORTUNITIES AMONG ADVANCED BIOREFINERY COMPANIES	40
TABLE 21 STAFFING AND SALARY PROJECTIONS FOR A PROTOTYPE 10-MILLION-GALLON-PER-YEAR RURAL BIOREFINERY, THROUGH 2020 (\$ THOUSANDS)	42
TABLE 22 SELECTED SCIENCE OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)	43
TABLE 23 SELECTED ENGINEERING AND MAPPING OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)	44
TABLE 24 SELECTED CONSTRUCTION AND MATERIAL-MOVING OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)	45
TABLE 25 SELECTED INDUSTRIAL MICROBIOLOGY OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)	47
TABLE 26 SELECTED AGRICULTURE OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)	48
TABLE 27 SELECTED PRODUCTION OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)	48
TABLE 28 SELECTED SALES OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)	49

TABLE HEADING	PAGE NO.
TABLE 29 SELECTED MANAGEMENT AND BUSINESS SPECIALIST OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)	50
TABLE 30 SELECTED MECHANIC AND MAINTENANCE OCCUPATIONS AND MEDIAN ANNUAL WAGES, THROUGH 2021 (\$ THOUSANDS)	50
TABLE 31 RFS2 DATA, CONVENTIONAL BIOFUEL AND ADVANCED BIOFUEL (BILLION GALLONS)	51
TABLE 32 BIOMASS CONVERSION TECHNOLOGY MATURITY STATUS	52
TABLE 33 ANTICIPATED CHEMICAL AND MATERIAL DEVELOPMENT PATHWAY BY KEY FEEDSTOCK	53
TABLE 34 U.S. FEDERAL FUNDING FOR ADVANCED BIOREFINERY TECHNOLOGIES, 2007-2014 (\$ MILLIONS)	54
TABLE 35 U.S. FEDERAL AND PUBLIC FUNDING FOR ADVANCED BIOREFINERY TECHNOLOGIES 2015-2016 (\$ MILLIONS)	54
TABLE 36 IMPORTANT DEVELOPMENTS IN BIOREFINERY TECHNOLOGIES	55
TABLE 37 REAL GDP AND INDUSTRIAL PRODUCTION GROWTH, THROUGH 2021 (% CHANGE ON PREVIOUS YEAR)	60
TABLE 38 GLOBAL MARKET FOR BIOREFINERY TECHNOLOGIES BY TYPE OF PLATFORM, THROUGH 2021 (%)	61
TABLE 39 PHYSICOCHEMICAL CONVERSION OF BUILDING-BLOCK CHEMICALS, THEIR DERIVATIVES AND POTENTIAL APPLICATIONS	63
TABLE 40 GLOBAL MARKET FOR THE PHYSICOCHEMICAL TECHNOLOGY PLATFORM BY PRODUCT SEGMENT, THROUGH 2021 (\$ BILLIONS)	67
TABLE 41 GLOBAL MARKET FOR BIO-DERIVED FINE CHEMICALS PRODUCED BY PHYSICOCHEMICAL CONVERSION TYPE, THROUGH 2021 (\$ MILLIONS)	70
TABLE 42 GLOBAL MARKET FOR LIPID CONVERSION BIOPOLYMER/ BIOPLASTIC BUILDING-BLOCK TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)	71
TABLE 43 BIOCOMPOSITE TECHNOLOGY VALUE ADDITION	72
TABLE 44 NATURAL FIBER PROCESS TECHNIQUES AND APPLICATIONS	73
TABLE 45 BIOCOMPOSITE PRODUCT STRUCTURE	74
TABLE 46 BIOCOMPOSITE PROCESSING TECHNOLOGY	74
TABLE 47 GLOBAL MARKET FOR BIOCOMPOSITE TECHNOLOGY BY TYPE, THROUGH 2021 (\$ BILLIONS)	76
TABLE 48 GLOBAL MARKET FOR BIOCOMPOSITE PRODUCTION TECHNOLOGY BY TYPE, THROUGH 2021 (\$ BILLIONS)	77
TABLE 49 GLOBAL MARKET FOR VEGETABLE OIL FUEL TECHNOLOGY BY TYPE, THROUGH 2021 (\$ BILLIONS)	77
TABLE 50 GLOBAL MARKET FOR STRAIGHT VEGETABLE OIL ENGINE TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)	78
TABLE 51 CURRENT GLOBAL ANNUAL PRODUCTION CAPACITY OF HVO DROP-IN BIOFUELS	79
TABLE 52 GLOBAL MARKET FOR HYDROGENATED VEGETABLE OIL FUEL BY TYPE OF ENGINE TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)	80
TABLE 53 BIODIESEL BY ESTERIFICATION OF VEGETABLE OIL PRODUCTION	82
TABLE 54 FLOW CHART OF PHYSICOCHEMICAL PRODUCTION OF BIODIESEL	82
TABLE 55 GLOBAL MARKET FOR VEGETABLE OIL IN BIODIESEL PRODUCTION BY TYPE OF FEEDSTOCK TECHNOLOGY, THROUGH 2021 (THOUSAND METRIC TONS)	84
TABLE 56 GLOBAL MARKET FOR BIODIESEL BY TYPE OF ESTERIFICATION TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)	85
TABLE 57 GLOBAL MARKET FOR PHYSICOCHEMICAL CATALYSIS OF BIODIESEL BY TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)	87
TABLE 58 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)	88

TABLE HEADING	PAGE NO.
TABLE 59 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY BY TYPE OF PLANT ROOT, THROUGH 2021 (\$ BILLIONS)	92
TABLE 60 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY BY TYPE OF PLANT BARK, THROUGH 2021 (\$ BILLIONS)	95
TABLE 61 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY BY TYPE OF STEM AND WOOD, THROUGH 2021 (\$ BILLIONS)	96
TABLE 62 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY BY TYPE OF PLANT LEAF, THROUGH 2021 (\$ BILLIONS)	100
TABLE 63 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY BY TYPE OF PLANT FLOWER, THROUGH 2021 (\$ BILLIONS)	102
TABLE 64 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY BY TYPE OF PLANT FRUIT AND SEED, THROUGH 2021 (\$ BILLIONS)	105
TABLE 65 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY BY TYPE OF PLANT RHIZOME, THROUGH 2021 (\$ BILLIONS)	107
TABLE 66 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL TECHNOLOGY BY TYPE OF LOWER PLANT, THROUGH 2021 (\$ BILLIONS)	109
TABLE 67 GLOBAL MARKET FOR HERBAL/BOTANICAL AND PHYTOCHEMICAL COMPOUNDS BY EXTRACTION TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)	112
TABLE 68 GLOBAL MARKET FOR THE BIOLOGICAL PLATFORM BY TYPE OF TRANSFORMATION, THROUGH 2021 (\$ BILLIONS)	114
TABLE 69 BIOTECHNOLOGY SEGMENTS	115
TABLE 70 BIOLOGICAL CONVERSION FOR CHEMICAL BUILDING BLOCKS, THEIR DERIVATIVES AND THEIR POTENTIAL APPLICATIONS	116
TABLE 71 GLOBAL MARKET FOR FERMENTATIVE TECHNOLOGY BY PRODUCT SEGMENT, THROUGH 2021 (\$ BILLIONS)	119
TABLE 72 GLOBAL MARKET FOR FEEDSTOCK IN BIOETHANOL PRODUCTION, THROUGH 2021 (THOUSAND METRIC TONS)	120
TABLE 73 GLOBAL MARKET FOR BIOETHANOL PRODUCTION BY MALTING TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)	121
TABLE 74 GLOBAL MARKET FOR BIOETHANOL PRODUCTION BY TYPE OF CORN MILLING TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)	122
TABLE 75 GLOBAL MARKET FOR BIOETHANOL PRODUCTION BY TYPE OF SUGAR FEEDSTOCK TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)	124
TABLE 76 GLOBAL MARKET FOR BIOETHANOL PRODUCTION BY TYPE OF CELLULOSIC FEEDSTOCK TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)	125
TABLE 77 GLOBAL MARKET FOR BIOETHANOL PRODUCTION BY TYPE OF CELLULOSIC HYDROLYSIS TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)	126
TABLE 78 GLOBAL MARKET FOR BIOETHANOL BY TYPE OF DEHYDRATION TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)	128
TABLE 79 GLOBAL MARKET FOR FERMENTATIVE BIOGAS PRODUCTION TECHNOLOGY BY TYPE OF ENVIRONMENT, THROUGH 2021 (\$ BILLIONS)	128
TABLE 80 MICROBIAL GROUPS INVOLVED IN ENVIRONMENTAL REMEDIATION	129
TABLE 81 ANAEROBIC DIGESTION TECHNOLOGY	132
TABLE 82 GLOBAL MARKET FOR ANAEROBIC DIGESTION TECHNOLOGY BY TYPE OF ENVIRONMENT, THROUGH 2021 (\$ BILLIONS)	134
TABLE 83 GLOBAL MARKET FOR LANDFILL BIOGAS BY TYPE OF ENVIRONMENT, THROUGH 2021 (\$ BILLIONS)	135
TABLE 84 SULFUR REMOVAL TECHNOLOGY	135
TABLE 85 GLOBAL MARKET FOR BIOGAS BY TYPE OF RECOVERY AND PURIFICATION TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)	138
TABLE 86 GLOBAL INDUSTRIAL PRODUCTION OF ORGANIC ACID FROM BIOMASS FEEDSTOCKS	140

TABLE HEADING	PAGE NO.
TABLE 87 GLOBAL MARKET FOR FERMENTATION-DERIVED SPECIALTY/FINE CHEMICAL TECHNOLOGY BY TYPE, THROUGH 2021 (\$ MILLIONS)	141
TABLE 88 GLOBAL MARKET FOR BIOTRANSFORMATION TECHNOLOGY BY PRODUCT CATEGORY, THROUGH 2021 (\$ BILLIONS)*	142
TABLE 89 VALUE-ADDED BIOCHEMICALS POTENTIALLY DERIVED FROM CELLULOSE, HEMICELLULOSE AND LIGNIN (LIGNOCELLULOSIC BIOMASS)	143
TABLE 90 GLOBAL MARKET FOR BIOTRANSFORMATION TECHNOLOGY BY TYPE OF CHEMICAL, THROUGH 2021 (\$ MILLIONS)	147
TABLE 91 GLOBAL MARKET FOR BIOTRANSFORMATION TECHNOLOGY BY TYPE OF ACTIVE PHARMACEUTICAL INGREDIENT, THROUGH 2021 (\$ BILLIONS)	148
TABLE 92 GLOBAL MARKET FOR BIOTRANSFORMATION TECHNOLOGY BY TYPE OF DRUG, THROUGH 2021 (\$ BILLIONS)	149
TABLE 93 GLOBAL MARKET FOR BIOTRANSFORMATION TECHNOLOGY BY TYPE OF SPECIALTY/FINE CHEMICAL, THROUGH 2021 (\$ MILLIONS)	151
TABLE 94 BIOTRANSFORMATION OF POLYMERS	152
TABLE 95 GLOBAL MARKET FOR BIOTRANSFORMATION OF POLYMERS BY TYPE, THROUGH 2021 (\$ MILLIONS)	155
TABLE 96 GLOBAL MARKET FOR BIOTRANSFORMATION OF VINYL POLYMER BY TYPE, THROUGH 2021 (\$ MILLIONS)	157
TABLE 97 BIOFUEL PRODUCTION VIA BIOTRANSFORMATION TECHNOLOGY	158
TABLE 98 GLOBAL MARKET FOR BIOTRANSFORMATION TECHNOLOGY BY TYPE OF BIOFUEL, THROUGH 2021 (\$ MILLIONS)	160
TABLE 99 GLOBAL MARKET FOR BIOFUEL PRODUCTION TECHNOLOGY BY TYPE OF MICROALGAE POND DESIGN, THROUGH 2021 (\$ MILLIONS)	162
TABLE 100 GLOBAL MARKET FOR BIOTRANSFORMATION TECHNOLOGY BY TYPE OF MICROALGAE BY MODE OF OPERATION, THROUGH 2021 (\$ MILLIONS)	163
TABLE 101 GLOBAL MARKET FOR BIOFUEL PRODUCTION TECHNOLOGY BY TYPE OF MICROALGAE EXTRACTION TECHNOLOGY THROUGH 2021 (\$ MILLIONS)	165
TABLE 102 THERMOCHEMICAL CONVERSION FOR POWER, HEAT, CHEMICAL FEEDSTOCKS AND FUEL	168
TABLE 103 GLOBAL MARKET FOR THERMOCHEMICAL PLATFORM BY TYPE OF CONVERSION, THROUGH 2021 (\$ BILLIONS)	169
TABLE 104 GLOBAL MARKET FOR BIOMASS INDUSTRIAL DIRECT COMBUSTION TECHNOLOGY BY TYPE OF REACTOR, THROUGH 2021 (\$ BILLIONS)	171
TABLE 105 GLOBAL MARKET FOR BIOMASS GASIFICATION BY TYPE OF REACTOR TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)	172
TABLE 106 COMMERCIAL AND PRE-COMMERCIAL (\geq 50 TONS PER DAY) BIO-OIL FACILITIES	172
TABLE 107 GLOBAL MARKET FOR BIOMASS PYROLYSIS TECHNOLOGY BY TYPE, THROUGH 2021 (\$ BILLIONS)	174
TABLE 108 GLOBAL MARKET FOR BIOMASS HYDROTHERMAL LIQUEFACTION TECHNOLOGY BY TYPE, THROUGH 2021 (\$ BILLIONS)	175
TABLE 109 GLOBAL MARKET FOR THERMOCHEMICAL TECHNOLOGY PLATFORM BY TYPE OF ENERGY RECOVERY TECHNOLOGY, THROUGH 2021 (\$ BILLIONS)	177
TABLE 110 HYBRID BIOREFINERY PLATFORMS	179
TABLE 111 GLOBAL MARKET FOR HYBRID TECHNOLOGY PLATFORM BY TYPE OF COMBINATION, THROUGH 2021 (\$ BILLIONS)	181
TABLE 112 METHODS FOR CONVERTING DIFFERENT BIOMASS SOURCES INTO BIOPRODUCTS	183
TABLE 113 CONVERSION OF BIOMASS TO BIO-BASED PRODUCTS	184
TABLE 114 DESCRIPTION OF AN ADVANCED BIOREFINERY PLANT	185

TABLE HEADING	PAGE NO.
TABLE 115 ADVANCED BIOREFINERY PLANTS BY PLANT SIZE RANGE SORTED BY TECHNOLOGY PLATFORM (NUMBER OF PLANTS)	186
TABLE 116 ADVANCED BIOREFINERY TECHNOLOGY DEVELOPMENT	186
TABLE 117 BIO-DERIVED PRODUCTS WITHIN THE ECONOMY	188
TABLE 118 BIOREFINERY TECHNOLOGIES DEVELOPMENT AND SIGNIFICANCE	189
TABLE 119 BIOLOGICAL PLATFORM DEVELOPMENTS (TONS PER YEAR)	203
TABLE 120 INTEGRATED CELLULOSIC ETHANOL BIOREFINERY	207
TABLE 121 BIOETHANOL FROM WOOD STRAW BY ACID HYDROLYSIS AND FERMENTATION TECHNOLOGY	208
TABLE 122 MOST PROMISING PRETREATMENT TECHNOLOGIES BY METHOD OF PRETREATMENT	209
TABLE 123 THERMOCHEMICAL PLATFORM DEVELOPMENTS	211
TABLE 124 PHYSICOCHEMICAL PLATFORM DEVELOPMENTS (TONS PER YEAR)	214
TABLE 125 HYBRID PLATFORM DEVELOPMENTS	215
TABLE 126 MAJOR BIOMASS CONVERSION BY TECHNOLOGY	218
TABLE 127 PETROREFINERY SUPPLY CHAIN	220
TABLE 128 NECESSARY VALUE CHAINS AND CAPITAL INVESTMENTS BY TYPE OF BIOREFINERY	221
TABLE 129 ADDED VALUE OF BIO-DERIVED PRODUCTS THROUGH PROCESSING AND STANDARDIZATION	222
TABLE 130 VALUE ADDITION OF BIO-BASED PRODUCTS	223
TABLE 131 GEOGRAPHICAL COMMERCIALIZATION OF ADVANCED BIOREFINERIES	224
TABLE 132 HORIZON 2020 ENERGY EFFICIENCY CALL 2015-2016 (€ MILLIONS)	224
TABLE 133 TITLE IX OF THE AGRICULTURE ACT OF 2014, THROUGH 2018 (\$ MILLIONS)	225
TABLE 134 COMMERCIALIZATION STAGE OF BIOPRODUCTS AND TECHNOLOGIES	226
TABLE 135 PATH TO COMMERCIAL DEPLOYMENT OF ADVANCED BIOREFINERIES BY COMPANY, 2003-2021	228
TABLE 136 TYPICAL SCALE OF OPERATION FOR VARIOUS SECOND-GENERATION BIOFUEL PLANTS USING ENERGY CROP-BASED LIGNOCELLULOSIC FEEDSTOCKS	237
TABLE 137 CAPITAL COSTS AND EFFICIENCIES OF PRINCIPAL BIOELECTRICITY AND COMPETITIVE CONVERSION TECHNOLOGIES	238
TABLE 138 U.S. DEPARTMENT OF ENERGY COFUNDED INTEGRATED BIOREFINERIES	239
TABLE 139 GEOGRAPHIC DISTRIBUTION OF BIOREFINERY JOBS	241
TABLE 140 GEOGRAPHIC TRENDS IN BIOREFINERY TECHNOLOGY PRODUCTS BY COUNTRY	243
TABLE 141 GLOBAL COMMODITY PRICES, THROUGH 2021 (NOMINAL \$ U.S.)	248
TABLE 142 GLOBAL POPULATION BY REGION, THROUGH 2020 (MILLION PEOPLE)	250
TABLE 143 GLOBAL TRENDS IN R&D SPENDING, 2014-2016 (\$ BILLIONS)	251
TABLE 144 GLOBAL ENERGY CONSUMPTION BY FEEDSTOCK, THROUGH 2021 (MILLION METRIC TONNES OF OIL EQUIVALENT)	253
TABLE 145 GLOBAL SUPPLY AND DISTRIBUTION OF MAJOR VEGETABLE OILS BY TYPE OF OIL, THROUGH 2021 (MILLION METRIC TONS PER YEAR)	255
TABLE 146 YEARLY AVERAGE EXCHANGE RATES FOR CONVERTING FOREIGN CURRENCIES INTO U.S. DOLLARS*	257
TABLE 147 IMPORTANT UPCOMING ENVIRONMENTAL REGULATIONS BY ACTIVITY	260

LIST OF FIGURES

FIGURE TITLE	PAGE NO.
SUMMARY FIGURE GLOBAL MARKET FOR BIOREFINERY TECHNOLOGIES BY TYPE OF PLATFORM, 2013-2021 (\$ BILLIONS)	12
FIGURE 1 VALUE CHAIN OF THE NATURAL INGREDIENT INDUSTRY	28
FIGURE 2 BASIC OLEOCHEMICAL, DOWNSTREAM OLEOCHEMICAL AND DERIVATIVE PRODUCTION TECHNOLOGY	65
FIGURE 3 TRANSESTERIFICATION AND EPOXIDATION, HYDROFORMYLATION AND METATHESIS REACTIONS	65
FIGURE 4 BASIC OLEOCHEMICAL AND DOWNSTREAM OLEOCHEMICAL PRODUCTION TECHNOLOGY	66
FIGURE 5 CHEMICAL PROCESSES FOR METHYL OR ETHYL ESTER BIODIESEL PRODUCTION AND PRODUCT YIELDS	81
FIGURE 6 BIOTECHNICAL SYNTHESIS OF END PRODUCTS AND INTERMEDIATES FOR THE CHEMICAL, MATERIAL, FUEL, AND ENERGY INDUSTRIES	117
FIGURE 7 POLYLACTIC ACID PRODUCTION FROM BIOMASS	153
FIGURE 8 BIO-BASED ROUTES TO 1, 3-PROPANEDIOL	154