

The Global Market for Biobased and Sustainable Materials 2024-2035

<https://marketpublishers.com/r/G1971FE9D7A9EN.html>

Date: April 2024

Pages: 2585

Price: US\$ 1,266.00 (Single User License)

ID: G1971FE9D7A9EN

Abstracts

Advancements in science and technology are enabling companies to develop and design chemicals and materials for a more sustainable future. The global plastics industry is increasingly turning to biobased alternatives to supplement production and address sustainability concerns, as less than 10% of the world's plastic is currently recycled. Biobased materials are products primarily derived from living matter (biomass), either occurring naturally or synthesized. These materials can include bulk chemicals, platform chemicals, solvents, polymers, and biocomposites. Various processes are used to convert biomass components into value-added products and fuels, which can be broadly classified as biochemical or thermochemical. Additionally, biotechnological processes involving plant breeding, fermentation, and conventional enzyme isolation are employed. As new bio-based materials emerge, they have the potential to compete with conventional materials, and this publication explores the opportunities for their use in existing and novel products.

There is a growing demand from consumers and regulatory bodies for bio-based chemicals, materials, polymers, plastics, paints, coatings, and fuels that exhibit high performance, good recyclability, and biodegradable properties. This demand is driving the transition towards more sustainable manufacturing practices and products, as industries seek to reduce their environmental impact and meet evolving consumer preferences.

The Global Market for Bio-based and Sustainable Materials 2024-2035 offers comprehensive overview of the rapidly growing field of biobased and sustainable materials. It provides in-depth insights into a wide array of innovative materials, such as biobased chemicals and intermediates sourced from plants, wastes, and microbial and mineral origins. The report presents a thorough analysis of the production processes,

applications, and global market trends for essential biochemicals, including lysine, isosorbide, lactic acid, succinic acid, and many others. It also examines the current state and future prospects of the biobased chemicals market, highlighting key drivers, challenges, and opportunities.

The report offers a detailed assessment of the properties, production methods, and applications of synthetic biobased polymers, such as PLA, Bio-PET, and Bio-PP, as well as natural polymers like PHA and cellulose. The report analyzes the market dynamics, production capacities, and end-use markets for these sustainable alternatives to conventional plastics, providing valuable insights for manufacturers, suppliers, and investors.

Additionally, the report explores the potential of natural fiber plastics and composites, presenting a comprehensive analysis of various plant-based fibers, their properties, and applications across industries, including automotive, packaging, construction, and consumer goods. It evaluates the competitive landscape, market trends, and future outlook for this promising sector, enabling stakeholders to make informed decisions and capitalize on emerging opportunities.

Sustainable construction materials represent another key focus area of the report. It examines the latest trends and innovations in this field, such as hemp-based products, mycelium composites, green concrete, and advanced insulation solutions like aerogels. The report assesses the market drivers, challenges, and opportunities in the sustainable construction industry, providing valuable insights for companies looking to enhance their sustainability practices and gain a competitive edge.

The report also covers biobased packaging materials, sustainable textiles and apparel, biobased coatings and resins, biofuels, and sustainable electronics. It identifies key players, market trends, and growth potential across these industries, offering a comprehensive overview of the current market landscape and future prospects.

The report also provides in-depth company profiles, detailed market data, and expert analysis, making it an indispensable resource for businesses, investors, and stakeholders seeking to understand and capitalize on the immense potential of biobased and sustainable materials. Companies profiled include Aduro Clean Technologies, Agilyx, Alt.Leather, Alterra, Amsty, APK?AG, Aquafil, Arcus, Arda Biomaterials, Avantium, Axens, BASF Chemcycling, Beyond Leather Materials ApS, BiologiQ, Biome Bioplastics, Biophilica, Bpacks, Braskem, Bucha Bio, Byogy Renewables, Caphenia, Carbios, CJ CheilJedang, DePoly, Dow, Earthodic, Eastman

Chemical, Ecovative, Ensyn, EREMA Group GmbH, Evolved by Nature, Extractive, ExxonMobil, FlexSea, FORGE Hydrocarbons Corporation, Fych Technologies, Garbo, Gozen Bioworks, gr3n SA, Hyundai Chemical, cytos, Ioniqa, Itero, Kelpi, Kvasir Technologies, Licella, LignoPure GmbH, MeduSoil, Modern Meadow, Mura Technology, MycoWorks, Natural Fiber Welding, Notpla, Origin Materials, Pack2Earth, PersiSKIN, Plastic Energy, Plastogaz SA, Polybion, ProjectEx, Polystyvert, Pyrowave, Recyc'ELIT, RePEaT Co., Ltd., revalyu Resources GmbH, SA-Dynamics, Solugen, Stora Enso, Strong By Form, Sulapac, UBG Materials, UNCAGED Innovations, Verde Bioresins, and ZymoChem.

Report contents include:

Biobased Chemicals and Intermediates

Biorefineries

Bio-based Feedstock and Land Use

Plant-based (Starch, Sugar Crops, Lignocellulosic Biomass, Plant Oils, Non-Edible Milk)

Waste (Food, Agricultural, Forestry, Aquaculture/Fishing, Municipal Solid, Industrial, Waste Oils)

Microbial & Mineral Sources (Microalgae, Macroalgae, Mineral)

Gaseous (Biogas, Syngas, Off Gases)

Company Profiles

Biobased Polymers and Plastics

Drop-in Bio-based Plastics

Novel Bio-based Plastics

Biodegradable and Compostable Plastics

Types and Key Market Players

Synthetic Biobased Polymers (PLA, PET, PTT, PEF, PA, PBAT, PBS, PE, PP)

Natural Biobased Polymers (PHA, Cellulose, Protein-based, Algal, Fungal, Chitosan)

Production by Region

End Use Markets (Packaging, Consumer Products, Automotive, Construction, Textiles, Electronics, Agriculture)

Lignin

Company Profiles

Natural Fiber Plastics and Composites

Introduction

Types of Natural Fibers (Plants, Animal, Wood-based)

Processing and Treatment

Interface and Compatibility

Manufacturing Processes

Global Market (Automotive, Packaging, Construction, Appliances, Consumer Electronics, Furniture)

Competitive Landscape

Future Outlook

Revenues (by End Use Market, Material Type, Plastic Type, Region)

Company Profiles

Sustainable Construction Materials

Market Overview

Types (Hemp-based, Mycelium-based, Sustainable Concrete, Natural Fiber Composites, Sustainable Insulation, Carbon Capture and Utilization, Green Steel, Aerogels)

Markets and Applications

Company Profiles

Biobased Packaging Materials

Market Overview

Materials (Synthetic Bio-based, Natural Bio-based)

Applications (Paper and Board, Food Packaging)

Biobased Films and Coatings

Carbon Capture Derived Materials

Global Markets (Flexible, Rigid, Coatings and Films)

Company Profiles

Sustainable Textiles and Apparel

Types of Bio-based Fibers (Natural, Man-made)

Bio-based Leather

Markets

Global Market Revenues (by Region, End Use Market)

Company Profiles

Biobased Coatings and Resins

Overview (Biobased Epoxy, Polyurethane, Others)

Types

Global Revenues (by Types, Market)

Company Profiles

Biofuels

Comparison to Fossil Fuels

Role in the Circular Economy

Market Drivers and Challenges

Liquid Biofuels Market

Global Biofuels Market (Diesel Substitutes, Gasoline Substitutes)

SWOT Analysis

Comparison of Biofuel Costs by Type

Types (Solid, Liquid, Gaseous, Conventional, Advanced)

Feedstocks (First to Fourth Generation)

Hydrocarbon Biofuels (Biodiesel, Renewable Diesel, Bio-aviation Fuel, Bio-naphtha)

Alcohol Fuels (Biomethanol, Ethanol, Biobutanol)

Biomass-based Gas (Biomethane, Biosyngas, Biohydrogen)

Chemical Recycling for Biofuels

Electrofuels

Algae-derived Biofuels

Green Ammonia

Biofuels from Carbon Capture (CO2 Capture, Direct Air Capture, Carbon Utilization)

Bio-oils

Refuse Derived Fuels

Company Profiles

Sustainable Electronics

Overview

Green Electronics Manufacturing

Global Market (PCB Manufacturing, Sustainable PCBs, Sustainable ICs)

Company Profiles

Biobased Adhesives and Sealants

Overview

Types

Global Revenues (by Types, Market)

Company Profiles

Contents

1 RESEARCH METHODOLOGY

2 INTRODUCTION

2.1 Definition of Biobased and Sustainable Materials

2.2 Importance and Benefits of Biobased and Sustainable Materials

3 BIOBASED CHEMICALS AND INTERMEDIATES

3.1 BIOREFINERIES

3.2 BIO-BASED FEEDSTOCK AND LAND USE

3.3 PLANT-BASED

3.3.1 STARCH

3.3.1.1 Overview

3.3.1.2 Sources

3.3.1.3 Global production

3.3.1.4 Lysine

3.3.1.4.1 Source

3.3.1.4.2 Applications

3.3.1.4.3 Global production

3.3.1.5 Glucose

3.3.1.5.1 HMDA

3.3.1.5.1.1 Overview

3.3.1.5.1.2 Sources

3.3.1.5.1.3 Applications

3.3.1.5.1.4 Global production

3.3.1.5.2 1,5-diaminopentane (DA5)

3.3.1.5.2.1 Overview

3.3.1.5.2.2 Sources

3.3.1.5.2.3 Applications

3.3.1.5.2.4 Global production

3.3.1.5.3 Sorbitol

3.3.1.5.3.1 Isosorbide

3.3.1.5.3.1.1 Overview

3.3.1.5.3.1.2 Sources

3.3.1.5.3.1.3 Applications

3.3.1.5.3.1.4 Global production

- 3.3.1.5.4 Lactic acid
 - 3.3.1.5.4.1 Overview
 - 3.3.1.5.4.2 D-lactic acid
 - 3.3.1.5.4.3 L-lactic acid
 - 3.3.1.5.4.4 Lactide
- 3.3.1.5.5 Itaconic acid
 - 3.3.1.5.5.1 Overview
 - 3.3.1.5.5.2 Sources
 - 3.3.1.5.5.3 Applications
 - 3.3.1.5.5.4 Global production
- 3.3.1.5.6 3-HP
 - 3.3.1.5.6.1 Overview
 - 3.3.1.5.6.2 Sources
 - 3.3.1.5.6.3 Applications
 - 3.3.1.5.6.4 Global production
 - 3.3.1.5.6.5 Acrylic acid
 - 3.3.1.5.6.5.1 Overview
 - 3.3.1.5.6.5.2 Applications
 - 3.3.1.5.6.5.3 Global production
 - 3.3.1.5.6.6 1,3-Propanediol (1,3-PDO)
 - 3.3.1.5.6.6.1 Overview
 - 3.3.1.5.6.6.2 Applications
 - 3.3.1.5.6.6.3 Global production
- 3.3.1.5.7 Succinic Acid
 - 3.3.1.5.7.1 Overview
 - 3.3.1.5.7.2 Sources
 - 3.3.1.5.7.3 Applications
 - 3.3.1.5.7.4 Global production
 - 3.3.1.5.7.5 1,4-Butanediol (1,4-BDO)
 - 3.3.1.5.7.5.1 Overview
 - 3.3.1.5.7.5.2 Applications
 - 3.3.1.5.7.5.3 Global production
 - 3.3.1.5.7.6 Tetrahydrofuran (THF)
 - 3.3.1.5.7.6.1 Overview
 - 3.3.1.5.7.6.2 Applications
 - 3.3.1.5.7.6.3 Global production
- 3.3.1.5.8 Adipic acid
 - 3.3.1.5.8.1 Overview
 - 3.3.1.5.8.2 Applications

- 3.3.1.5.8.3 Caprolactame
 - 3.3.1.5.8.3.1 Overview
 - 3.3.1.5.8.3.2 Applications
 - 3.3.1.5.8.3.3 Global production
- 3.3.1.5.9 Isobutanol
 - 3.3.1.5.9.1 Overview
 - 3.3.1.5.9.2 Sources
 - 3.3.1.5.9.3 Applications
 - 3.3.1.5.9.4 Global production
 - 3.3.1.5.9.5 p-Xylene
 - 3.3.1.5.9.5.1 Overview
 - 3.3.1.5.9.5.2 Sources
 - 3.3.1.5.9.5.3 Applications
 - 3.3.1.5.9.5.4 Global production
 - 3.3.1.5.9.5.5 Terephthalic acid
 - 3.3.1.5.9.5.6 Overview
- 3.3.1.5.10 1,3 Propanediol
 - 3.3.1.5.10.1 Overview
 - 3.3.1.5.10.2 Sources
 - 3.3.1.5.10.3 Applications
 - 3.3.1.5.10.4 Global production
- 3.3.1.5.11 Monoethylene glycol (MEG)
 - 3.3.1.5.11.1 Overview
 - 3.3.1.5.11.2 Sources
 - 3.3.1.5.11.3 Applications
 - 3.3.1.5.11.4 Global production
- 3.3.1.5.12 Ethanol
 - 3.3.1.5.12.1 Overview
 - 3.3.1.5.12.2 Sources
 - 3.3.1.5.12.3 Applications
 - 3.3.1.5.12.4 Global production
 - 3.3.1.5.12.5 Ethylene
 - 3.3.1.5.12.5.1 Overview
 - 3.3.1.5.12.5.2 Applications
 - 3.3.1.5.12.5.3 Global production
 - 3.3.1.5.12.5.4 Propylene
 - 3.3.1.5.12.5.5 Vinyl chloride
 - 3.3.1.5.12.6 Methly methacrylate
- 3.3.2 SUGAR CROPS

3.3.2.1 Saccharose

3.3.2.1.1 Aniline

3.3.2.1.1.1 Overview

3.3.2.1.1.2 Applications

3.3.2.1.1.3 Global production

3.3.2.1.2 Fructose

3.3.2.1.2.1 Overview

3.3.2.1.2.2 Applications

3.3.2.1.2.3 Global production

3.3.2.1.2.4 5-Hydroxymethylfurfural (5-HMF)

3.3.2.1.2.4.1 Overview

3.3.2.1.2.4.2 Applications

3.3.2.1.2.4.3 Global production

3.3.2.1.2.5 5-Chloromethylfurfural (5-CMF)

3.3.2.1.2.5.1 Overview

3.3.2.1.2.5.2 Applications

3.3.2.1.2.5.3 Global production

3.3.2.1.2.6 Levulinic Acid

3.3.2.1.2.6.1 Overview

3.3.2.1.2.6.2 Applications

3.3.2.1.2.6.3 Global production

3.3.2.1.2.7 FDME

3.3.2.1.2.7.1 Overview

3.3.2.1.2.7.2 Applications

3.3.2.1.2.7.3 Global production

3.3.2.1.2.8 2,5-FDCA

3.3.2.1.2.8.1 Overview

3.3.2.1.2.8.2 Applications

3.3.2.1.2.8.3 Global production

3.3.3 LIGNOCELLULOSIC BIOMASS

3.3.3.1 Levoglucosenone

3.3.3.1.1 Overview

3.3.3.1.2 Applications

3.3.3.1.3 Global production

3.3.3.2 Hemicellulose

3.3.3.2.1 Overview

3.3.3.2.2 Biochemicals from hemicellulose

3.3.3.2.3 Global production

3.3.3.2.4 Furfural

- 3.3.3.2.4.1 Overview
- 3.3.3.2.4.2 Applications
- 3.3.3.2.4.3 Global production
- 3.3.3.2.4.4 Furfuyl alcohol
 - 3.3.3.2.4.4.1 Overview
 - 3.3.3.2.4.4.2 Applications
 - 3.3.3.2.4.4.3 Global production
- 3.3.3.3 Lignin
 - 3.3.3.3.1 Overview
 - 3.3.3.3.2 Sources
 - 3.3.3.3.3 Applications
 - 3.3.3.3.3.1 Aromatic compounds
 - 3.3.3.3.3.1.1 Benzene, toluene and xylene
 - 3.3.3.3.3.1.2 Phenol and phenolic resins
 - 3.3.3.3.3.1.3 Vanillin
 - 3.3.3.3.3.2 Polymers
 - 3.3.3.3.4 Global production
- 3.3.4 PLANT OILS
 - 3.3.4.1 Overview
 - 3.3.4.2 Glycerol
 - 3.3.4.2.1 Overview
 - 3.3.4.2.2 Applications
 - 3.3.4.2.3 Global production
 - 3.3.4.2.4 MPG
 - 3.3.4.2.4.1 Overview
 - 3.3.4.2.4.2 Applications
 - 3.3.4.2.4.3 Global production
 - 3.3.4.2.5 ECH
 - 3.3.4.2.5.1 Overview
 - 3.3.4.2.5.2 Applications
 - 3.3.4.2.5.3 Global production
 - 3.3.4.3 Fatty acids
 - 3.3.4.3.1 Overview
 - 3.3.4.3.2 Applications
 - 3.3.4.3.3 Global production
 - 3.3.4.4 Castor oil
 - 3.3.4.4.1 Overview
 - 3.3.4.4.2 Sebacic acid
 - 3.3.4.4.2.1 Overview

- 3.3.4.4.2.2 Applications
- 3.3.4.4.2.3 Global production
- 3.3.4.4.3 11-Aminoundecanoic acid (11-AA)
 - 3.3.4.4.3.1 Overview
 - 3.3.4.4.3.2 Applications
 - 3.3.4.4.3.3 Global production
- 3.3.4.5 Dodecanedioic acid (DDDA)
 - 3.3.4.5.1 Overview
 - 3.3.4.5.2 Applications
 - 3.3.4.5.3 Global production
- 3.3.4.6 Pentamethylene diisocyanate
 - 3.3.4.6.1 Overview
 - 3.3.4.6.2 Applications
 - 3.3.4.6.3 Global production
- 3.3.5 NON-EDIBLE MILK
 - 3.3.5.1 Casein
 - 3.3.5.1.1 Overview
 - 3.3.5.1.2 Applications
 - 3.3.5.1.3 Global production
- 3.4 WASTE
 - 3.4.1 Food waste
 - 3.4.1.1 Overview
 - 3.4.1.2 Products and applications
 - 3.4.1.2.1 Global production
 - 3.4.2 Agricultural waste
 - 3.4.2.1 Overview
 - 3.4.2.2 Products and applications
 - 3.4.2.3 Global production
 - 3.4.3 Forestry waste
 - 3.4.3.1 Overview
 - 3.4.3.2 Products and applications
 - 3.4.3.3 Global production
 - 3.4.4 Aquaculture/fishing waste
 - 3.4.4.1 Overview
 - 3.4.4.2 Products and applications
 - 3.4.4.3 Global production
 - 3.4.5 Municipal solid waste
 - 3.4.5.1 Overview
 - 3.4.5.2 Products and applications

3.4.5.3 Global production

3.4.6 Industrial waste

3.4.6.1 Overview

3.4.7 Waste oils

3.4.7.1 Overview

3.4.7.2 Products and applications

3.4.7.3 Global production

3.5 MICROBIAL & MINERAL SOURCES

3.5.1 Microalgae

3.5.1.1 Overview

3.5.1.2 Products and applications

3.5.1.3 Global production

3.5.2 Macroalgae

3.5.2.1 Overview

3.5.2.2 Products and applications

3.5.2.3 Global production

3.5.3 Mineral sources

3.5.3.1 Overview

3.5.3.2 Products and applications

3.6 GASEOUS

3.6.1 Biogas

3.6.1.1 Overview

3.6.1.2 Products and applications

3.6.1.3 Global production

3.6.2 Syngas

3.6.2.1 Overview

3.6.2.2 Products and applications

3.6.2.3 Global production

3.6.3 Off gases - fermentation CO₂, CO

3.6.3.1 Overview

3.6.3.2 Products and applications

3.7 COMPANY PROFILES 231 (115 company profiles)

4 BIOBASED POLYMERS AND PLASTICS

4.1 Overview

4.1.1 Drop-in bio-based plastics

4.1.2 Novel bio-based plastics

4.2 Biodegradable and compostable plastics

- 4.2.1 Biodegradability
- 4.2.2 Compostability
- 4.3 Types
- 4.4 Key market players
- 4.5 Synthetic biobased polymers
 - 4.5.1 Polylactic acid (Bio-PLA)
 - 4.5.1.1 Market analysis
 - 4.5.1.2 Production
 - 4.5.1.3 Producers and production capacities, current and planned
 - 4.5.1.3.1 Lactic acid producers and production capacities
 - 4.5.1.3.2 PLA producers and production capacities
 - 4.5.1.3.3 Polylactic acid (Bio-PLA) production 2019-2035 (1,000 tonnes)
 - 4.5.2 Polyethylene terephthalate (Bio-PET)
 - 4.5.2.1 Market analysis
 - 4.5.2.2 Producers and production capacities
 - 4.5.2.3 Polyethylene terephthalate (Bio-PET) production 2019-2035 (1,000 tonnes)
 - 4.5.3 Polytrimethylene terephthalate (Bio-PTT)
 - 4.5.3.1 Market analysis
 - 4.5.3.2 Producers and production capacities
 - 4.5.3.3 Polytrimethylene terephthalate (PTT) production 2019-2035 (1,000 tonnes)
 - 4.5.4 Polyethylene furanoate (Bio-PEF)
 - 4.5.4.1 Market analysis
 - 4.5.4.2 Comparative properties to PET
 - 4.5.4.3 Producers and production capacities
 - 4.5.4.3.1 FDCA and PEF producers and production capacities
 - 4.5.4.3.2 Polyethylene furanoate (Bio-PEF) production 2019-2035 (1,000 tonnes).
 - 4.5.5 Polyamides (Bio-PA)
 - 4.5.5.1 Market analysis
 - 4.5.5.2 Producers and production capacities
 - 4.5.5.3 Polyamides (Bio-PA) production 2019-2035 (1,000 tonnes)
 - 4.5.6 Poly(butylene adipate-co-terephthalate) (Bio-PBAT)
 - 4.5.6.1 Market analysis
 - 4.5.6.2 Producers and production capacities
 - 4.5.6.3 Poly(butylene adipate-co-terephthalate) (Bio-PBAT) production 2019-2035 (1,000 tonnes)
 - 4.5.7 Polybutylene succinate (PBS) and copolymers
 - 4.5.7.1 Market analysis
 - 4.5.7.2 Producers and production capacities
 - 4.5.7.3 Polybutylene succinate (PBS) production 2019-2035 (1,000 tonnes)

4.5.8 Polyethylene (Bio-PE)

4.5.8.1 Market analysis

4.5.8.2 Producers and production capacities

4.5.8.3 Polyethylene (Bio-PE) production 2019-2035 (1,000 tonnes).

4.5.9 Polypropylene (Bio-PP)

4.5.9.1 Market analysis

4.5.9.2 Producers and production capacities

4.5.9.3 Polypropylene (Bio-PP) production 2019-2035 (1,000 tonnes)

4.6 Natural biobased polymers

4.6.1 Polyhydroxyalkanoates (PHA)

4.6.1.1 Technology description

4.6.1.2 Types

4.6.1.2.1 PHB

4.6.1.2.2 PHBV

4.6.1.3 Synthesis and production processes

4.6.1.4 Market analysis

4.6.1.5 Commercially available PHAs

4.6.1.6 Markets for PHAs

4.6.1.6.1 Packaging

4.6.1.6.2 Cosmetics

4.6.1.6.2.1 PHA microspheres

4.6.1.6.3 Medical

4.6.1.6.3.1 Tissue engineering

4.6.1.6.3.2 Drug delivery

4.6.1.6.4 Agriculture

4.6.1.6.4.1 Mulch film

4.6.1.6.4.2 Grow bags

4.6.1.7 Producers and production capacities

4.6.1.8 PHA production capacities 2019-2035 (1,000 tonnes)

4.6.2 Cellulose

4.6.2.1 Microfibrillated cellulose (MFC)

4.6.2.1.1 Market analysis

4.6.2.1.2 Producers and production capacities

4.6.2.2 Nanocellulose

4.6.2.2.1 Cellulose nanocrystals

4.6.2.2.1.1 Synthesis

4.6.2.2.1.2 Properties

4.6.2.2.1.3 Production

4.6.2.2.1.4 Applications

- 4.6.2.2.1.5 Market analysis
- 4.6.2.2.1.6 Producers and production capacities
- 4.6.2.2.2 Cellulose nanofibers
 - 4.6.2.2.2.1 Applications
 - 4.6.2.2.2.2 Market analysis
 - 4.6.2.2.2.3 Producers and production capacities
- 4.6.2.2.3 Bacterial Nanocellulose (BNC)
 - 4.6.2.2.3.1 Production
 - 4.6.2.2.3.2 Applications
- 4.6.3 Protein-based bioplastics
 - 4.6.3.1 Types, applications and producers
- 4.6.4 Algal and fungal
 - 4.6.4.1 Algal
 - 4.6.4.1.1 Advantages
 - 4.6.4.1.2 Production
 - 4.6.4.1.3 Producers
 - 4.6.4.2 Mycelium
 - 4.6.4.2.1 Properties
 - 4.6.4.2.2 Applications
 - 4.6.4.2.3 Commercialization
- 4.6.5 Chitosan
 - 4.6.5.1 Technology description
- 4.7 Production by region
 - 4.7.1 North America
 - 4.7.2 Europe
 - 4.7.3 Asia-Pacific
 - 4.7.3.1 China
 - 4.7.3.2 Japan
 - 4.7.3.3 Thailand
 - 4.7.3.4 Indonesia
 - 4.7.4 Latin America
- 4.8 End use markets
 - 4.8.1 Packaging
 - 4.8.1.1 Processes for bioplastics in packaging
 - 4.8.1.2 Applications
 - 4.8.1.3 Flexible packaging
 - 4.8.1.3.1 Production volumes 2019-2035
 - 4.8.1.4 Rigid packaging
 - 4.8.1.4.1 Production volumes 2019-2035

- 4.8.2 Consumer products
 - 4.8.2.1 Applications
 - 4.8.2.2 Production volumes 2019-2035
- 4.8.3 Automotive
 - 4.8.3.1 Applications
 - 4.8.3.2 Production volumes 2019-2035
- 4.8.4 Construction
 - 4.8.4.1 Applications
 - 4.8.4.2 Production volumes 2019-2035
- 4.8.5 Textiles
 - 4.8.5.1 Apparel
 - 4.8.5.2 Footwear
 - 4.8.5.3 Medical textiles
 - 4.8.5.4 Production volumes 2019-2035
- 4.8.6 Electronics
 - 4.8.6.1 Applications
 - 4.8.6.2 Production volumes 2019-2035
- 4.8.7 Agriculture and horticulture
 - 4.8.7.1 Production volumes 2019-2035
- 4.9 Lignin
 - 4.9.1 Introduction
 - 4.9.1.1 What is lignin?
 - 4.9.1.1.1 Lignin structure
 - 4.9.1.2 Types of lignin
 - 4.9.1.2.1 Sulfur containing lignin
 - 4.9.1.2.2 Sulfur-free lignin from biorefinery process
 - 4.9.1.3 Properties
 - 4.9.1.4 The lignocellulose biorefinery
 - 4.9.1.5 Markets and applications
 - 4.9.1.6 Challenges for using lignin
 - 4.9.2 Lignin production processes
 - 4.9.2.1 Lignosulphonates
 - 4.9.2.2 Kraft Lignin
 - 4.9.2.2.1 LignoBoost process
 - 4.9.2.2.2 LignoForce method
 - 4.9.2.2.3 Sequential Liquid Lignin Recovery and Purification
 - 4.9.2.2.4 A-Recovery+
 - 4.9.2.3 Soda lignin
 - 4.9.2.4 Biorefinery lignin

4.9.2.4.1 Commercial and pre-commercial biorefinery lignin production facilities and processes

4.9.2.5 Organosolv lignins

4.9.2.6 Hydrolytic lignin

4.9.3 Markets for lignin

4.9.3.1 Market drivers and trends for lignin

4.9.3.2 Production capacities

4.9.3.2.1 Technical lignin availability (dry ton/y)

4.9.3.2.2 Biomass conversion (Biorefinery)

4.9.3.3 Estimated consumption of lignin

4.9.3.4 Prices

4.9.3.5 Heat and power energy

4.9.3.6 Pyrolysis and syngas

4.9.3.7 Aromatic compounds

4.9.3.7.1 Benzene, toluene and xylene

4.9.3.7.2 Phenol and phenolic resins

4.9.3.7.3 Vanillin

4.9.3.8 Plastics and polymers

4.10 COMPANY PROFILES 441 (516 company profiles)

5 NATURAL FIBER PLASTICS AND COMPOSITES

5.1 Introduction

5.1.1 What are natural fiber materials?

5.1.2 Benefits of natural fibers over synthetic

5.1.3 Markets and applications for natural fibers

5.1.4 Commercially available natural fiber products

5.1.5 Market drivers for natural fibers

5.1.6 Market challenges

5.1.7 Wood flour as a plastic filler

5.2 Types of natural fibers in plastic composites

5.2.1 Plants

5.2.1.1 Seed fibers

5.2.1.1.1 Kapok

5.2.1.1.2 Luffa

5.2.1.2 Bast fibers

5.2.1.2.1 Jute

5.2.1.2.2 Hemp

5.2.1.2.3 Flax

- 5.2.1.2.4 Ramie
- 5.2.1.2.5 Kenaf
- 5.2.1.3 Leaf fibers
 - 5.2.1.3.1 Sisal
 - 5.2.1.3.2 Abaca
- 5.2.1.4 Fruit fibers
 - 5.2.1.4.1 Coir
 - 5.2.1.4.2 Banana
 - 5.2.1.4.3 Pineapple
- 5.2.1.5 Stalk fibers from agricultural residues
 - 5.2.1.5.1 Rice fiber
 - 5.2.1.5.2 Corn
- 5.2.1.6 Cane, grasses and reed
 - 5.2.1.6.1 Switchgrass
 - 5.2.1.6.2 Sugarcane (agricultural residues)
 - 5.2.1.6.3 Bamboo
 - 5.2.1.6.4 Fresh grass (green biorefinery)
- 5.2.1.7 Modified natural polymers
 - 5.2.1.7.1 Mycelium
 - 5.2.1.7.2 Chitosan
 - 5.2.1.7.3 Alginate
- 5.2.2 Animal (fibrous protein)
 - 5.2.2.1 Silk fiber
- 5.2.3 Wood-based natural fibers
 - 5.2.3.1 Cellulose fibers
 - 5.2.3.1.1 Market overview
 - 5.2.3.1.2 Producers
 - 5.2.3.2 Microfibrillated cellulose (MFC)
 - 5.2.3.2.1 Market overview
 - 5.2.3.2.2 Producers
 - 5.2.3.3 Cellulose nanocrystals
 - 5.2.3.3.1 Market overview
 - 5.2.3.3.2 Producers
 - 5.2.3.4 Cellulose nanofibers
 - 5.2.3.4.1 Market overview
 - 5.2.3.4.2 Producers
- 5.3 Processing and Treatment of Natural Fibers
- 5.4 Interface and Compatibility of Natural Fibers with Plastic Matrices
 - 5.4.1 Adhesion and Bonding

- 5.4.2 Moisture Absorption and Dimensional Stability
- 5.4.3 Thermal Expansion and Compatibility
- 5.4.4 Dispersion and Distribution
- 5.4.5 Matrix Selection
- 5.4.6 Fiber Content and Alignment
- 5.4.7 Manufacturing Techniques
- 5.5 Manufacturing processes
 - 5.5.1 Injection molding
 - 5.5.2 Compression moulding
 - 5.5.3 Extrusion
 - 5.5.4 Thermoforming
 - 5.5.5 Thermoplastic pultrusion
 - 5.5.6 Additive manufacturing (3D printing)
- 5.6 Global market for natural fibers
 - 5.6.1 Automotive
 - 5.6.1.1 Applications
 - 5.6.1.2 Commercial production
 - 5.6.1.3 SWOT analysis
 - 5.6.2 Packaging
 - 5.6.2.1 Applications
 - 5.6.2.2 SWOT analysis
 - 5.6.3 Construction
 - 5.6.3.1 Applications
 - 5.6.3.2 SWOT analysis
 - 5.6.4 Appliances
 - 5.6.4.1 Applications
 - 5.6.4.2 SWOT analysis
 - 5.6.5 Consumer electronics
 - 5.6.5.1 Applications
 - 5.6.5.2 SWOT analysis
 - 5.6.6 Furniture
 - 5.6.6.1 Applications
 - 5.6.6.2 SWOT analysis
- 5.7 Competitive landscape
- 5.8 Future outlook
- 5.9 Revenues
 - 5.9.1 By end use market
 - 5.9.2 By Material Type
 - 5.9.3 By Plastic Type

5.9.4 By region

5.10 Company profiles 951 (67 company profiles)

6 SUSTAINABLE CONSTRUCTION MATERIALS 1029

6.1 Market overview 1029

6.1.1 Benefits of Sustainable Construction 1029

6.1.2 Global Trends and Drivers 1030

6.1.3 Global revenues 1030

6.1.3.1 By materials type 1031

6.1.3.2 By market 1031

6.2 Types 1032

6.2.1 Established bio-based construction materials 1032

6.2.2 Hemp-based Materials 1032

6.2.2.1 Hemp Concrete (Hempcrete) 1032

6.2.2.2 Hemp Fiberboard 1033

6.2.2.3 Hemp Insulation 1034

6.2.3 Mycelium-based Materials 1034

6.2.4 Sustainable Concrete and Cement Alternatives 1035

6.2.4.1 Self-healing concrete 1035

6.2.4.2 Bioconcrete 1037

6.2.4.3 Fibre concrete 1038

6.2.4.4 Microalgae biocement 1038

6.2.4.5 Carbon-negative concrete 1039

6.2.5 Natural Fiber Composites 1040

6.2.6 Sustainable Insulation Materials 1040

6.2.6.1 Cellulose Insulation 1040

6.2.6.1.1 Cellulose nanofibers 1040

6.2.6.1.1.1 Sandwich composites 1041

6.2.6.1.1.2 Cement additives 1041

6.2.6.1.1.3 Pump primers 1041

6.2.6.1.1.4 Thermal insulation and damping 1042

6.2.6.2 Aerogel Insulation 1042

6.2.6.2.1 Silica aerogels 1045

6.2.6.2.1.1 Properties 1046

6.2.6.2.1.2 Thermal conductivity 1046

6.2.6.2.1.3 Mechanical 1047

6.2.6.2.1.4 Silica aerogel precursors 1047

6.2.6.2.1.5 Products 1047

- 6.2.6.2.1.5.1 Monoliths 1047
- 6.2.6.2.1.5.2 Powder 1048
- 6.2.6.2.1.5.3 Granules 1049
- 6.2.6.2.1.5.4 Blankets 1050
- 6.2.6.2.1.5.5 Aerogel boards 1051
- 6.2.6.2.1.5.6 Aerogel renders 1052
- 6.2.6.2.1.6 3D printing of aerogels 1053
- 6.2.6.2.1.7 Silica aerogel from sustainable feedstocks 1053
- 6.2.6.2.1.8 Silica composite aerogels 1054
 - 6.2.6.2.1.8.1 Organic crosslinkers 1054
- 6.2.6.2.1.9 Cost of silica aerogels 1055
- 6.2.6.2.1.10 Main players 1056
- 6.2.6.2.2 Aerogel-like foam materials 1057
 - 6.2.6.2.2.1 Properties 1057
 - 6.2.6.2.2.2 Applications 1057
- 6.2.6.2.3 Metal oxide aerogels 1058
- 6.2.6.2.4 Organic aerogels 1059
 - 6.2.6.2.4.1 Polymer aerogels 1059
- 6.2.6.2.5 Biobased and sustainable aerogels (bio-aerogels) 1061
- 6.2.6.2.6 Cellulose aerogels 1062
 - 6.2.6.2.6.1 Cellulose nanofiber (CNF) aerogels 1063
 - 6.2.6.2.6.2 Cellulose nanocrystal aerogels 1064
 - 6.2.6.2.6.3 Bacterial nanocellulose aerogels 1064
- 6.2.6.3 Lignin aerogels 1064
- 6.2.6.4 Alginate aerogels 1065
- 6.2.6.5 Starch aerogels 1065
- 6.2.6.6 Chitosan aerogels 1066
- 6.2.6.7 Protein aerogels 1067
 - 6.2.6.7.1 Albumin aerogels 1067
 - 6.2.6.7.2 Casein aerogels 1067
 - 6.2.6.7.3 Gelatin aerogels 1067
- 6.2.6.8 Silk fiber 1067
 - 6.2.6.8.1 Carbon aerogels 1069
 - 6.2.6.8.2 Carbon nanotube aerogels 1071
 - 6.2.6.8.3 Graphene and graphite aerogels 1071
 - 6.2.6.8.4 Additive manufacturing (3D printing) 1072
- 6.2.6.9 Graphene oxide 1073
- 6.2.6.10 Carbon nitride 1073
- 6.2.6.11 Gold 1074

6.2.6.12 Cellulose	1074
6.2.6.12.1 Hybrid aerogels	1075
6.2.7 Carbon capture and utilization	1075
6.2.7.1 Overview	1076
6.2.7.2 Market structure	1078
6.2.7.3 CCUS technologies in the cement industry	1081
6.2.7.4 Products	1083
6.2.7.4.1 Carbonated aggregates	1083
6.2.7.4.2 Additives during mixing	1085
6.2.7.4.3 Carbonates from natural minerals	1086
6.2.7.4.4 Carbonates from waste	1087
6.2.7.5 Concrete curing	1088
6.2.7.6 Costs	1089
6.2.7.7 Challenges	1089
6.2.8 Green steel	1090
6.2.9 Current Steelmaking processes	1090
6.2.10 Decarbonization target and policies	1094
6.2.10.1 EU Carbon Border Adjustment Mechanism (CBAM)	1096
6.2.11 Advances in clean production technologies	1097
6.2.12 Production technologies	1097
6.2.12.1 The role of hydrogen	1097
6.2.12.2 Comparative analysis	1099
6.2.12.3 Hydrogen Direct Reduced Iron (DRI)	1100
6.2.12.4 Electrolysis	1102
6.2.12.5 Carbon Capture, Utilization and Storage (CCUS)	1103
6.2.12.6 Biochar replacing coke	1105
6.2.12.7 Hydrogen Blast Furnace	1106
6.2.12.8 Renewable energy powered processes	1108
6.2.12.9 Flash ironmaking	1108
6.2.12.10 Hydrogen Plasma Iron Ore Reduction	1110
6.2.12.11 Ferrous Bioprocessing	1111
6.2.12.12 Microwave Processing	1112
6.2.12.13 Additive Manufacturing	1112
6.2.12.14 Technology readiness level (TRL)	1113
6.2.13 Properties	1114
6.3 Markets and applications	1116
6.3.1 Residential Buildings	1116
6.3.2 Commercial and Office Buildings	1116
6.3.3 Infrastructure	1116

6.4 Company profiles 1118 (112 company profiles)

7 BIOBASED PACKAGING MATERIALS 1229

7.1 Market overview 1229

7.1.1 Current global packaging market and materials 1229

7.1.2 Market trends 1230

7.1.3 Drivers for recent growth in bioplastics in packaging 1232

7.1.4 Challenges for bio-based and sustainable packaging 1232

7.2 Materials 1234

7.2.1 Materials innovation 1234

7.2.2 Active packaging 1234

7.2.3 Monomaterial packaging 1235

7.2.4 Conventional polymer materials used in packaging 1235

7.2.4.1 Polyolefins: Polypropylene and polyethylene 1236

7.2.4.2 PET and other polyester polymers 1239

7.2.4.3 Renewable and bio-based polymers for packaging 1239

7.2.4.4 Comparison of synthetic fossil-based and bio-based polymers 1241

7.2.4.5 Processes for bioplastics in packaging 1242

7.2.4.6 End-of-life treatment of bio-based and sustainable packaging 1243

7.3 Synthetic bio-based packaging materials 1244

7.3.1 Polylactic acid (Bio-PLA) 1244

7.3.1.1 Market analysis 1245

7.3.1.2 Producers and production capacities, current and planned 1246

7.3.1.2.1 Lactic acid producers and production capacities 1247

7.3.1.2.2 LA producers and production capacities 1247

7.3.2 Polyethylene terephthalate (Bio-PET) 1249

7.3.2.1 Market analysis 1249

7.3.2.2 Producers and production capacities 1250

7.3.3 Polytrimethylene terephthalate (Bio-PTT) 1250

7.3.3.1 Market analysis 1251

7.3.3.2 Producers and production capacities 1251

7.3.4 Polyethylene furanoate (Bio-PEF) 1251

7.3.4.1 Market analysis 1252

7.3.4.2 Comparative properties to PET 1253

7.3.4.3 Producers and production capacities 1254

7.3.4.3.1 FDCA and PEF producers and production capacities 1254

7.3.5 Polyamides (Bio-PA) 1255

7.3.5.1 Market analysis 1255

- 7.3.5.2 Producers and production capacities 1256
- 7.3.6 Poly(butylene adipate-co-terephthalate) (Bio-PBAT)- Aliphatic aromatic copolyesters 1256
 - 7.3.6.1 Market analysis 1257
 - 7.3.6.2 Producers and production capacities 1257
- 7.3.7 Polybutylene succinate (PBS) and copolymers 1258
 - 7.3.7.1 Market analysis 1259
 - 7.3.7.2 Producers and production capacities 1259
- 7.3.8 Polyethylene furanoate (Bio-PEF) 1260
 - 7.3.8.1 Market analysis 1260
 - 7.3.8.2 Comparative properties to PET 1262
 - 7.3.8.3 Producers and production capacities 1262
 - 7.3.8.3.1 FDCA and PEF producers and production capacities 1262
 - 7.3.8.3.2 Polyethylene furanoate (Bio-PEF) production capacities 2019-2035 (1,000 tons). 1263
- 7.3.9 Polyethylene (Bio-PE) 1264
 - 7.3.9.1 Market analysis 1265
 - 7.3.9.2 Producers and production capacities 1266
- 7.3.10 Polypropylene (Bio-PP) 1266
 - 7.3.10.1 Market analysis 1266
 - 7.3.10.2 Producers and production capacities 1267
- 7.4 Natural bio-based packaging materials 1268
 - 7.4.1 Polyhydroxyalkanoates (PHA) 1268
 - 7.4.1.1 Technology description 1268
 - 7.4.1.2 Types 1270
 - 7.4.1.2.1 PHB 1272
 - 7.4.1.2.2 PHBV 1273
 - 7.4.1.3 Synthesis and production processes 1274
 - 7.4.1.4 Market analysis 1277
 - 7.4.1.5 Commercially available PHAs 1279
 - 7.4.1.6 PHAs in packaging 1280
 - 7.4.1.7 PHA production capacities 2019-2035 (1,000 tons) 1284
 - 7.4.2 Starch-based blends 1285
 - 7.4.2.1 Properties 1285
 - 7.4.2.2 Applications in packaging 1285
 - 7.4.3 Cellulose 1285
 - 7.4.3.1 Feedstocks 1287
 - 7.4.3.1.1 Wood 1288
 - 7.4.3.1.2 Plant 1288

- 7.4.3.1.3 Tunicate 1289
- 7.4.3.1.4 Algae 1289
- 7.4.3.1.5 Bacteria 1290
- 7.4.3.2 Microfibrillated cellulose (MFC) 1291
 - 7.4.3.2.1 Properties 1291
- 7.4.3.3 Nanocellulose 1292
 - 7.4.3.3.1 Cellulose nanocrystals 1292
 - 7.4.3.3.1.1 Applications in packaging 1292
 - 7.4.3.3.2 Cellulose nanofibers 1294
 - 7.4.3.3.2.1 Applications in packaging 1295
 - 7.4.3.3.2.1.1 Reinforcement and barrier 1300
 - 7.4.3.3.2.1.2 Biodegradable food packaging foil and films 1300
 - 7.4.3.3.2.1.3 Paperboard coatings 1301
 - 7.4.3.3.3 Bacterial Nanocellulose (BNC) 1301
 - 7.4.3.3.3.1 Applications in packaging 1304
- 7.4.4 Protein-based bioplastics in packaging 1305
- 7.4.5 Lipids and waxes for packaging 1308
- 7.4.6 Seaweed-based packaging 1308
 - 7.4.6.1 Production 1310
 - 7.4.6.2 Applications in packaging 1310
 - 7.4.6.3 Producers 1311
- 7.4.7 Mycelium 1311
 - 7.4.7.1 Applications in packaging 1312
- 7.4.8 Chitosan 1314
 - 7.4.8.1 Applications in packaging 1315
- 7.4.9 Bio-naphtha 1315
 - 7.4.9.1 Overview 1315
 - 7.4.9.2 Markets and applications 1316
- 7.5 Applications 1318
 - 7.5.1 Paper and board packaging 1318
 - 7.5.2 Food packaging 1319
 - 7.5.2.1 Bio-Based films and trays 1319
 - 7.5.2.2 Bio-Based pouches and bags 1320
 - 7.5.2.3 Bio-Based textiles and nets 1320
 - 7.5.2.4 Bioadhesives 1321
 - 7.5.2.4.1 Starch 1322
 - 7.5.2.4.2 Cellulose 1322
 - 7.5.2.4.3 Protein-Based 1322
 - 7.5.2.5 Barrier coatings and films 1323

- 7.5.2.5.1 Polysaccharides 1324
 - 7.5.2.5.1.1 Chitin 1324
 - 7.5.2.5.1.2 Chitosan 1324
 - 7.5.2.5.1.3 Starch 1325
- 7.5.2.5.2 Poly(lactic acid) (PLA) 1325
- 7.5.2.5.3 Poly(butylene Succinate) 1325
- 7.5.2.5.4 Functional Lipid and Proteins Based Coatings 1325
- 7.5.2.6 Active and Smart Food Packaging 1325
 - 7.5.2.6.1 Active Materials and Packaging Systems 1325
 - 7.5.2.6.2 Intelligent and Smart Food Packaging 1327
- 7.5.2.7 Antimicrobial films and agents 1328
 - 7.5.2.7.1 Natural 1329
 - 7.5.2.7.2 Inorganic nanoparticles 1330
 - 7.5.2.7.3 Biopolymers 1330
- 7.5.2.8 Bio-based Inks and Dyes 1331
- 7.5.2.9 Edible films and coatings 1331
- 7.6 Biobased films and coatings in packaging 1333
 - 7.6.1 Challenges using bio-based paints and coatings 1334
 - 7.6.2 Types of bio-based coatings and films in packaging 1337
 - 7.6.2.1 Polyurethane coatings 1337
 - 7.6.2.1.1 Properties 1337
 - 7.6.2.1.2 Bio-based polyurethane coatings 1337
 - 7.6.2.1.3 Products 1339
 - 7.6.2.2 Acrylate resins 1339
 - 7.6.2.2.1 Properties 1340
 - 7.6.2.2.2 Bio-based acrylates 1340
 - 7.6.2.2.3 Products 1340
 - 7.6.2.3 Polylactic acid (Bio-PLA) 1341
 - 7.6.2.3.1 Properties 1343
 - 7.6.2.3.2 Bio-PLA coatings and films 1343
 - 7.6.2.4 Polyhydroxyalkanoates (PHA) coatings 1344
 - 7.6.2.5 Cellulose coatings and films 1345
 - 7.6.2.5.1 Microfibrillated cellulose (MFC) 1345
 - 7.6.2.5.2 Cellulose nanofibers 1346
 - 7.6.2.5.2.1 Properties 1346
 - 7.6.2.5.2.2 Product developers 1348
 - 7.6.2.6 Lignin coatings 1350
 - 7.6.2.7 Protein-based biomaterials for coatings 1351
 - 7.6.2.7.1 Plant derived proteins 1351

- 7.6.2.7.2 Animal origin proteins 1351
- 7.7 Carbon capture derived materials for packaging 1354
 - 7.7.1 Benefits of carbon utilization for plastics feedstocks 1355
 - 7.7.2 CO₂-derived polymers and plastics 1357
 - 7.7.3 CO₂ utilization products 1358
- 7.8 Global biobased packaging markets 1360
 - 7.8.1 Flexible packaging 1360
 - 7.8.2 Rigid packaging 1364
 - 7.8.3 Coatings and films 1367
- 7.9 Company profiles 1368 (220 company profiles)

8 SUSTAINABLE TEXTILES AND APPAREL 1554

- 8.1 Types of bio-based fibres 1554
 - 8.1.1 Natural fibres 1554
 - 8.1.2 Man-made bio-based fibres 1556
- 8.2 Natural fibres 1557
- 8.3 Man-made cellulosic fibres 1559
- 8.4 Bio-based synthetics 1561
- 8.5 Recyclability of bio-based fibres 1562
- 8.6 Bio-based leather 1564
 - 8.6.1 Properties of bio-based leathers 1567
 - 8.6.1.1 Tear strength. 1568
 - 8.6.1.2 Tensile strength 1568
 - 8.6.1.3 Bally flexing 1569
 - 8.6.2 Comparison with conventional leathers 1569
 - 8.6.3 Comparative analysis of bio-based leathers 1573
 - 8.6.4 Plant-based leather 1573
 - 8.6.4.1 Overview 1573
 - 8.6.4.2 Production processes 1574
 - 8.6.4.2.1 Feedstocks 1575
 - 8.6.4.2.1.1 Agriculture Residues 1575
 - 8.6.4.2.1.2 Food Processing Waste 1575
 - 8.6.4.2.1.3 Invasive Plants 1575
 - 8.6.4.2.1.4 Culture-Grown Inputs 1575
 - 8.6.4.2.2 Textile-Based 1575
 - 8.6.4.2.3 Bio-Composite 1576
 - 8.6.4.3 Products 1577
 - 8.6.4.4 Market players 1578

8.6.5 Mycelium leather	1580
8.6.5.1 Overview	1580
8.6.5.2 Production process	1583
8.6.5.2.1 Growth conditions	1583
8.6.5.2.2 Tanning Mycelium Leather	1584
8.6.5.2.3 Dyeing Mycelium Leather	1584
8.6.5.3 Products	1585
8.6.5.4 Market players	1585
8.6.6 Microbial leather	1586
8.6.6.1 Overview	1586
8.6.6.2 Production process	1586
8.6.6.3 Fermentation conditions	1587
8.6.6.4 Harvesting	1588
8.6.6.5 Products	1589
8.6.6.6 Market players	1592
8.6.7 Lab grown leather	1592
8.6.7.1 Overview	1593
8.6.7.2 Production process	1593
8.6.7.3 Products	1594
8.6.7.4 Market players	1594
8.6.8 Protein-based leather	1595
8.6.8.1 Overview	1595
8.6.8.2 Production process	1596
8.6.8.3 Commercial activity	1596
8.6.9 Sustainable textiles coatings and dyes	1597
8.6.9.1 Overview	1597
8.6.9.1.1 Coatings	1598
8.6.9.1.2 Dyes	1598
8.6.9.2 Commercial activity	1599
8.7 Markets	1601
8.7.1 Footwear	1601
8.7.2 Fashion & Accessories	1602
8.7.3 Automotive & Transport	1603
8.7.4 Furniture	1604
8.8 Global market revenues	1606
8.8.1 By region	1606
8.8.2 By end use market	1609
8.9 Company profiles	1611 (71 company profiles)

9 BIOBASED COATINGS AND RESINS 1670

- 9.1 Drop-in replacements 1671
- 9.2 Bio-based resins 1671
- 9.3 Reducing carbon footprint in industrial and protective coatings 1672
- 9.4 Market drivers 1672
- 9.5 Challenges using bio-based coatings 1673
- 9.6 Types 1674
 - 9.6.1 Eco-friendly coatings technologies 1674
 - 9.6.1.1 UV-cure 1675
 - 9.6.1.2 Waterborne coatings 1676
 - 9.6.1.3 Treatments with less or no solvents 1676
 - 9.6.1.4 Hyperbranched polymers for coatings 1676
 - 9.6.1.5 Powder coatings 1677
 - 9.6.1.6 High solid (HS) coatings 1678
 - 9.6.1.7 Use of bio-based materials in coatings 1678
 - 9.6.1.7.1 Biopolymers 1678
 - 9.6.1.7.2 Coatings based on agricultural waste 1679
 - 9.6.1.7.3 Vegetable oils and fatty acids 1679
 - 9.6.1.7.4 Proteins 1680
 - 9.6.1.7.5 Cellulose 1680
 - 9.6.1.7.6 Plant-Based wax coatings 1681
 - 9.6.2 Barrier coatings 1683
 - 9.6.2.1 Polysaccharides 1684
 - 9.6.2.1.1 Chitin 1685
 - 9.6.2.1.2 Chitosan 1685
 - 9.6.2.1.3 Starch 1685
 - 9.6.2.2 Poly(lactic acid) (PLA) 1685
 - 9.6.2.3 Poly(butylene Succinate 1686
 - 9.6.2.4 Functional Lipid and Proteins Based Coatings 1686
 - 9.6.3 Alkyd coatings 1687
 - 9.6.3.1 Alkyd resin properties 1687
 - 9.6.3.2 Bio-based alkyd coatings 1688
 - 9.6.3.3 Products 1689
 - 9.6.4 Polyurethane coatings 1691
 - 9.6.4.1 Properties 1691
 - 9.6.4.2 Bio-based polyurethane coatings 1692
 - 9.6.4.2.1 Bio-based polyols 1692
 - 9.6.4.2.2 Non-isocyanate polyurethane (NIPU) 1693

- 9.6.4.3 Products 1693
- 9.6.5 Epoxy coatings 1694
 - 9.6.5.1 Properties 1694
 - 9.6.5.2 Bio-based epoxy coatings 1695
 - 9.6.5.3 Products 1697
- 9.6.6 Acrylate resins 1697
 - 9.6.6.1 Properties 1698
 - 9.6.6.2 Bio-based acrylates 1698
 - 9.6.6.3 Products 1698
- 9.6.7 Polylactic acid (Bio-PLA) 1699
 - 9.6.7.1 Properties 1701
 - 9.6.7.2 Bio-PLA coatings and films 1702
- 9.6.8 Polyhydroxyalkanoates (PHA) 1702
 - 9.6.8.1 Properties 1704
 - 9.6.8.2 PHA coatings 1707
 - 9.6.8.3 Commercially available PHAs 1707
- 9.6.9 Cellulose 1710
 - 9.6.9.1 Microfibrillated cellulose (MFC) 1716
 - 9.6.9.1.1 Properties 1716
 - 9.6.9.1.2 Applications in coatings 1718
 - 9.6.9.2 Cellulose nanofibers 1719
 - 9.6.9.2.1 Properties 1719
 - 9.6.9.2.2 Applications in coatings 1721
 - 9.6.9.3 Cellulose nanocrystals 1725
 - 9.6.9.4 Bacterial Nanocellulose (BNC) 1727
- 9.6.10 Rosins 1728
- 9.6.11 Bio-based carbon black 1728
 - 9.6.11.1 Lignin-based 1728
 - 9.6.11.2 Algae-based 1729
- 9.6.12 Lignin coatings 1729
- 9.6.13 Edible films and coatings 1730
- 9.6.14 Antimicrobial films and agents 1732
 - 9.6.14.1 Natural 1733
 - 9.6.14.2 Inorganic nanoparticles 1734
 - 9.6.14.3 Biopolymers 1734
- 9.6.15 Nanocoatings 1735
- 9.6.16 Protein-based biomaterials for coatings 1736
 - 9.6.16.1 Plant derived proteins 1736
 - 9.6.16.2 Animal origin proteins 1737

- 9.6.17 Algal coatings 1738
- 9.6.18 Polypeptides 1741
- 9.7 Global revenues 1743
 - 9.7.1 By types 1743
 - 9.7.2 By market 1744
- 9.8 Company profiles 1747 (167 company profiles)

10 BIOFUELS 1903

- 10.1 Comparison to fossil fuels 1903
- 10.2 Role in the circular economy 1904
- 10.3 Market drivers 1904
- 10.4 Market challenges 1905
- 10.5 Liquid biofuels market 1906
 - 10.5.1 Liquid biofuel production and consumption (in thousands of m3), 2000-2022 1906
 - 10.5.2 Liquid biofuels market 2020-2035, by type and production. 1907
- 10.6 The global biofuels market 1911
 - 10.6.1 Diesel substitutes and alternatives 1912
 - 10.6.2 Gasoline substitutes and alternatives 1913
- 10.7 SWOT analysis: Biofuels market 1914
- 10.8 Comparison of biofuel costs 2023, by type 1915
- 10.9 Types 1916
 - 10.9.1 Solid Biofuels 1916
 - 10.9.2 Liquid Biofuels 1917
 - 10.9.3 Gaseous Biofuels 1917
 - 10.9.4 Conventional Biofuels 1918
 - 10.9.5 Advanced Biofuels 1919
- 10.10 Feedstocks 1921
 - 10.10.1 First-generation (1-G) 1923
 - 10.10.2 Second-generation (2-G) 1924
 - 10.10.2.1 Lignocellulosic wastes and residues 1925
 - 10.10.2.2 Biorefinery lignin 1926
 - 10.10.3 Third-generation (3-G) 1930
 - 10.10.3.1 Algal biofuels 1930
 - 10.10.3.1.1 Properties 1931
 - 10.10.3.1.2 Advantages 1932
 - 10.10.4 Fourth-generation (4-G) 1933
 - 10.10.5 Advantages and disadvantages, by generation 1933

- 10.10.6 Energy crops 1935
 - 10.10.6.1 Feedstocks 1935
 - 10.10.6.2 SWOT analysis 1936
- 10.10.7 Agricultural residues 1937
 - 10.10.7.1 Feedstocks 1937
 - 10.10.7.2 SWOT analysis 1937
- 10.10.8 Manure, sewage sludge and organic waste 1939
 - 10.10.8.1 Processing pathways 1939
 - 10.10.8.2 SWOT analysis 1939
- 10.10.9 Forestry and wood waste 1940
 - 10.10.9.1 Feedstocks 1940
 - 10.10.9.2 SWOT analysis 1941
- 10.10.10 Feedstock costs 1942
- 10.11 Hydrocarbon biofuels 1943
 - 10.11.1 Biodiesel 1943
 - 10.11.1.1 Biodiesel by generation 1945
 - 10.11.1.2 SWOT analysis 1946
 - 10.11.1.3 Production of biodiesel and other biofuels 1947
 - 10.11.1.3.1 Pyrolysis of biomass 1948
 - 10.11.1.3.2 Vegetable oil transesterification 1951
 - 10.11.1.3.3 Vegetable oil hydrogenation (HVO) 1952
 - 10.11.1.3.3.1 Production process 1953
 - 10.11.1.3.4 Biodiesel from tall oil 1954
 - 10.11.1.3.5 Fischer-Tropsch BioDiesel 1954
 - 10.11.1.3.6 Hydrothermal liquefaction of biomass 1956
 - 10.11.1.3.7 CO₂ capture and Fischer-Tropsch (FT) 1957
 - 10.11.1.3.8 Dimethyl ether (DME) 1957
 - 10.11.1.4 Prices 1958
 - 10.11.1.5 Global production and consumption 1959
 - 10.11.2 Renewable diesel 1962
 - 10.11.2.1 Production 1962
 - 10.11.2.2 SWOT analysis 1963
 - 10.11.2.3 Global consumption 1964
 - 10.11.2.4 Prices 1966
 - 10.11.3 Bio-aviation fuel (bio-jet fuel, sustainable aviation fuel, renewable jet fuel or aviation biofuel) 1967
 - 10.11.3.1 Description 1967
 - 10.11.3.2 SWOT analysis 1967
 - 10.11.3.3 Global production and consumption 1968

- 10.11.3.4 Production pathways 1969
- 10.11.3.5 Prices 1971
- 10.11.3.6 Bio-aviation fuel production capacities 1972
- 10.11.3.7 Market challenges 1972
- 10.11.3.8 Global consumption 1973
- 10.11.4 Bio-naphtha 1975
 - 10.11.4.1 Overview 1975
 - 10.11.4.2 SWOT analysis 1976
 - 10.11.4.3 Markets and applications 1977
 - 10.11.4.4 Prices 1979
 - 10.11.4.5 Production capacities, by producer, current and planned 1979
 - 10.11.4.6 Production capacities, total (tonnes), historical, current and planned 1980
- 10.12 Alcohol fuels 1981
 - 10.12.1 Biomethanol 1981
 - 10.12.1.1 SWOT analysis 1982
 - 10.12.1.2 Methanol-to gasoline technology 1982
 - 10.12.1.2.1 Production processes 1984
 - 10.12.1.2.1.1 Anaerobic digestion 1984
 - 10.12.1.2.1.2 Biomass gasification 1985
 - 10.12.1.2.1.3 Power to Methane 1986
 - 10.12.2 Ethanol 1986
 - 10.12.2.1 Technology description 1986
 - 10.12.2.2 1G Bio-Ethanol 1987
 - 10.12.2.3 SWOT analysis 1988
 - 10.12.2.4 Ethanol to jet fuel technology 1989
 - 10.12.2.5 Methanol from pulp & paper production 1989
 - 10.12.2.6 Sulfite spent liquor fermentation 1990
 - 10.12.2.7 Gasification 1990
 - 10.12.2.7.1 Biomass gasification and syngas fermentation 1990
 - 10.12.2.7.2 Biomass gasification and syngas thermochemical conversion 1991
 - 10.12.2.8 CO₂ capture and alcohol synthesis 1991
 - 10.12.2.9 Biomass hydrolysis and fermentation 1992
 - 10.12.2.9.1 Separate hydrolysis and fermentation 1992
 - 10.12.2.9.2 Simultaneous saccharification and fermentation (SSF) 1993
 - 10.12.2.9.3 Pre-hydrolysis and simultaneous saccharification and fermentation (PSSF) 1993
 - 10.12.2.9.4 Simultaneous saccharification and co-fermentation (SSCF) 1993
 - 10.12.2.9.5 Direct conversion (consolidated bioprocessing) (CBP) 1993
 - 10.12.2.10 Global ethanol consumption 1994

- 10.12.3 Biobutanol 1996
 - 10.12.3.1 Production 1998
 - 10.12.3.2 Prices 1998
- 10.13 Biomass-based Gas 1999
 - 10.13.1 Feedstocks 2001
 - 10.13.1.1 Biomethane 2001
 - 10.13.1.2 Production pathways 2003
 - 10.13.1.2.1 Landfill gas recovery 2003
 - 10.13.1.2.2 Anaerobic digestion 2004
 - 10.13.1.2.3 Thermal gasification 2005
 - 10.13.1.3 SWOT analysis 2006
 - 10.13.1.4 Global production 2007
 - 10.13.1.5 Prices 2007
 - 10.13.1.5.1 Raw Biogas 2007
 - 10.13.1.5.2 Upgraded Biomethane 2007
 - 10.13.1.6 Bio-LNG 2008
 - 10.13.1.6.1 Markets 2008
 - 10.13.1.6.1.1 Trucks 2008
 - 10.13.1.6.1.2 Marine 2008
 - 10.13.1.6.2 Production 2008
 - 10.13.1.6.3 Plants 2009
 - 10.13.1.7 bio-CNG (compressed natural gas derived from biogas) 2009
 - 10.13.1.8 Carbon capture from biogas 2010
 - 10.13.2 Biosyngas 2011
 - 10.13.2.1 Production 2011
 - 10.13.2.2 Prices 2012
 - 10.13.3 Biohydrogen 2012
 - 10.13.3.1 Description 2012
 - 10.13.3.2 SWOT analysis 2013
 - 10.13.3.3 Production of biohydrogen from biomass 2014
 - 10.13.3.3.1 Biological Conversion Routes 2015
 - 10.13.3.3.1.1 Bio-photochemical Reaction 2015
 - 10.13.3.3.1.2 Fermentation and Anaerobic Digestion 2015
 - 10.13.3.3.2 Thermochemical conversion routes 2016
 - 10.13.3.3.2.1 Biomass Gasification 2016
 - 10.13.3.3.2.2 Biomass Pyrolysis 2016
 - 10.13.3.3.2.3 Biomethane Reforming 2017
 - 10.13.3.4 Applications 2017
 - 10.13.3.5 Prices 2018

- 10.13.4 Biochar in biogas production 2018
- 10.13.5 Bio-DME 2019
- 10.14 Chemical recycling for biofuels 2019
 - 10.14.1 Plastic pyrolysis 2019
 - 10.14.2 Used tires pyrolysis 2020
 - 10.14.2.1 Conversion to biofuel 2022
 - 10.14.3 Co-pyrolysis of biomass and plastic wastes 2023
 - 10.14.4 Gasification 2024
 - 10.14.4.1 Syngas conversion to methanol 2025
 - 10.14.4.2 Biomass gasification and syngas fermentation 2029
 - 10.14.4.3 Biomass gasification and syngas thermochemical conversion 2029
 - 10.14.5 Hydrothermal cracking 2030
 - 10.14.6 SWOT analysis 2031
- 10.15 Electrofuels (E-fuels, power-to-gas/liquids/fuels) 2032
 - 10.15.1 Introduction 2032
 - 10.15.2 Benefits of e-fuels 2034
 - 10.15.3 Feedstocks 2035
 - 10.15.3.1 Hydrogen electrolysis 2035
 - 10.15.3.2 CO2 capture 2036
 - 10.15.4 SWOT analysis 2036
 - 10.15.5 Production 2037
 - 10.15.5.1 eFuel production facilities, current and planned 2040
 - 10.15.6 Electrolysers 2041
 - 10.15.6.1 Commercial alkaline electrolyser cells (AECs) 2042
 - 10.15.6.2 PEM electrolyzers (PEMEC) 2042
 - 10.15.6.3 High-temperature solid oxide electrolyser cells (SOECs) 2043
 - 10.15.7 Prices 2043
 - 10.15.8 Market challenges 2046
 - 10.15.9 Companies 2047
- 10.16 Algae-derived biofuels 2048
 - 10.16.1 Technology description 2048
 - 10.16.2 Conversion pathways 2048
 - 10.16.3 SWOT analysis 2049
 - 10.16.4 Production 2050
 - 10.16.5 Market challenges 2051
 - 10.16.6 Prices 2052
 - 10.16.7 Producers 2053
- 10.17 Green Ammonia 2053
 - 10.17.1 Production 2053

- 10.17.1.1 Decarbonisation of ammonia production 2055
- 10.17.1.2 Green ammonia projects 2056
- 10.17.2 Green ammonia synthesis methods 2056
 - 10.17.2.1 Haber-Bosch process 2056
 - 10.17.2.2 Biological nitrogen fixation 2057
 - 10.17.2.3 Electrochemical production 2058
 - 10.17.2.4 Chemical looping processes 2058
- 10.17.3 SWOT analysis 2058
- 10.17.4 Blue ammonia 2059
 - 10.17.4.1 Blue ammonia projects 2059
- 10.17.5 Markets and applications 2060
 - 10.17.5.1 Chemical energy storage 2060
 - 10.17.5.1.1 Ammonia fuel cells 2060
 - 10.17.5.2 Marine fuel 2061
- 10.17.6 Prices 2063
- 10.17.7 Estimated market demand 2065
- 10.17.8 Companies and projects 2065
- 10.18 Biofuels from carbon capture 2067
 - 10.18.1 Overview 2068
 - 10.18.2 CO₂ capture from point sources 2070
 - 10.18.3 Production routes 2071
 - 10.18.4 SWOT analysis 2072
 - 10.18.5 Direct air capture (DAC) 2073
 - 10.18.5.1 Description 2073
 - 10.18.5.2 Deployment 2075
 - 10.18.5.3 Point source carbon capture versus Direct Air Capture 2075
 - 10.18.5.4 Technologies 2076
 - 10.18.5.4.1 Solid sorbents 2078
 - 10.18.5.4.2 Liquid sorbents 2079
 - 10.18.5.4.3 Liquid solvents 2080
 - 10.18.5.4.4 Airflow equipment integration 2081
 - 10.18.5.4.5 Passive Direct Air Capture (PDAC) 2081
 - 10.18.5.4.6 Direct conversion 2082
 - 10.18.5.4.7 Co-product generation 2082
 - 10.18.5.4.8 Low Temperature DAC 2082
 - 10.18.5.4.9 Regeneration methods 2082
 - 10.18.5.5 Commercialization and plants 2083
 - 10.18.5.6 Metal-organic frameworks (MOFs) in DAC 2084
 - 10.18.5.7 DAC plants and projects-current and planned 2084

- 10.18.5.8 Markets for DAC 2091
- 10.18.5.9 Costs 2092
- 10.18.5.10 Challenges 2097
- 10.18.5.11 Players and production 2098
- 10.18.6 Carbon utilization for biofuels 2098
 - 10.18.6.1 Production routes 2102
 - 10.18.6.1.1 Electrolyzers 2103
 - 10.18.6.1.2 Low-carbon hydrogen 2103
 - 10.18.6.2 Products & applications 2105
 - 10.18.6.2.1 Vehicles 2105
 - 10.18.6.2.2 Shipping 2105
 - 10.18.6.2.3 Aviation 2106
 - 10.18.6.2.4 Costs 2107
 - 10.18.6.2.5 Ethanol 2107
 - 10.18.6.2.6 Methanol 2108
 - 10.18.6.2.7 Sustainable Aviation Fuel 2112
 - 10.18.6.2.8 Methane 2113
 - 10.18.6.2.9 Algae based biofuels 2114
 - 10.18.6.2.10 CO₂-fuels from solar 2115
 - 10.18.6.3 Challenges 2117
 - 10.18.6.4 SWOT analysis 2118
 - 10.18.6.5 Companies 2119
- 10.19 Bio-oils (pyrolysis oils) 2122
 - 10.19.1 Description 2122
 - 10.19.1.1 Advantages of bio-oils 2122
 - 10.19.2 Production 2124
 - 10.19.2.1 Fast Pyrolysis 2124
 - 10.19.2.2 Costs of production 2124
 - 10.19.2.3 Upgrading 2124
 - 10.19.3 SWOT analysis 2126
 - 10.19.4 Applications 2127
 - 10.19.5 Bio-oil producers 2127
 - 10.19.6 Prices 2128
- 10.20 Refuse Derived Fuels (RDF) 2129
 - 10.20.1 Overview 2129
 - 10.20.2 Production 2129
 - 10.20.2.1 Production process 2130
 - 10.20.2.2 Mechanical biological treatment 2130
 - 10.20.3 Markets 2131

10.21 Company profiles 2132 (214 company profiles)

11 SUSTAINABLE ELECTRONICS 2305

11.1 Overview 2306

11.1.1 Green electronics manufacturing 2306

11.1.2 Drivers for sustainable electronics 2307

11.1.3 Environmental Impacts of Electronics Manufacturing 2308

11.1.3.1 E-Waste Generation 2308

11.1.3.2 Carbon Emissions 2309

11.1.3.3 Resource Utilization 2309

11.1.3.4 Waste Minimization 2310

11.1.3.5 Supply Chain Impacts 2311

11.1.4 New opportunities from sustainable electronics 2311

11.1.5 Regulations 2312

11.1.5.1 Certifications 2313

11.1.6 Powering sustainable electronics (Bio-based batteries) 2313

11.1.7 Bioplastics in injection moulded electronics parts 2315

11.2 Green electronics manufacturing 2316

11.2.1 Conventional electronics manufacturing 2316

11.2.2 Benefits of Green Electronics manufacturing 2316

11.2.3 Challenges in adopting Green Electronics manufacturing 2318

11.2.4 Approaches 2318

11.2.4.1 Closed-Loop Manufacturing 2318

11.2.4.2 Digital Manufacturing 2320

11.2.4.2.1 Advanced robotics & automation 2320

11.2.4.2.2 AI & machine learning analytics 2320

11.2.4.2.3 Internet of Things (IoT) 2320

11.2.4.2.4 Additive manufacturing 2321

11.2.4.2.5 Virtual prototyping 2321

11.2.4.2.6 Blockchain-enabled supply chain traceability 2321

11.2.4.3 Renewable Energy Usage 2321

11.2.4.4 Energy Efficiency 2323

11.2.4.5 Materials Efficiency 2324

11.2.4.6 Sustainable Chemistry 2324

11.2.4.7 Recycled Materials 2325

11.2.4.7.1 Advanced chemical recycling 2326

11.2.4.8 Bio-Based Materials 2328

11.2.5 Greening the Supply Chain 2331

- 11.2.5.1 Key focus areas 2332
- 11.2.5.2 Sustainability activities from major electronics brands 2335
- 11.2.5.3 Key challenges 2336
- 11.2.5.4 Use of digital technologies 2336
- 11.2.6 Sustainable Printed Circuit Board (PCB) manufacturing 2337
 - 11.2.6.1 Conventional PCB manufacturing 2337
 - 11.2.6.2 Trends in PCBs 2339
 - 11.2.6.2.1 High-Speed PCBs 2339
 - 11.2.6.2.2 Flexible PCBs 2339
 - 11.2.6.2.3 3D Printed PCBs 2340
 - 11.2.6.2.4 Sustainable PCBs 2341
 - 11.2.6.3 Reconciling sustainability with performance 2342
 - 11.2.6.4 Sustainable supply chains 2342
 - 11.2.6.5 Sustainability in PCB manufacturing 2343
 - 11.2.6.5.1 Sustainable cleaning of PCBs 2344
 - 11.2.6.6 Design of PCBs for sustainability 2345
 - 11.2.6.6.1 Rigid 2347
 - 11.2.6.6.2 Flexible 2347
 - 11.2.6.6.3 Additive manufacturing 2348
 - 11.2.6.6.4 In-mold electronics (IME) 2349
 - 11.2.6.7 Materials 2350
 - 11.2.6.7.1 Metal cores 2350
 - 11.2.6.7.2 Recycled laminates 2350
 - 11.2.6.7.3 Conductive inks 2350
 - 11.2.6.7.4 Green and lead-free solder 2353
 - 11.2.6.7.5 Biodegradable substrates 2354
 - 11.2.6.7.5.1 Bacterial Cellulose 2354
 - 11.2.6.7.5.2 Mycelium 2355
 - 11.2.6.7.5.3 Lignin 2357
 - 11.2.6.7.5.4 Cellulose Nanofibers 2360
 - 11.2.6.7.5.5 Soy Protein 2363
 - 11.2.6.7.5.6 Algae 2363
 - 11.2.6.7.5.7 PHAs 2364
 - 11.2.6.7.6 Biobased inks 2365
 - 11.2.6.8 Substrates 2365
 - 11.2.6.8.1 Halogen-free FR4 2365
 - 11.2.6.8.1.1 FR4 limitations 2365
 - 11.2.6.8.1.2 FR4 alternatives 2367
 - 11.2.6.8.1.3 Bio-Polyimide 2367

- 11.2.6.8.2 Metal-core PCBs 2369
- 11.2.6.8.3 Biobased PCBs 2369
 - 11.2.6.8.3.1 Flexible (bio) polyimide PCBs 2370
 - 11.2.6.8.3.2 Recent commercial activity 2371
- 11.2.6.8.4 Paper-based PCBs 2372
- 11.2.6.8.5 PCBs without solder mask 2372
- 11.2.6.8.6 Thinner dielectrics 2373
- 11.2.6.8.7 Recycled plastic substrates 2373
- 11.2.6.8.8 Flexible substrates 2373
- 11.2.6.9 Sustainable patterning and metallization in electronics manufacturing 2373
 - 11.2.6.9.1 Introduction 2374
 - 11.2.6.9.2 Issues with sustainability 2374
 - 11.2.6.9.3 Regeneration and reuse of etching chemicals 2375
 - 11.2.6.9.4 Transition from Wet to Dry phase patterning 2376
 - 11.2.6.9.5 Print-and-plate 2376
 - 11.2.6.9.6 Approaches 2377
 - 11.2.6.9.6.1 Direct Printed Electronics 2377
 - 11.2.6.9.6.2 Photonic Sintering 2379
 - 11.2.6.9.6.3 Biometallization 2379
 - 11.2.6.9.6.4 Plating Resist Alternatives 2380
 - 11.2.6.9.6.5 Laser-Induced Forward Transfer 2380
 - 11.2.6.9.6.6 Electrohydrodynamic Printing 2383
 - 11.2.6.9.6.7 Electrically conductive adhesives (ECAs) 2383
 - 11.2.6.9.6.8 Green electroless plating 2385
 - 11.2.6.9.6.9 Smart Masking 2386
 - 11.2.6.9.6.10 Component Integration 2386
 - 11.2.6.9.6.11 Bio-inspired material deposition 2386
 - 11.2.6.9.6.12 Multi-material jetting 2387
 - 11.2.6.9.6.13 Vacuumless deposition 2389
 - 11.2.6.9.6.14 Upcycling waste streams 2389
- 11.2.6.10 Sustainable attachment and integration of components 2389
 - 11.2.6.10.1 Conventional component attachment materials 2389
 - 11.2.6.10.2 Materials 2391
 - 11.2.6.10.2.1 Conductive adhesives 2391
 - 11.2.6.10.2.2 Biodegradable adhesives 2391
 - 11.2.6.10.2.3 Magnets 2391
 - 11.2.6.10.2.4 Bio-based solders 2392
 - 11.2.6.10.2.5 Bio-derived solders 2392
 - 11.2.6.10.2.6 Recycled plastics 2392

- 11.2.6.10.2.7 Nano adhesives 2393
- 11.2.6.10.2.8 Shape memory polymers 2393
- 11.2.6.10.2.9 Photo-reversible polymers 2394
- 11.2.6.10.2.10 Conductive biopolymers 2395
- 11.2.6.10.3 Processes 2396
 - 11.2.6.10.3.1 Traditional thermal processing methods 2396
 - 11.2.6.10.3.2 Low temperature solder 2397
 - 11.2.6.10.3.3 Reflow soldering 2400
 - 11.2.6.10.3.4 Induction soldering 2400
 - 11.2.6.10.3.5 UV curing 2401
 - 11.2.6.10.3.6 Near-infrared (NIR) radiation curing 2401
 - 11.2.6.10.3.7 Photonic sintering/curing 2402
 - 11.2.6.10.3.8 Hybrid integration 2402
- 11.2.7 Sustainable integrated circuits 2403
 - 11.2.7.1 IC manufacturing 2403
 - 11.2.7.2 Sustainable IC manufacturing 2404
 - 11.2.7.3 Wafer production 2404
 - 11.2.7.3.1 Silicon 2405
 - 11.2.7.3.2 Gallium nitride ICs 2405
 - 11.2.7.3.3 Flexible ICs 2406
 - 11.2.7.3.4 Fully printed organic ICs 2406
 - 11.2.7.4 Oxidation methods 2407
 - 11.2.7.4.1 Sustainable oxidation 2407
 - 11.2.7.4.2 Metal oxides 2408
 - 11.2.7.4.3 Recycling 2409
 - 11.2.7.4.4 Thin gate oxide layers 2409
 - 11.2.7.5 Patterning and doping 2410
 - 11.2.7.5.1 Processes 2410
 - 11.2.7.5.1.1 Wet etching 2410
 - 11.2.7.5.1.2 Dry plasma etching 2410
 - 11.2.7.5.1.3 Lift-off patterning 2411
 - 11.2.7.5.1.4 Surface doping 2411
 - 11.2.7.6 Metallization 2412
 - 11.2.7.6.1 Evaporation 2412
 - 11.2.7.6.2 Plating 2413
 - 11.2.7.6.3 Printing 2413
 - 11.2.7.6.3.1 Printed metal gates for organic thin film transistors 2413
 - 11.2.7.6.4 Physical vapour deposition (PVD) 2414
- 11.2.8 End of life 2415

- 11.2.8.1 Hazardous waste 2415
- 11.2.8.2 Emissions 2416
- 11.2.8.3 Water Usage 2417
- 11.2.8.4 Recycling 2418
 - 11.2.8.4.1 Mechanical recycling 2419
 - 11.2.8.4.2 Electro-Mechanical Separation 2420
 - 11.2.8.4.3 Chemical Recycling 2420
- 11.2.8.5 Electrochemical Processes 2421
 - 11.2.8.5.1 Thermal Recycling 2421
- 11.2.8.6 Green Certification 2422
- 11.3 Global market 2423
 - 11.3.1 Global PCB manufacturing industry 2423
 - 11.3.1.1 PCB revenues 2423
 - 11.3.2 Sustainable PCBs 2424
 - 11.3.3 Sustainable ICs 2427
- 11.4 Company profiles 2429 (45 company profiles)

12 BIOBASED ADHESIVES AND SEALANTS 2483

- 12.1 Overview 2483
 - 12.1.1 Biobased Epoxy Adhesives 2483
 - 12.1.2 Biobased Polyurethane Adhesives 2483
 - 12.1.3 Other Biobased Adhesives and Sealants 2483
- 12.2 Types 2484
 - 12.2.1 Cellulose-Based 2484
 - 12.2.2 Starch-Based 2485
 - 12.2.3 Lignin-Based 2485
 - 12.2.4 Vegetable Oils 2486
 - 12.2.5 Protein-Based 2487
 - 12.2.6 Tannin-Based 2487
- 12.3 Global revenues 2488
 - 12.3.1 By types 2488
 - 12.3.2 By market 2489
- 12.4 Companies profiles 2492 (22 company profiles)

13 REFERENCES 2512

List Of Tables

LIST OF TABLES

- Table 1. Plant-based feedstocks and biochemicals produced.
- Table 2. Waste-based feedstocks and biochemicals produced.
- Table 3. Microbial and mineral-based feedstocks and biochemicals produced.
- Table 4. Common starch sources that can be used as feedstocks for producing biochemicals.
- Table 5. Common lysine sources that can be used as feedstocks for producing biochemicals.
- Table 6. Applications of lysine as a feedstock for biochemicals.
- Table 7. HDMA sources that can be used as feedstocks for producing biochemicals.
- Table 8. Applications of bio-based HDMA.
- Table 9. Biobased feedstocks that can be used to produce 1,5-diaminopentane (DA5).
- Table 10. Applications of DN5.
- Table 11. Biobased feedstocks for isosorbide.
- Table 12. Applications of bio-based isosorbide.
- Table 13. Lactide applications.
- Table 14. Biobased feedstock sources for itaconic acid.
- Table 15. Applications of bio-based itaconic acid.
- Table 16. Biobased feedstock sources for 3-HP.
- Table 17. Applications of 3-HP.
- Table 18. Applications of bio-based acrylic acid.
- Table 19. Applications of bio-based 1,3-Propanediol (1,3-PDO).
- Table 20. Biobased feedstock sources for Succinic acid.
- Table 21. Applications of succinic acid.
- Table 22. Applications of bio-based 1,4-Butanediol (BDO).
- Table 23. Applications of bio-based Tetrahydrofuran (THF).
- Table 24. Applications of bio-based adipic acid.
- Table 25. Applications of bio-based caprolactam.
- Table 26. Biobased feedstock sources for isobutanol.
- Table 27. Applications of bio-based isobutanol.
- Table 28. Biobased feedstock sources for p-Xylene.
- Table 29. Applications of bio-based p-Xylene.
- Table 30. Applications of bio-based Terephthalic acid (TPA).
- Table 31. Biobased feedstock sources for 1,3 Propanediol.
- Table 32. Applications of bio-based 1,3 Propanediol.
- Table 33. Biobased feedstock sources for MEG.

Table 34. Applications of bio-based MEG.
Table 35. Biobased MEG producers capacities.
Table 36. Biobased feedstock sources for ethanol.
Table 37. Applications of bio-based ethanol.
Table 38. Applications of bio-based ethylene.
Table 39. Applications of bio-based propylene.
Table 40. Applications of bio-based vinyl chloride.
Table 41. Applications of bio-based Methly methacrylate.
Table 42. Applications of bio-based aniline.
Table 43. Applications of biobased fructose.
Table 44. Applications of bio-based 5-Hydroxymethylfurfural (5-HMF).
Table 45. Applications of 5-(Chloromethyl)furfural (CMF).
Table 46. Applications of Levulinic acid.
Table 47. Markets and applications for bio-based FDME.
Table 48. Applications of FDCA.
Table 49. Markets and applications for bio-based levoglucosenone.
Table 50. Biochemicals derived from hemicellulose
Table 51. Markets and applications for bio-based hemicellulose
Table 52. Markets and applications for bio-based furfuryl alcohol.
Table 53. Commercial and pre-commercial biorefinery lignin production facilities and processes
Table 54. Lignin aromatic compound products.
Table 55. Prices of benzene, toluene, xylene and their derivatives.
Table 56. Lignin products in polymeric materials.
Table 57. Application of lignin in plastics and composites.
Table 58. Markets and applications for bio-based glycerol.
Table 59. Markets and applications for Bio-based MPG.
Table 60. Markets and applications: Bio-based ECH.
Table 61. Mineral source products and applications.
Table 62. Type of biodegradation.
Table 63. Advantages and disadvantages of biobased plastics compared to conventional plastics.
Table 64. Types of Bio-based and/or Biodegradable Plastics, applications.
Table 65. Key market players by Bio-based and/or Biodegradable Plastic types.
Table 66. Polylactic acid (PLA) market analysis-manufacture, advantages, disadvantages and applications.
Table 67. Lactic acid producers and production capacities.
Table 68. PLA producers and production capacities.
Table 69. Planned PLA capacity expansions in China.

- Table 70. Bio-based Polyethylene terephthalate (Bio-PET) market analysis-manufacture, advantages, disadvantages and applications.
- Table 71. Bio-based Polyethylene terephthalate (PET) producers and production capacities,
- Table 72. Polytrimethylene terephthalate (PTT) market analysis-manufacture, advantages, disadvantages and applications.
- Table 73. Production capacities of Polytrimethylene terephthalate (PTT), by leading producers.
- Table 74. Polyethylene furanoate (PEF) market analysis-manufacture, advantages, disadvantages and applications.
- Table 75. PEF vs. PET.
- Table 76. FDCA and PEF producers.
- Table 77. Bio-based polyamides (Bio-PA) market analysis - manufacture, advantages, disadvantages and applications.
- Table 78. Leading Bio-PA producers production capacities.
- Table 79. Poly(butylene adipate-co-terephthalate) (PBAT) market analysis-manufacture, advantages, disadvantages and applications.
- Table 80. Leading PBAT producers, production capacities and brands.
- Table 81. Bio-PBS market analysis-manufacture, advantages, disadvantages and applications.
- Table 82. Leading PBS producers and production capacities.
- Table 83. Bio-based Polyethylene (Bio-PE) market analysis- manufacture, advantages, disadvantages and applications.
- Table 84. Leading Bio-PE producers.
- Table 85. Bio-PP market analysis- manufacture, advantages, disadvantages and applications.
- Table 86. Leading Bio-PP producers and capacities.
- Table 87. Types of PHAs and properties.
- Table 88. Comparison of the physical properties of different PHAs with conventional petroleum-based polymers.
- Table 89. Polyhydroxyalkanoate (PHA) extraction methods.
- Table 90. Polyhydroxyalkanoates (PHA) market analysis.
- Table 91. Commercially available PHAs.
- Table 92. Markets and applications for PHAs.
- Table 93. Applications, advantages and disadvantages of PHAs in packaging.
- Table 94. Polyhydroxyalkanoates (PHA) producers.
- Table 95. Microfibrillated cellulose (MFC) market analysis-manufacture, advantages, disadvantages and applications.
- Table 96. Leading MFC producers and capacities.

Table 97. Synthesis methods for cellulose nanocrystals (CNC).
Table 98. CNC sources, size and yield.
Table 99. CNC properties.
Table 100. Mechanical properties of CNC and other reinforcement materials.
Table 101. Applications of nanocrystalline cellulose (NCC).
Table 102. Cellulose nanocrystals analysis.
Table 103: Cellulose nanocrystal production capacities and production process, by producer.
Table 104. Applications of cellulose nanofibers (CNF).
Table 105. Cellulose nanofibers market analysis.
Table 106. CNF production capacities (by type, wet or dry) and production process, by producer, metric tonnes.
Table 107. Applications of bacterial nanocellulose (BNC).
Table 108. Types of protein based-bioplastics, applications and companies.
Table 109. Types of algal and fungal based-bioplastics, applications and companies.
Table 110. Overview of alginate-description, properties, application and market size.
Table 111. Companies developing algal-based bioplastics.
Table 112. Overview of mycelium fibers-description, properties, drawbacks and applications.
Table 113. Companies developing mycelium-based bioplastics.
Table 114. Overview of chitosan-description, properties, drawbacks and applications.
Table 115. Global production capacities of biobased and sustainable plastics in 2019-2035, by region, 1,000 tonnes.
Table 116. Biobased and sustainable plastics producers in North America.
Table 117. Biobased and sustainable plastics producers in Europe.
Table 118. Biobased and sustainable plastics producers in Asia-Pacific.
Table 119. Biobased and sustainable plastics producers in Latin America.
Table 120. Processes for bioplastics in packaging.
Table 121. Comparison of bioplastics (PLA and PHAs) properties to other common polymers used in product packaging.
Table 122. Typical applications for bioplastics in flexible packaging.
Table 123. Typical applications for bioplastics in rigid packaging.
Table 124. Technical lignin types and applications.
Table 125. Classification of technical lignins.
Table 126. Lignin content of selected biomass.
Table 127. Properties of lignins and their applications.
Table 128. Example markets and applications for lignin.
Table 129. Processes for lignin production.
Table 130. Biorefinery feedstocks.

Table 131. Comparison of pulping and biorefinery lignins.

Table 132. Commercial and pre-commercial biorefinery lignin production facilities and processes

Table 133. Market drivers and trends for lignin.

Table 134. Production capacities of technical lignin producers.

Table 135. Production capacities of biorefinery lignin producers.

Table 136. Estimated consumption of lignin, 2019-2035 (000 MT).

Table 137. Prices of benzene, toluene, xylene and their derivatives.

Table 138. Application of lignin in plastics and polymers.

Table 139. Lactips plastic pellets.

Table 140. Oji Holdings CNF products.

Table 141. Types of natural fibers.

Table 142. Markets and applications for natural fibers.

Table 143. Commercially available natural fiber products.

Table 144. Market drivers for natural fibers.

Table 145. Typical properties of natural fibers.

Table 146. Overview of kapok fibers-description, properties, drawbacks and applications.

Table 147. Overview of luffa fibers-description, properties, drawbacks and applications.

Table 148. Overview of jute fibers-description, properties, drawbacks and applications.

Table 149. Overview of hemp fibers-description, properties, drawbacks and applications.

Table 150. Overview of flax fibers-description, properties, drawbacks and applications.

Table 151. Overview of ramie fibers-description, properties, drawbacks and applications.

Table 152. Overview of kenaf fibers-description, properties, drawbacks and applications.

Table 153. Overview of sisal fibers-description, properties, drawbacks and applications.

Table 154. Overview of abaca fibers-description, properties, drawbacks and applications.

Table 155. Overview of coir fibers-description, properties, drawbacks and applications.

Table 156. Overview of banana fibers-description, properties, drawbacks and applications.

Table 157. Overview of pineapple fibers-description, properties, drawbacks and applications.

Table 158. Overview of rice fibers-description, properties, drawbacks and applications.

Table 159. Overview of corn fibers-description, properties, drawbacks and applications.

Table 160. Overview of switch grass fibers-description, properties and applications.

Table 161. Overview of sugarcane fibers-description, properties, drawbacks and

application and market size.

Table 162. Overview of bamboo fibers-description, properties, drawbacks and applications.

Table 163. Overview of mycelium fibers-description, properties, drawbacks and applications.

Table 164. Overview of chitosan fibers-description, properties, drawbacks and applications.

Table 165. Overview of alginate-description, properties, application and market size.

Table 166. Overview of silk fibers-description, properties, application and market size.

Table 167. Next-gen silk producers.

Table 168. Companies developing cellulose fibers for application in plastic composites.

Table 169. Microfibrillated cellulose (MFC) market analysis.

Table 170. Leading MFC producers and capacities.

Table 171. Cellulose nanocrystals market overview.

Table 172. Cellulose nanocrystal production capacities and production process, by producer.

Table 173. Cellulose nanofibers market analysis.

Table 174. CNF production capacities and production process, by producer, in metric tons.

Table 175. Processing and treatment methods for natural fibers used in plastic composites.

Table 176. Application, manufacturing method, and matrix materials of natural fibers.

Table 177. Properties of natural fiber-bio-based polymer compounds.

Table 178. Typical properties of short natural fiber-thermoplastic composites.

Table 179. Properties of non-woven natural fiber mat composites.

Table 180. Applications of natural fibers in plastics.

Table 181. Applications of natural fibers in the automotive industry.

Table 182. Natural fiber-reinforced polymer composite in the automotive market.

Table 183. Applications of natural fibers in packaging.

Table 184. Applications of natural fibers in construction.

Table 185. Applications of natural fibers in the appliances market.

Table 186. Applications of natural fibers in the consumer electronics market.

Table 187. Global market for natural fiber based plastics, 2018-2035, by end use sector (Billion USD).

Table 188. Global market for natural fiber based plastics, 2018-2035, by material type (Billion USD).

Table 189. Global market for natural fiber based plastics, 2018-2035, by plastic type (Billion USD).

Table 190. Global market for natural fiber based plastics, 2018-2035, by region (Billion

USD).

Table 191. Granbio Nanocellulose Processes.

Table 192. Oji Holdings CNF products.

Table 193. Global revenues in sustainable construction materials, by type 2018-2035 (billions USD).

Table 194. Types of self-healing concrete.

Table 195. Applications of cellulose nanofibers in building and construction.

Table 196. General properties and value of aerogels.

Table 197. Key properties of silica aerogels.

Table 198. Chemical precursors used to synthesize silica aerogels.

Table 199. Commercially available aerogel-enhanced blankets.

Table 200. Main manufacturers of silica aerogels and product offerings.

Table 201. Typical structural properties of metal oxide aerogels.

Table 202. Polymer aerogels companies.

Table 203. Types of biobased aerogels.

Table 204. Carbon aerogel companies.

Table 205. Conversion pathway for CO₂-derived building materials.

Table 206. Carbon capture technologies and projects in the cement sector

Table 207. Carbonation of recycled concrete companies.

Table 208. Current and projected costs for some key CO₂ utilization applications in the construction industry.

Table 209. Market challenges for CO₂ utilization in construction materials.

Table 210. Global Decarbonization Targets and Policies related to Green Steel.

Table 211. Estimated cost for iron and steel industry under the Carbon Border Adjustment Mechanism (CBAM).

Table 212. Hydrogen-based steelmaking technologies.

Table 213. Comparison of green steel production technologies.

Table 214. Advantages and disadvantages of each potential hydrogen carrier.

Table 215. CCUS in green steel production.

Table 216. Biochar in steel and metal.

Table 217. Hydrogen blast furnace schematic.

Table 218. Applications of microwave processing in green steelmaking.

Table 219. Applications of additive manufacturing (AM) in steelmaking.

Table 220. Technology readiness level (TRL) for key green steel production technologies.

Table 221. Properties of Green steels.

Table 222. Applications of green steel in the construction industry.

Table 223. Market trends in bio-based and sustainable packaging 1006

Table 224. Drivers for recent growth in the bioplastics and biopolymers markets. 1008

Table 225. Challenges for bio-based and sustainable packaging.	1008
Table 226. Types of bio-based plastics and fossil-fuel-based plastics	1011
Table 227. Comparison of synthetic fossil-based and bio-based polymers.	1017
Table 228. Processes for bioplastics in packaging.	1018
Table 229. Polylactic acid (PLA) market analysis-manufacture, advantages, disadvantages and applications.	1021
Table 230. Lactic acid producers and production capacities.	1023
Table 231. PLA producers and production capacities.	1023
Table 232. Planned PLA capacity expansions in China.	1024
Table 233. Bio-based Polyethylene terephthalate (Bio-PET) market analysis-manufacture, advantages, disadvantages and applications.	1025
Table 234. Bio-based Polyethylene terephthalate (PET) producers and production capacities,	1026
Table 235. Polytrimethylene terephthalate (PTT) market analysis-manufacture, advantages, disadvantages and applications.	1027
Table 236. Production capacities of Polytrimethylene terephthalate (PTT), by leading producers.	1027
Table 237. Polyethylene furanoate (PEF) market analysis-manufacture, advantages, disadvantages and applications.	1028
Table 238. PEF vs. PET.	1029
Table 239. FDCA and PEF producers.	1030
Table 240. Bio-based polyamides (Bio-PA) market analysis - manufacture, advantages, disadvantages and applications.	1031
Table 241. Leading Bio-PA producers production capacities.	1032
Table 242. Poly(butylene adipate-co-terephthalate) (PBAT) market analysis-manufacture, advantages, disadvantages and applications.	1033
Table 243. Leading PBAT producers, production capacities and brands.	1033
Table 244. Bio-PBS market analysis-manufacture, advantages, disadvantages and applications.	1035
Table 245. Leading PBS producers and production capacities.	1035
Table 246. Polyethylene furanoate (PEF) market analysis-manufacture, advantages, disadvantages and applications.	1037
Table 247. PEF vs. PET.	1038
Table 248. FDCA and PEF producers.	1039
Table 249. Bio-based Polyethylene (Bio-PE) market analysis- manufacture, advantages, disadvantages and applications.	1041
Table 250. Leading Bio-PE producers.	1042
Table 251. Bio-PP market analysis- manufacture, advantages, disadvantages and applications.	1042

Table 252. Leading Bio-PP producers and capacities.	1043
Table 253. Types of PHAs and properties.	1047
Table 254. Comparison of the physical properties of different PHAs with conventional petroleum-based polymers.	1049
Table 255. Polyhydroxyalkanoate (PHA) extraction methods.	1052
Table 256. Polyhydroxyalkanoates (PHA) market analysis.	1053
Table 257. Commercially available PHAs.	1055
Table 258. Markets and applications for PHAs.	1056
Table 259. Applications, advantages and disadvantages of PHAs in packaging.	1057
Table 260. Length and diameter of nanocellulose and MFC.	1061
Table 261. Major polymers found in the extracellular covering of different algae.	1066
Table 262. Market overview for cellulose microfibrils (microfibrillated cellulose) in paperboard and packaging-market age, key benefits, applications and producers.	1067
Table 263. Applications of nanocrystalline cellulose (NCC).	1069
Table 264. Market overview for cellulose nanofibers in packaging.	1071
Table 265. Types of protein based-bioplastics, applications and companies.	1082
Table 266. Overview of alginate-description, properties, application and market size.	1085
Table 267. Companies developing algal-based bioplastics.	1087
Table 268. Overview of mycelium fibers-description, properties, drawbacks and applications.	1087
Table 269. Overview of chitosan-description, properties, drawbacks and applications.	1090
Table 270. Bio-based naphtha markets and applications.	1092
Table 271. Bio-naphtha market value chain.	1093
Table 272. Pros and cons of different type of food packaging materials.	1095
Table 273. Active Biodegradable Films films and their food applications.	1103
Table 274. Intelligent Biodegradable Films.	1103
Table 275. Edible films and coatings market summary.	1107
Table 276. Summary of barrier films and coatings for packaging.	1111
Table 277. Types of polyols.	1113
Table 278. Polyol producers.	1114
Table 279. Bio-based polyurethane coating products.	1115
Table 280. Bio-based acrylate resin products.	1116
Table 281. Polylactic acid (PLA) market analysis.	1117
Table 282. Commercially available PHAs.	1120
Table 283. Market overview for cellulose nanofibers in paints and coatings.	1122
Table 284. Companies developing cellulose nanofibers products in paints and coatings.	1124

Table 285. Types of protein based-biomaterials, applications and companies.	1128
Table 286. CO2 utilization and removal pathways.	1131
Table 287. CO2 utilization products developed by chemical and plastic producers.	1134
Table 288. Comparison of bioplastics (PLA and PHAs) properties to other common polymers used in product packaging.	1136
Table 289. Typical applications for bioplastics in flexible packaging.	1137
Table 290. Typical applications for bioplastics in rigid packaging.	1140
Table 291. Market revenues for bio-based coatings, 2018-2035 (billions USD), high estimate.	1144
Table 292. Lactips plastic pellets.	1250
Table 293. Oji Holdings CNF products.	1279
Table 294. Properties and applications of the main natural fibres	1330
Table 295. Properties and applications of the main man-made cellulosic fibres	1332
Table 296. Types of sustainable alternative leathers.	1342
Table 297. Properties of bio-based leathers.	1344
Table 298. Comparison with conventional leathers.	1346
Table 299. Price of commercially available sustainable alternative leather products.	1347
Table 300. Comparative analysis of sustainable alternative leathers.	1349
Table 301. Key processing steps involved in transforming plant fibers into leather materials.	1350
Table 302. Current and emerging plant-based leather products.	1353
Table 303. Companies developing plant-based leather products.	1354
Table 304. Overview of mycelium-description, properties, drawbacks and applications.	1356
Table 305. Companies developing mycelium-based leather products.	1361
Table 306. Types of microbial-derived leather alternative.	1365
Table 307. Companies developing microbial leather products.	1368
Table 308. Companies developing plant-based leather products.	1370
Table 309. Types of protein-based leather alternatives.	1371
Table 310. Companies developing protein based leather.	1373
Table 311. Companies developing sustainable coatings and dyes for leather -	1375
Table 312. Markets and applications for bio-based textiles and leather.	1377
Table 313. Applications of biobased leather in furniture and upholstery.	1381
Table 314. Global revenues for bio-based textiles by type, 2018-2035 (millions USD).	1382
Table 315. Global revenues for bio-based and sustainable textiles by end use market, 2018-2035 (millions USD).	1385
Table 316. Market drivers and trends in bio-based and sustainable coatings.	1448

Table 317. Example environmentally friendly coatings, advantages and disadvantages.	1451
Table 318. Plant Waxes.	1458
Table 319. Types of alkyd resins and properties.	1463
Table 320. Market summary for bio-based alkyd coatings-raw materials, advantages, disadvantages, applications and producers.	1465
Table 321. Bio-based alkyd coating products.	1466
Table 322. Types of polyols.	1467
Table 323. Polyol producers.	1468
Table 324. Bio-based polyurethane coating products.	1469
Table 325. Market summary for bio-based epoxy resins.	1471
Table 326. Bio-based polyurethane coating products.	1473
Table 327. Bio-based acrylate resin products.	1475
Table 328. Polylactic acid (PLA) market analysis.	1475
Table 329. PLA producers and production capacities.	1477
Table 330. Polyhydroxyalkanoates (PHA) market analysis.	1479
Table 331. Types of PHAs and properties.	1482
Table 332. Polyhydroxyalkanoates (PHA) producers.	1483
Table 333. Commercially available PHAs.	1485
Table 334. Properties of micro/nanocellulose, by type.	1487
Table 335. Types of nanocellulose.	1490
Table 336. Microfibrillated Cellulose (MFC) production capacities in metric tons and production process, by producer, metric tons.	1493
Table 337. Commercially available Microfibrillated Cellulose products.	1493
Table 338. Market overview for cellulose nanofibers in paints and coatings.	1495
Table 339. Market assessment for cellulose nanofibers in paints and coatings- application, key benefits and motivation for use, megatrends, market drivers, technology drawbacks, competing materials, material loading, main global paints and coatings OEMs.	1497
Table 340. Companies developing CNF products in paints and coatings, applications targeted and stage of commercialization.	1500
Table 341. CNC properties.	1501
Table 342. Cellulose nanocrystal capacities (by type, wet or dry) and production process, by producer, metric tonnes.	1502
Table 343. Applications of bacterial nanocellulose (BNC).	1503
Table 344. Edible films and coatings market summary.	1506
Table 345. Types of protein based-biomaterials, applications and companies.	1513
Table 346. Overview of algal coatings-description, properties, application and market size.	1515

Table 347. Companies developing algal-based plastics. 1517
Table 348. Global market revenues for bio-based coatings, by types, 2018-2035 (billions USD). 1519
Table 349. Market revenues for bio-based coatings by market, 2018-2035 (billions USD), conservative estimate. 1521
Table 350. Lactips plastic pellets. 1606
Table 351. Oji Holdings CNF products. 1632
Table 352. Market drivers for biofuels. 1680
Table 353. Market challenges for biofuels. 1681
Table 354. Liquid biofuels market 2020-2035, by type and production. 1683
Table 355. Comparison of biofuels. 1686
Table 356. Comparison of biofuel costs (USD/liter) 2023, by type. 1691
Table 357. Categories and examples of solid biofuel. 1692
Table 358. Comparison of biofuels and e-fuels to fossil and electricity. 1695
Table 359. Classification of biomass feedstock. 1697
Table 360. Biorefinery feedstocks. 1698
Table 361. Feedstock conversion pathways. 1698
Table 362. First-Generation Feedstocks. 1699
Table 363. Lignocellulosic ethanol plants and capacities. 1701
Table 364. Comparison of pulping and biorefinery lignins. 1702
Table 365. Commercial and pre-commercial biorefinery lignin production facilities and processes 1703
Table 366. Operating and planned lignocellulosic biorefineries and industrial flue gas-to-ethanol. 1705
Table 367. Properties of microalgae and macroalgae. 1707
Table 368. Yield of algae and other biodiesel crops. 1708
Table 369. Advantages and disadvantages of biofuels, by generation. 1709
Table 370. Biodiesel by generation. 1721
Table 371. Biodiesel production techniques. 1723
Table 372. Summary of pyrolysis technique under different operating conditions. 1724
Table 373. Biomass materials and their bio-oil yield. 1726
Table 374. Biofuel production cost from the biomass pyrolysis process. 1726
Table 375. Properties of vegetable oils in comparison to diesel. 1728
Table 376. Main producers of HVO and capacities. 1729
Table 377. Example commercial Development of BtL processes. 1731
Table 378. Pilot or demo projects for biomass to liquid (BtL) processes. 1731
Table 379. Global biodiesel consumption, 2010-2035 (M litres/year). 1736
Table 380. Global renewable diesel consumption, 2010-2035 (M litres/year). 1741
Table 381. Renewable diesel price ranges. 1742

Table 382. Advantages and disadvantages of Bio-aviation fuel.	1743
Table 383. Production pathways for Bio-aviation fuel.	1745
Table 384. Current and announced Bio-aviation fuel facilities and capacities.	1748
Table 385. Global bio-jet fuel consumption 2019-2035 (Million litres/year).	1749
Table 386. Bio-based naphtha markets and applications.	1753
Table 387. Bio-naphtha market value chain.	1754
Table 388. Bio-naphtha pricing against petroleum-derived naphtha and related fuel products.	1755
Table 389. Bio-based Naphtha production capacities, by producer.	1755
Table 390. Comparison of biogas, biomethane and natural gas.	1760
Table 391. Processes in bioethanol production.	1768
Table 392. Microorganisms used in CBP for ethanol production from biomass lignocellulosic.	1770
Table 393. Ethanol consumption 2010-2035 (million litres).	1771
Table 394. Biogas feedstocks.	1777
Table 395. Existing and planned bio-LNG production plants.	1785
Table 396. Methods for capturing carbon dioxide from biogas.	1786
Table 397. Comparison of different Bio-H ₂ production pathways.	1790
Table 398. Markets and applications for biohydrogen.	1793
Table 399. Summary of gasification technologies.	1800
Table 400. Overview of hydrothermal cracking for advanced chemical recycling.	1806
Table 401. Applications of e-fuels, by type.	1809
Table 402. Overview of e-fuels.	1810
Table 403. Benefits of e-fuels.	1810
Table 404. eFuel production facilities, current and planned.	1816
Table 405. Main characteristics of different electrolyzer technologies.	1817
Table 406. Market challenges for e-fuels.	1822
Table 407. E-fuels companies.	1823
Table 408. Algae-derived biofuel producers.	1829
Table 409. Green ammonia projects (current and planned).	1832
Table 410. Blue ammonia projects.	1836
Table 411. Ammonia fuel cell technologies.	1836
Table 412. Market overview of green ammonia in marine fuel.	1838
Table 413. Summary of marine alternative fuels.	1838
Table 414. Estimated costs for different types of ammonia.	1840
Table 415. Main players in green ammonia.	1841
Table 416. Market overview for CO ₂ derived fuels.	1844
Table 417. Point source examples.	1847
Table 418. Advantages and disadvantages of DAC.	1850

Table 419. Companies developing airflow equipment integration with DAC. 1857
Table 420. Companies developing Passive Direct Air Capture (PDAC) technologies. 1857
Table 421. Companies developing regeneration methods for DAC technologies. 1859
Table 422. DAC companies and technologies. 1859
Table 423. DAC technology developers and production. 1861
Table 424. DAC projects in development. 1866
Table 425. Markets for DAC. 1867
Table 426. Costs summary for DAC. 1868
Table 427. Cost estimates of DAC. 1871
Table 428. Challenges for DAC technology. 1873
Table 429. DAC companies and technologies. 1874
Table 430. Market overview for CO ₂ derived fuels. 1876
Table 431. Main production routes and processes for manufacturing fuels from captured carbon dioxide. 1879
Table 432. CO ₂ -derived fuels projects. 1880
Table 433. Thermochemical methods to produce methanol from CO ₂ . 1885
Table 434. pilot plants for CO ₂ -to-methanol conversion. 1888
Table 435. Microalgae products and prices. 1890
Table 436. Main Solar-Driven CO ₂ Conversion Approaches. 1893
Table 437. Market challenges for CO ₂ derived fuels. 1893
Table 438. Companies in CO ₂ -derived fuel products. 1895
Table 439. Typical composition and physicochemical properties reported for bio-oils and heavy petroleum-derived oils. 1899
Table 440. Properties and characteristics of pyrolysis liquids derived from biomass versus a fuel oil. 1899
Table 441. Main techniques used to upgrade bio-oil into higher-quality fuels. 1901
Table 442. Markets and applications for bio-oil. 1903
Table 443. Bio-oil producers. 1903
Table 444. Key resource recovery technologies 1906
Table 445. Markets and end uses for refuse-derived fuels (RDF). 1907
Table 446. Granbio Nanocellulose Processes. 1982
Table 447. Key factors driving adoption of green electronics. 2083
Table 448. Key circular economy strategies for electronics. 2086
Table 449. Regulations pertaining to green electronics. 2088
Table 450. Companies developing bio-based batteries for application in sustainable electronics. 2090
Table 451. Benefits of Green Electronics Manufacturing 2092
Table 452. Challenges in adopting Green Electronics manufacturing. 2094

Table 453. Major chipmakers' renewable energy road maps. 2099
Table 454. Energy efficiency in sustainable electronics manufacturing. 2099
Table 455. Composition of plastic waste streams. 2102
Table 456. Comparison of mechanical and advanced chemical recycling. 2103
Table 457. Example chemically recycled plastic products. 2104
Table 458. Bio-based and non-toxic materials in sustainable electronics. 2105
Table 459. Key focus areas for enabling greener and ethically responsible electronics supply chains. 2108
Table 460. Sustainability programs and disclosure from major electronics brands. 2111
Table 461. PCB manufacturing process. 2114
Table 462. Challenges in PCB manufacturing. 2114
Table 463. 3D PCB manufacturing. 2117
Table 464. Comparison of some sustainable PCB alternatives against conventional options in terms of key performance factors. 2118
Table 465. Sustainable PCB supply chain. 2119
Table 466. Key areas where the PCB industry can improve sustainability. 2119
Table 467. Improving sustainability of PCB design. 2121
Table 468. PCB design options for sustainability. 2122
Table 469. Sustainability benefits and challenges associated with 3D printing. 2124
Table 470. Conductive ink producers. 2128
Table 471. Green and lead-free solder companies. 2129
Table 472. Biodegradable substrates for PCBs. 2130
Table 473. Overview of mycelium fibers-description, properties, drawbacks and applications. 2131
Table 474. Application of lignin in composites. 2133
Table 475. Properties of lignins and their applications. 2134
Table 476. Properties of flexible electronics-cellulose nanofiber film (nanopaper). 2136
Table 477. Companies developing cellulose nanofibers for electronics. 2137
Table 478. Commercially available PHAs. 2140
Table 479. Main limitations of the FR4 material system used for manufacturing printed circuit boards (PCBs). 2142
Table 480. Halogen-free FR4 companies. 2144
Table 481. Properties of biobased PCBs. 2145
Table 482. Applications of flexible (bio) polyimide PCBs. 2147
Table 483. Main patterning and metallization steps in PCB fabrication and sustainable options. 2150
Table 484. Sustainability issues with conventional metallization processes. 2150
Table 485. Benefits of print-and-plate. 2152
Table 486. Sustainable alternative options to standard plating resists used in printed

circuit board (PCB) fabrication. 2156

Table 487. Applications for laser induced forward transfer 2157

Table 488. Copper versus silver inks in laser-induced forward transfer (LIFT) for electronics fabrication. 2158

Table 489. Approaches for in-situ oxidation prevention. 2158

Table 490. Market readiness and maturity of different lead-free solders and electrically conductive adhesives (ECAs) for electronics manufacturing. 2160

Table 491. Advantages of green electroless plating. 2161

Table 492. Comparison of component attachment materials. 2165

Table 493. Comparison between sustainable and conventional component attachment materials for printed circuit boards 2166

Table 494. Comparison between the SMAs and SMPs. 2169

Table 495. Comparison of conductive biopolymers versus conventional materials for printed circuit board fabrication. 2171

Table 496. Comparison of curing and reflow processes used for attaching components in electronics assembly. 2172

Table 497. Low temperature solder alloys. 2173

Table 498. Thermally sensitive substrate materials. 2174

Table 499. Limitations of existing IC production. 2179

Table 500. Strategies for improving sustainability in integrated circuit (IC) manufacturing. 2180

Table 501. Comparison of oxidation methods and level of sustainability. 2183

Table 502. Stage of commercialization for oxides. 2184

Table 503. Alternative doping techniques. 2188

Table 504. Metal content mg / Kg in Printed Circuit Boards (PCBs) from waste desktop computers. 2195

Table 505. Chemical recycling methods for handling electronic waste. 2196

Table 506. Electrochemical processes for recycling metals from electronic waste 2197

Table 507. Thermal recycling processes for electronic waste. 2197

Table 508. Global PCB revenues 2018-2035 (billions USD), by substrate types. 2199

Table 509. Global sustainable PCB revenues 2018-2035, by type (millions USD). 2200

Table 510. Global sustainable ICs revenues 2018-2035, by type (millions USD). 2203

Table 511. Oji Holdings CNF products. 2239

Table 512. Global market revenues for bio-based adhesives & sealants, by types, 2018-2035 (millions USD). 2264

Table 513. Global market revenues for bio-based adhesives & sealants, by market, 2018-2035 (millions USD). 2266

List Of Figures

LIST OF FIGURES

- Figure 1. Schematic of biorefinery processes.
- Figure 2. Global production of starch for biobased chemicals and intermediates, 2018-2035 (million metric tonnes).
- Figure 3. Global production of biobased lysine, 2018-2035 (metric tonnes).
- Figure 4. Global glucose production for bio-based chemicals and intermediates 2018-2035 (million metric tonnes).
- Figure 5. Global production volumes of bio-HMDA, 2018 to 2035 in metric tonnes.
- Figure 6. Global production of bio-based DN5, 2018-2035 (metric tonnes).
- Figure 7. Global production of bio-based isosorbide, 2018-2035 (metric tonnes).
- Figure 8. L-lactic acid (L-LA) production, 2018-2035 (metric tonnes).
- Figure 9. Global lactide production, 2018-2035 (metric tonnes).
- Figure 10. Global production of bio-itaconic acid, 2018-2035 (metric tonnes).
- Figure 11. Global production of 3-HP, 2018-2035 (metric tonnes).
- Figure 12. Global production of bio-based acrylic acid, 2018-2035 (metric tonnes).
- Figure 13. Global production of bio-based 1,3-Propanediol (1,3-PDO), 2018-2035 (metric tonnes).
- Figure 14. Global production of bio-based Succinic acid, 2018-2035 (metric tonnes).
- Figure 15. Global production of 1,4-Butanediol (BDO), 2018-2035 (metric tonnes).
- Figure 16. Global production of bio-based tetrahydrofuran (THF), 2018-2035 (metric tonnes).
- Figure 17. Overview of Toray process.
- Figure 18. Global production of bio-based caprolactam, 2018-2035 (metric tonnes).
- Figure 19. Global production of bio-based isobutanol, 2018-2035 (metric tonnes).
- Figure 20. Global production of bio-based p-xylene, 2018-2035 (metric tonnes).
- Figure 21. Global production of biobased terephthalic acid (TPA), 2018-2035 (metric tonnes).
- Figure 22. Global production of biobased 1,3 Propanediol, 2018-2035 (metric tonnes).
- Figure 23. Global production of biobased MEG, 2018-2035 (metric tonnes).
- Figure 24. Global production of biobased ethanol, 2018-2035 (million metric tonnes).
- Figure 25. Global production of biobased ethylene, 2018-2035 (million metric tonnes).
- Figure 26. Global production of biobased propylene, 2018-2035 (metric tonnes).
- Figure 27. Global production of biobased vinyl chloride, 2018-2035 (metric tonnes).
- Figure 28. Global production of bio-based Methly methacrylate, 2018-2035 (metric tonnes).
- Figure 29. Global production of biobased aniline, 2018-2035 (metric tonnes).

- Figure 30. Global production of biobased fructose, 2018-2035 (metric tonnes).
- Figure 31. Global production of biobased 5-Hydroxymethylfurfural (5-HMF), 2018-2035 (metric tonnes).
- Figure 32. Global production of biobased 5-(Chloromethyl)furfural (CMF), 2018-2035 (metric tonnes).
- Figure 33. Global production of biobased Levulinic acid, 2018-2035 (metric tonnes).
- Figure 34. Global production of biobased FDME, 2018-2035 (metric tonnes).
- Figure 35. Global production of biobased Furan-2,5-dicarboxylic acid (FDCA), 2018-2035 (metric tonnes).
- Figure 36. Global production projections for bio-based levoglucosenone from 2018 to 2035 in metric tonnes:
- Figure 37. Global production of hemicellulose, 2018-2035 (metric tonnes).
- Figure 38. Global production of biobased furfural, 2018-2035 (metric tonnes).
- Figure 39. Global production of biobased furfuryl alcohol, 2018-2035 (metric tonnes).
- Figure 40. Schematic of WISA plywood home.
- Figure 41. Global production of biobased lignin, 2018-2035 (metric tonnes).
- Figure 42. Global production of biobased glycerol, 2018-2035 (metric tonnes).
- Figure 43. Global production of Bio-MPG, 2018-2035 (metric tonnes).
- Figure 44. Global production of biobased ECH, 2018-2035 (metric tonnes).
- Figure 45. Global production of biobased fatty acids, 2018-2035 (million metric tonnes).
- Figure 46. Global production of biobased sebacic acid, 2018-2035 (metric tonnes).
- Figure 47. Global production of biobased 11-Aminoundecanoic acid (11-AA), 2018-2035 (metric tonnes).
- Figure 48. Global production of biobased Dodecanedioic acid (DDDA), 2018-2035 (metric tonnes).
- Figure 49. Global production of biobased Pentamethylene diisocyanate, 2018-2035 (metric tonnes).
- Figure 50. Global production of biobased casein, 2018-2035 (metric tonnes).
- Figure 51. Global production of food waste for biochemicals, 2018-2035 (million metric tonnes).
- Figure 52. Global production of agricultural waste for biochemicals, 2018-2035 (million metric tonnes).
- Figure 53. Global production of forestry waste for biochemicals, 2018-2035 (million metric tonnes).
- Figure 54. Global production of aquaculture/fishing waste for biochemicals, 2018-2035 (million metric tonnes).
- Figure 55. Global production of municipal solid waste for biochemicals, 2018-2035 (million metric tonnes).
- Figure 56. Global production of waste oils for biochemicals, 2018-2035 (million metric tonnes).

tonnes).

Figure 57. Global microalgae production, 2018-2035 (million metric tonnes).

Figure 58. Global macroalgae production, 2018-2035 (million metric tonnes).

Figure 59. Global production of biogas, 2018-2035 (billion m3).

Figure 60. Global production of syngas, 2018-2035 (billion m3).

Figure 61. formicobio technology.

Figure 62. Domsjo process.

Figure 63. TMP-Bio Process.

Figure 64. Lignin gel.

Figure 65. BioFlex process.

Figure 66. LX Process.

Figure 67. METNIN Lignin refining technology.

Figure 68. Enfinity cellulosic ethanol technology process.

Figure 69. Precision Photosynthesis technology.

Figure 70. Fabric consisting of 70 per cent wool and 30 per cent Qmilk.

Figure 71. UPM biorefinery process.

Figure 72. The Proesa Process.

Figure 73. Goldilocks process and applications.

Figure 74. Coca-Cola PlantBottle .

Figure 75. Interrelationship between conventional, bio-based and biodegradable plastics.

Figure 76. Polylactic acid (Bio-PLA) production 2019-2035 (1,000 tonnes).

Figure 77. Polyethylene terephthalate (Bio-PET) production 2019-2035 (1,000 tonnes)

Figure 78. Polytrimethylene terephthalate (PTT) production 2019-2035 (1,000 tonnes).

Figure 79. Production capacities of Polyethylene furanoate (PEF) to 2025.

Figure 80. Polyethylene furanoate (Bio-PEF) production 2019-2035 (1,000 tonnes).

Figure 81. Polyamides (Bio-PA) production 2019-2035 (1,000 tonnes).

Figure 82. Poly(butylene adipate-co-terephthalate) (Bio-PBAT) production 2019-2035 (1,000 tonnes).

Figure 83. Polybutylene succinate (PBS) production 2019-2035 (1,000 tonnes).

Figure 84. Polyethylene (Bio-PE) production 2019-2035 (1,000 tonnes).

Figure 85. Polypropylene (Bio-PP) production capacities 2019-2035 (1,000 tonnes).

Figure 86. PHA family.

Figure 87. PHA production capacities 2019-2035 (1,000 tonnes).

Figure 88. TEM image of cellulose nanocrystals.

Figure 89. CNC preparation.

Figure 90. Extracting CNC from trees.

Figure 91. CNC slurry.

Figure 92. CNF gel.

Figure 93. Bacterial nanocellulose shapes

Figure 94. BLOOM masterbatch from Algix.

Figure 95. Typical structure of mycelium-based foam.

Figure 96. Commercial mycelium composite construction materials.

Figure 97. Global production capacities for bioplastics by regionn 2019-2035, 1,000 tonnes.

Figure 98. Global production capacities for bioplastics by end user market 2019-2035, 1,000 tonnes.

Figure 99. PHA bioplastics products.

Figure 100. The global market for biobased and biodegradable plastics for flexible packaging 2019 2033 (000 tonnes).

Figure 101. Production volumes for bioplastics for rigid packaging, 2019 2033 (000 tonnes).

Figure 102. Global production for biobased and biodegradable plastics in consumer products 2019-2035, in 1,000 tonnes.

Figure 103. Global production capacities for biobased and biodegradable plastics in automotive 2019-2035, in 1,000 tonnes.

Figure 104. Global production volumes for biobased and biodegradable plastics in building and construction 2019-2035, in 1,000 tonnes.

Figure 105. Global production volumes for biobased and biodegradable plastics in textiles 2019-2035, in 1,000 tonnes.

Figure 106. Global production volumes for biobased and biodegradable plastics in electronics 2019-2035, in 1,000 tonnes.

Figure 107. Biodegradable mulch films.

Figure 108. Global production volulmes for biobased and biodegradable plastics in agriculture 2019-2035, in 1,000 tonnes.

Figure 109. High purity lignin.

Figure 110. Lignocellulose architecture.

Figure 111. Extraction processes to separate lignin from lignocellulosic biomass and corresponding technical lignins.

Figure 112. The lignocellulose biorefinery.

Figure 113. LignoBoost process.

Figure 114. LignoForce system for lignin recovery from black liquor.

Figure 115. Sequential liquid-lignin recovery and purification (SLPR) system.

Figure 116. A-Recovery+ chemical recovery concept.

Figure 117. Schematic of a biorefinery for production of carriers and chemicals.

Figure 118. Organosolv lignin.

Figure 119. Hydrolytic lignin powder.

Figure 120. Estimated consumption of lignin, 2019-2035 (000 MT).

- Figure 121. Pluumo.
- Figure 122. ANDRITZ Lignin Recovery process.
- Figure 123. Anpoly cellulose nanofiber hydrogel.
- Figure 124. MEDICELLU .
- Figure 125. Asahi Kasei CNF fabric sheet.
- Figure 126. Properties of Asahi Kasei cellulose nanofiber nonwoven fabric.
- Figure 127. CNF nonwoven fabric.
- Figure 128. Roof frame made of natural fiber.
- Figure 129. Beyond Leather Materials product.
- Figure 130. BIOLO e-commerce mailer bag made from PHA.
- Figure 131. Reusable and recyclable foodservice cups, lids, and straws from Joinease Hong Kong Ltd., made with plant-based NuPlastiQ BioPolymer from BioLogiQ, Inc.
- Figure 132. Fiber-based screw cap.
- Figure 133. formicobio technology.
- Figure 134. nanoforest-S.
- Figure 135. nanoforest-PDP.
- Figure 136. nanoforest-MB.
- Figure 137. sunliquid production process.
- Figure 138. CuanSave film.
- Figure 139. Celish.
- Figure 140. Trunk lid incorporating CNF.
- Figure 141. ELLEX products.
- Figure 142. CNF-reinforced PP compounds.
- Figure 143. Kirekira! toilet wipes.
- Figure 144. Color CNF.
- Figure 145. Rheocrysta spray.
- Figure 146. DKS CNF products.
- Figure 147. Domsjo process.
- Figure 148. Mushroom leather.
- Figure 149. CNF based on citrus peel.
- Figure 150. Citrus cellulose nanofiber.
- Figure 151. Filler Bank CNC products.
- Figure 152. Fibers on kapok tree and after processing.
- Figure 153. TMP-Bio Process.
- Figure 154. Flow chart of the lignocellulose biorefinery pilot plant in Leuna.
- Figure 155. Water-repellent cellulose.
- Figure 156. Cellulose Nanofiber (CNF) composite with polyethylene (PE).
- Figure 157. PHA production process.
- Figure 158. CNF products from Furukawa Electric.

Figure 159. AVAPTM process.

Figure 160. GreenPower+ process.

Figure 161. Cutlery samples (spoon, knife, fork) made of nano cellulose and biodegradable plastic composite materials.

Figure 162. Non-aqueous CNF dispersion "Senaf" (Photo shows 5% of plasticizer).

Figure 163. CNF gel.

Figure 164. Block nanocellulose material.

Figure 165. CNF products developed by Hokuetsu.

Figure 166. Marine leather products.

Figure 167. Inner Mettle Milk products.

Figure 168. Kami Shoji CNF products.

Figure 169. Dual Graft System.

Figure 170. Engine cover utilizing Kao CNF composite resins.

Figure 171. Acrylic resin blended with modified CNF (fluid) and its molded product (transparent film), and image obtained with AFM (CNF 10wt% blended).

Figure 172. Kel Labs yarn.

Figure 173. 0.3% aqueous dispersion of sulfated esterified CNF and dried transparent film (front side).

Figure 174. Lignin gel.

Figure 175. BioFlex process.

Figure 176. Nike Algae Ink graphic tee.

Figure 177. LX Process.

Figure 178. Made of Air's HexChar panels.

Figure 179. TransLeather.

Figure 180. Chitin nanofiber product.

Figure 181. Marusumi Paper cellulose nanofiber products.

Figure 182. FibriMa cellulose nanofiber powder.

Figure 183. METNIN Lignin refining technology.

Figure 184. IPA synthesis method.

Figure 185. MOGU-Wave panels.

Figure 186. CNF slurries.

Figure 187. Range of CNF products.

Figure 188. Reishi.

Figure 189. Compostable water pod.

Figure 190. Leather made from leaves.

Figure 191. Nike shoe with beLEAF .

Figure 192. CNF clear sheets.

Figure 193. Oji Holdings CNF polycarbonate product.

Figure 194. Enfinity cellulosic ethanol technology process.

- Figure 195. Fabric consisting of 70 per cent wool and 30 per cent Qmilk.
- Figure 196. XCNF.
- Figure 197: Plantrose process.
- Figure 198. LOVR hemp leather.
- Figure 199. CNF insulation flat plates.
- Figure 200. Hansa lignin.
- Figure 201. Manufacturing process for STARCEL.
- Figure 202. Manufacturing process for STARCEL.
- Figure 203. 3D printed cellulose shoe.
- Figure 204. Lyocell process.
- Figure 205. North Face Spiber Moon Parka.
- Figure 206. PANGAIA LAB NXT GEN Hoodie.
- Figure 207. Spider silk production.
- Figure 208. Stora Enso lignin battery materials.
- Figure 209. 2 wt.% CNF suspension.
- Figure 210. BiNFi-s Dry Powder.
- Figure 211. BiNFi-s Dry Powder and Propylene (PP) Complex Pellet.
- Figure 212. Silk nanofiber (right) and cocoon of raw material.
- Figure 213. Sulapac cosmetics containers.
- Figure 214. Sulzer equipment for PLA polymerization processing.
- Figure 215. Solid Novolac Type lignin modified phenolic resins.
- Figure 216. Teijin bioplastic film for door handles.
- Figure 217. Corbion FDCA production process.
- Figure 218. Comparison of weight reduction effect using CNF.
- Figure 219. CNF resin products.
- Figure 220. UPM biorefinery process.
- Figure 221. Vegea production process.
- Figure 222. The Proesa Process.
- Figure 223. Goldilocks process and applications.
- Figure 224. Visolis Hybrid Bio-Thermocatalytic Process.
- Figure 225. HefCel-coated wood (left) and untreated wood (right) after 30 seconds flame test.
- Figure 226. Worn Again products.
- Figure 227. Zelfo Technology GmbH CNF production process.
- Figure 228. Absolut natural based fiber bottle cap.
- Figure 229. Adidas algae-ink tees.
- Figure 230. Carlsberg natural fiber beer bottle.
- Figure 231. Miratex watch bands.
- Figure 232. Adidas Made with Nature Ultraboost 22.

Figure 233. PUMA RE:SUEDE sneaker

Figure 234. Types of natural fibers.

Figure 235. Luffa cylindrica fiber.

Figure 236. Pineapple fiber.

Figure 237. Typical structure of mycelium-based foam.

Figure 238. Commercial mycelium composite construction materials.

Figure 239. SEM image of microfibrillated cellulose.

Figure 240. Hemp fibers combined with PP in car door panel.

Figure 241. Car door produced from Hemp fiber.

Figure 242. Natural fiber composites in the BMW M4 GT4 racing car.

Figure 243. Mercedes-Benz components containing natural fibers.

Figure 244. SWOT analysis: natural fibers in the automotive market.

Figure 245. SWOT analysis: natural fibers in the packaging market.

Figure 246. SWOT analysis: natural fibers in the appliances market.

Figure 247. SWOT analysis: natural fibers in the appliances market.

Figure 248. SWOT analysis: natural fibers in the consumer electronics market.

Figure 249. SWOT analysis: natural fibers in the furniture market.

Figure 250. Global market for natural fiber based plastics, 2018-2035, by market (Billion USD).

Figure 251. Global market for natural fiber based plastics, 2018-2035, by material type (Billion USD).

Figure 252. Global market for natural fiber based plastics, 2018-2035, by plastic type (Billion USD).

Figure 253. Global market for natural fiber based plastics, 2018-2035, by region (Billion USD).

Figure 254. Asahi Kasei CNF fabric sheet.

Figure 255. Properties of Asahi Kasei cellulose nanofiber nonwoven fabric.

Figure 256. CNF nonwoven fabric.

Figure 257. Roof frame made of natural fiber.

Figure 258. Tras Rei chair incorporating ampliTex fibers.

Figure 259. Natural fibres racing seat.

Figure 260. Porche Cayman GT4 Clubsport incorporating BComp flax fibers.

Figure 261. Fiber-based screw cap.

Figure 262. Cellugy materials.

Figure 263. CuanSave film.

Figure 264. Trunk lid incorporating CNF.

Figure 265. ELLEX products.

Figure 266. CNF-reinforced PP compounds.

Figure 267. Kirekira! toilet wipes.

- Figure 268. DKS CNF products.
- Figure 269. Cellulose Nanofiber (CNF) composite with polyethylene (PE).
- Figure 270. CNF products from Furukawa Electric.
- Figure 271. Cutlery samples (spoon, knife, fork) made of nano cellulose and biodegradable plastic composite materials.
- Figure 272. CNF gel.
- Figure 273. Block nanocellulose material.
- Figure 274. CNF products developed by Hokuetsu.
- Figure 275. Dual Graft System.
- Figure 276. Engine cover utilizing Kao CNF composite resins.
- Figure 277. Acrylic resin blended with modified CNF (fluid) and its molded product (transparent film), and image obtained with AFM (CNF 10wt% blended).
- Figure 278. Cellulomix production process.
- Figure 279. Nanobase versus conventional products.
- Figure 280. MOGU-Wave panels.
- Figure 281. CNF clear sheets.
- Figure 282. Oji Holdings CNF polycarbonate product.
- Figure 283. A vacuum cleaner part made of cellulose fiber (left) and the assembled vacuum cleaner.
- Figure 284. XCNF.
- Figure 285. Manufacturing process for STARCEL.
- Figure 286. 2 wt.% CNF suspension.
- Figure 287. Sulapac cosmetics containers.
- Figure 288. Comparison of weight reduction effect using CNF.
- Figure 289. CNF resin products.
- Figure 290. Global revenues in sustainable construction materials, by type 2018-2035 (billions USD).
- Figure 291. Typical structure of mycelium-based foam.
- Figure 292. Commercial mycelium composite construction materials.
- Figure 293. Self-healing bacteria crack filler for concrete.
- Figure 294. Self-healing concrete test study with cracked concrete (left) and self-healed concrete after 28 days (right).
- Figure 295. Self-healing concrete.
- Figure 296. Microalgae based biocement masonry bloc.
- Figure 297. Classification of aerogels.
- Figure 298. Flower resting on a piece of silica aerogel suspended in mid air by the flame of a bunsen burner.
- Figure 299. Monolithic aerogel.
- Figure 300. Aerogel granules.

- Figure 301. Internal aerogel granule applications.
- Figure 302. 3D printed aerogels.
- Figure 303. Lignin-based aerogels.
- Figure 304. Fabrication routes for starch-based aerogels.
- Figure 305. Schematic of silk fiber aerogel synthesis.
- Figure 306. Graphene aerogel.
- Figure 307. Schematic of CCUS in cement sector.
- Figure 308. Carbon8 Systems ACT process.
- Figure 309. CO₂ utilization in the Carbon Cure process.
- Figure 310. Share of (a) production, (b) energy consumption and (c) CO₂ emissions from different steel making routes.
- Figure 311. Transition to hydrogen-based production.
- Figure 312. CO₂ emissions from steelmaking (tCO₂/ton crude steel).
- Figure 313. CO₂ emissions of different process routes for liquid steel.
- Figure 314. Hydrogen Direct Reduced Iron (DRI) process.
- Figure 315. Molten oxide electrolysis process.
- Figure 316. Steelmaking with CCS.
- Figure 317. Flash ironmaking process.
- Figure 318. Hydrogen Plasma Iron Ore Reduction process.
- Figure 319. ArcelorMittal decarbonization strategy.
- Figure 320. Thermal Conductivity Performance of ArmaGel HT.
- Figure 321. SLENTEX roll (piece).
- Figure 322. Neustark modular plant.
- Figure 323. HIP AERO paint.
- Figure 324. Sunthru Aerogel pane.
- Figure 325. Quartzene .
- Figure 326. Schematic of HyREX technology.
- Figure 327. EAF Quantum.
- Figure 328. CNF insulation flat plates.
- Figure 329. Global packaging market by material type. 1005
- Figure 330. Routes for synthesizing polymers from fossil-based and bio-based resources. 1015
- Figure 331. PHA bioplastic packaging products. 1018
- Figure 332. Production capacities of Polyethylene furanoate (PEF) to 2025. 1029
- Figure 333. Production capacities of Polyethylene furanoate (PEF) to 2025. 1038
- Figure 334. Polyethylene furanoate (Bio-PEF) production capacities 2019-2035 (1,000 tons). 1039
- Figure 335. PHA family. 1046
- Figure 336. PHA production capacities 2019-2035 (1,000 tons). 1059

- Figure 337. Schematic diagram of partial molecular structure of cellulose chain with numbering for carbon atoms and n = number of cellobiose repeating unit. 1061
- Figure 338. Scale of cellulose materials. 1062
- Figure 339. Organization and morphology of cellulose synthesizing terminal complexes (TCs) in different organisms. 1063
- Figure 340. Biosynthesis of (a) wood cellulose (b) tunicate cellulose and (c) BC. 1064
- Figure 341. Cellulose microfibrils and nanofibrils. 1066
- Figure 342. TEM image of cellulose nanocrystals. 1067
- Figure 343. CNC slurry. 1068
- Figure 344. CNF gel. 1069
- Figure 345. Bacterial nanocellulose shapes 1078
- Figure 346. BLOOM masterbatch from Algix. 1085
- Figure 347. Typical structure of mycelium-based foam. 1088
- Figure 348. Commercial mycelium composite construction materials. 1088
- Figure 349. Types of bio-based materials used for antimicrobial food packaging application. 1104
- Figure 350. Schematic of gas barrier properties of nanoclay film. 1110
- Figure 351. Hefcel-coated wood (left) and untreated wood (right) after 30 seconds flame test. 1125
- Figure 352. Applications for CO₂. 1129
- Figure 353. Life cycle of CO₂-derived products and services. 1132
- Figure 354. Conversion pathways for CO₂-derived polymeric materials 1133
- Figure 355. Bioplastics for flexible packaging by bioplastic material type, 2019 2033 (000 tonnes). 1138
- Figure 356. Bioplastics for rigid packaging by bioplastic material type, 2019 2033 (000 tonnes). 1141
- Figure 357. Market revenues for bio-based coatings, 2018-2035 (billions USD), conservative estimate. 1142
- Figure 358. Pluumo. 1146
- Figure 359. Anpoly cellulose nanofiber hydrogel. 1154
- Figure 360. MEDICELLU . 1155
- Figure 361. Asahi Kasei CNF fabric sheet. 1162
- Figure 362. Properties of Asahi Kasei cellulose nanofiber nonwoven fabric. 1163
- Figure 363. CNF nonwoven fabric. 1164
- Figure 364. Passionfruit wrapped in Xgo Circular packaging. 1170
- Figure 365. BIOLO e-commerce mailer bag made from PHA. 1174
- Figure 366. Reusable and recyclable foodservice cups, lids, and straws from Joinease Hong Kong Ltd., made with plant-based NuPlastiQ BioPolymer from BioLogiQ, Inc. 1176

- Figure 367. Fiber-based screw cap. 1185
- Figure 368. CuanSave film. 1200
- Figure 369. ELLEX products. 1202
- Figure 370. CNF-reinforced PP compounds. 1203
- Figure 371. Kirekira! toilet wipes. 1203
- Figure 372. Rheocrysta spray. 1207
- Figure 373. DKS CNF products. 1208
- Figure 374. Photograph (a) and micrograph (b) of mineral/ MFC composite showing the high viscosity and fibrillar structure. 1220
- Figure 375. PHA production process. 1225
- Figure 376. AVAPTM process. 1230
- Figure 377. GreenPower+ process. 1231
- Figure 378. Cutlery samples (spoon, knife, fork) made of nano cellulose and biodegradable plastic composite materials. 1233
- Figure 379. CNF gel. 1235
- Figure 380. Block nanocellulose material. 1236
- Figure 381. CNF products developed by Hokuetsu. 1236
- Figure 382. Kami Shoji CNF products. 1242
- Figure 383. IPA synthesis method. 1262
- Figure 384. Compostable water pod. 1272
- Figure 385. XCNF. 1288
- Figure 386: Innventia AB movable nanocellulose demo plant. 1290
- Figure 387. Shellworks packaging containers. 1295
- Figure 388. Thales packaging incorporating Fibrease. 1302
- Figure 389. Sulapac cosmetics containers. 1304
- Figure 390. Sulzer equipment for PLA polymerization processing. 1305
- Figure 391. Silver / CNF composite dispersions. 1312
- Figure 392. CNF/nanosilver powder. 1312
- Figure 393. Corbion FDCA production process. 1314
- Figure 394. UPM biorefinery process. 1316
- Figure 395. Vegea production process. 1320
- Figure 396. Worn Again products. 1324
- Figure 397. S-CNF in powder form. 1325
- Figure 398. Conceptual landscape of next-gen leather materials. 1340
- Figure 399. Typical structure of mycelium-based foam. 1357
- Figure 400. Hermes bag made of MycoWorks' mycelium leather. 1360
- Figure 401. Ganni blazer made from bacterial cellulose. 1366
- Figure 402. Bou Bag by GANNI and Modern Synthesis. 1367
- Figure 403. Global revenues for bio-based textiles by type, 2018-2035 (millions USD).

1383

Figure 404. Global revenues for bio-based and sustainable textiles by end use market, 2018-2035 (millions USD). 1386

Figure 405. Beyond Leather Materials product. 1391

Figure 406. Treekind. 1393

Figure 407. Examples of Stella McCartney and Adidas products made using leather alternative Mylo. 1395

Figure 408. Mushroom leather. 1398

Figure 409. Ecovative Design Forager Hides. 1399

Figure 410. LUNA leather. 1405

Figure 411. TransLeather. 1408

Figure 412. Reishi. 1414

Figure 413. AirCarbon Pellets and AirCarbon Leather. 1420

Figure 414. Leather made from leaves. 1424

Figure 415. Nike shoe with beLEAF . 1425

Figure 416. Persiskin leather. 1428

Figure 417. LOVR hemp leather. 1433

Figure 418. North Face Spiber Moon Parka. 1436

Figure 419. PANGAIA LAB NXT GEN Hoodie. 1437

Figure 420. Ultrasuede headrest covers. 1439

Figure 421. Vegea production process. 1442

Figure 422. Schematic of production of powder coatings. 1452

Figure 423. Organization and morphology of cellulose synthesizing terminal complexes (TCs) in different organisms. 1456

Figure 424. PHA family. 1481

Figure 425: Schematic diagram of partial molecular structure of cellulose chain with numbering for carbon atoms and n = number of cellobiose repeating unit. 1485

Figure 426: Scale of cellulose materials. 1486

Figure 427. Nanocellulose preparation methods and resulting materials. 1487

Figure 428: Relationship between different kinds of nanocelluloses. 1489

Figure 429. SEM image of microfibrillated cellulose. 1491

Figure 430. Applications of cellulose nanofibers in paints and coatings. 1496

Figure 431: CNC slurry. 1501

Figure 432. Types of bio-based materials used for antimicrobial food packaging application. 1508

Figure 433. BLOOM masterbatch from Algix. 1515

Figure 434. Global market revenues for bio-based coatings by type, 2018-2035 (billions USD). 1519

Figure 435. Market revenues for bio-based coatings by market, 2018-2035 (billions

- USD), conservative estimate. 1521
- Figure 436. Dulux Better Living Air Clean Bio-based. 1524
- Figure 437. NCCTM Process. 1552
- Figure 438. CNC produced at Tech Futures pilot plant; cloudy suspension (1 wt.%), gel-like (10 wt.%), flake-like crystals, and very fine powder. Product advantages include: 1552
- Figure 439. Cellugy materials. 1554
- Figure 440. EcoLine 3690 (left) vs Solvent-Based Competitor Coating (right). 1559
- Figure 441. Rheocrysta spray. 1567
- Figure 442. DKS CNF products. 1567
- Figure 443. Domsjo process. 1569
- Figure 444. CNF gel. 1590
- Figure 445. Block nanocellulose material. 1590
- Figure 446. CNF products developed by Hokuetsu. 1591
- Figure 447. VIVAPUR MCC Spheres. 1597
- Figure 448. BioFlex process. 1610
- Figure 449. Marusumi Paper cellulose nanofiber products. 1613
- Figure 450. Melodea CNC barrier coating packaging. 1615
- Figure 451. Fluorene cellulose powder. 1636
- Figure 452. XCNF. 1645
- Figure 453. Plantrose process. 1646
- Figure 454. Spider silk production. 1658
- Figure 455. CNF dispersion and powder from Starlite. 1660
- Figure 456. 2 wt.% CNF suspension. 1664
- Figure 457. BiNFfi-s Dry Powder. 1665
- Figure 458. BiNFfi-s Dry Powder and Propylene (PP) Complex Pellet. 1665
- Figure 459. Silk nanofiber (right) and cocoon of raw material. 1666
- Figure 460. traceless hooks. 1669
- Figure 461. HefCel-coated wood (left) and untreated wood (right) after 30 seconds flame test. 1671
- Figure 462. Bio-based barrier bags prepared from Tempo-CNF coated bio-HDPE film. 1672
- Figure 463. Bioalkyd products. 1677
- Figure 464. Liquid biofuel production and consumption (in thousands of m3), 2000-2022. 1681
- Figure 465. Distribution of global liquid biofuel production in 2022. 1682
- Figure 466. Diesel and gasoline alternatives and blends. 1688
- Figure 467. SWOT analysis for biofuels. 1690
- Figure 468. Schematic of a biorefinery for production of carriers and chemicals. 1702

- Figure 469. Hydrolytic lignin powder. 1705
- Figure 470. SWOT analysis for energy crops in biofuels. 1712
- Figure 471. SWOT analysis for agricultural residues in biofuels. 1713
- Figure 472. SWOT analysis for Manure, sewage sludge and organic waste in biofuels. 1715
- Figure 473. SWOT analysis for forestry and wood waste in biofuels. 1717
- Figure 474. Range of biomass cost by feedstock type. 1718
- Figure 475. Regional production of biodiesel (billion litres). 1720
- Figure 476. SWOT analysis for biodiesel. 1722
- Figure 477. Flow chart for biodiesel production. 1726
- Figure 478. Biodiesel (B20) average prices, current and historical, USD/litre. 1733
- Figure 479. Global biodiesel consumption, 2010-2035 (M litres/year). 1735
- Figure 480. SWOT analysis for renewable diesel. 1739
- Figure 481. Global renewable diesel consumption, 2010-2035 (M litres/year). 1740
- Figure 482. SWOT analysis for Bio-aviation fuel. 1743
- Figure 483. Global bio-jet fuel consumption to 2019-2035 (Million litres/year). 1748
- Figure 484. SWOT analysis for bio-naphtha. 1752
- Figure 485. Bio-based naphtha production capacities, 2018-2035 (tonnes). 1756
- Figure 486. SWOT analysis biomethanol. 1757
- Figure 487. Renewable Methanol Production Processes from Different Feedstocks. 1758
- Figure 488. Production of biomethane through anaerobic digestion and upgrading. 1760
- Figure 489. Production of biomethane through biomass gasification and methanation. 1761
- Figure 490. Production of biomethane through the Power to methane process. 1761
- Figure 491. SWOT analysis for ethanol. 1764
- Figure 492. Ethanol consumption 2010-2035 (million litres). 1770
- Figure 493. Properties of petrol and biobutanol. 1772
- Figure 494. Biobutanol production route. 1772
- Figure 495. Biogas and biomethane pathways. 1775
- Figure 496. Overview of biogas utilization. 1777
- Figure 497. Biogas and biomethane pathways. 1778
- Figure 498. Schematic overview of anaerobic digestion process for biomethane production. 1780
- Figure 499. Schematic overview of biomass gasification for biomethane production. 1781
- Figure 500. SWOT analysis for biogas. 1782
- Figure 501. Total syngas market by product in MM Nm³/h of Syngas, 2021. 1786
- Figure 502. SWOT analysis for biohydrogen. 1789

- Figure 503. Waste plastic production pathways to (A) diesel and (B) gasoline 1795
- Figure 504. Schematic for Pyrolysis of Scrap Tires. 1796
- Figure 505. Used tires conversion process. 1798
- Figure 506. Total syngas market by product in MM Nm³/h of Syngas, 2021. 1801
- Figure 507. Overview of biogas utilization. 1802
- Figure 508. Biogas and biomethane pathways. 1803
- Figure 509. SWOT analysis for chemical recycling of biofuels. 1806
- Figure 510. Process steps in the production of electrofuels. 1807
- Figure 511. Mapping storage technologies according to performance characteristics. 1808
- Figure 512. Production process for green hydrogen. 1811
- Figure 513. SWOT analysis for E-fuels. 1812
- Figure 514. E-liquids production routes. 1813
- Figure 515. Fischer-Tropsch liquid e-fuel products. 1814
- Figure 516. Resources required for liquid e-fuel production. 1814
- Figure 517. Levelized cost and fuel-switching CO₂ prices of e-fuels. 1819
- Figure 518. Cost breakdown for e-fuels. 1821
- Figure 519. Pathways for algal biomass conversion to biofuels. 1823
- Figure 520. SWOT analysis for algae-derived biofuels. 1824
- Figure 521. Algal biomass conversion process for biofuel production. 1826
- Figure 522. Classification and process technology according to carbon emission in ammonia production. 1829
- Figure 523. Green ammonia production and use. 1830
- Figure 524. Schematic of the Haber Bosch ammonia synthesis reaction. 1832
- Figure 525. Schematic of hydrogen production via steam methane reformation. 1832
- Figure 526. SWOT analysis for green ammonia. 1834
- Figure 527. Estimated production cost of green ammonia. 1839
- Figure 528. Projected annual ammonia production, million tons. 1840
- Figure 529. CO₂ capture and separation technology. 1843
- Figure 530. Conversion route for CO₂-derived fuels and chemical intermediates. 1844
- Figure 531. Conversion pathways for CO₂-derived methane, methanol and diesel. 1845
- Figure 532. SWOT analysis for biofuels from carbon capture. 1848
- Figure 533. CO₂ captured from air using liquid and solid sorbent DAC plants, storage, and reuse. 1848
- Figure 534. Global CO₂ capture from biomass and DAC in the Net Zero Scenario. 1849
- Figure 535. DAC technologies. 1852
- Figure 536. Schematic of Climeworks DAC system. 1853
- Figure 537. Climeworks first commercial direct air capture (DAC) plant, based in Hinwil, Switzerland. 1854

- Figure 538. Flow diagram for solid sorbent DAC. 1854
- Figure 539. Direct air capture based on high temperature liquid sorbent by Carbon Engineering. 1855
- Figure 540. Global capacity of direct air capture facilities. 1860
- Figure 541. Global map of DAC and CCS plants. 1866
- Figure 542. Schematic of costs of DAC technologies. 1868
- Figure 543. DAC cost breakdown and comparison. 1869
- Figure 544. Operating costs of generic liquid and solid-based DAC systems. 1871
- Figure 545. Conversion route for CO₂-derived fuels and chemical intermediates. 1876
- Figure 546. Conversion pathways for CO₂-derived methane, methanol and diesel. 1877
- Figure 547. CO₂ feedstock for the production of e-methanol. 1886
- Figure 548. Schematic illustration of (a) biophotosynthetic, (b) photothermal, (c) microbial-photoelectrochemical, (d) photosynthetic and photocatalytic (PS/PC), (e) photoelectrochemical (PEC), and (f) photovoltaic plus electrochemical (PV+EC) approaches for CO₂. 1891
- Figure 549. SWOT analysis: CO₂ utilization in fuels. 1894
- Figure 550. Audi synthetic fuels. 1895
- Figure 551. Bio-oil upgrading/fractionation techniques. 1900
- Figure 552. SWOT analysis for bio-oils. 1901
- Figure 553. ANDRITZ Lignin Recovery process. 1914
- Figure 554. ChemCycling™ prototypes. 1921
- Figure 555. ChemCycling circle by BASF. 1921
- Figure 556. FBPO process 1934
- Figure 557. Direct Air Capture Process. 1938
- Figure 558. CRI process. 1941
- Figure 559. Cassandra Oil process. 1944
- Figure 560. Colyser process. 1953
- Figure 561. ECFORM electrolysis reactor schematic. 1958
- Figure 562. Dioxycle modular electrolyzer. 1959
- Figure 563. Domsjo process. 1960
- Figure 564. FuelPositive system. 1974
- Figure 565. INERATEC unit. 1993
- Figure 566. Infinitree swing method. 1995
- Figure 567. Audi/Krajete unit. 2001
- Figure 568. Enfinity cellulosic ethanol technology process. 2031
- Figure 569: Plantrose process. 2040
- Figure 570. Sunfire process for Blue Crude production. 2059
- Figure 571. Takavator. 2063
- Figure 572. O12 Reactor. 2066

- Figure 573. Sunglasses with lenses made from CO₂-derived materials. 2067
- Figure 574. CO₂ made car part. 2067
- Figure 575. The Velocys process. 2070
- Figure 576. Goldilocks process and applications. 2073
- Figure 577. The Proesa Process. 2074
- Figure 578. Closed-loop manufacturing. 2094
- Figure 579. Sustainable supply chain for electronics. 2107
- Figure 580. Flexible PCB. 2115
- Figure 581. Vapor degreasing. 2120
- Figure 582. Multi-layered PCB. 2121
- Figure 583. 3D printed PCB. 2123
- Figure 584. In-mold electronics prototype devices and products. 2124
- Figure 585. Silver nanocomposite ink after sintering and resin bonding of discrete electronic components. 2126
- Figure 586. Typical structure of mycelium-based foam. 2132
- Figure 587. Flexible electronic substrate made from CNF. 2136
- Figure 588. CNF composite. 2137
- Figure 589. Oji CNF transparent sheets. 2137
- Figure 590. Electronic components using cellulose nanofibers as insulating materials. 2138
- Figure 591. BLOOM masterbatch from Algix. 2138
- Figure 592. Dell's Concept Luna laptop. 2147
- Figure 593. Direct-write, precision dispensing, and 3D printing platform for 3D printed electronics. 2153
- Figure 594. 3D printed circuit boards from Nano Dimension. 2153
- Figure 595. Photonic sintering. 2154
- Figure 596. Laser-induced forward transfer (LIFT). 2156
- Figure 597. Material jetting 3d printing. 2163
- Figure 598. Material jetting 3d printing product. 2163
- Figure 599. The molecular mechanism of the shape memory effect under different stimuli. 2169
- Figure 600. Supercooled Soldering Technology. 2174
- Figure 601. Reflow soldering schematic. 2175
- Figure 602. Schematic diagram of induction heating reflow. 2176
- Figure 603. Fully-printed organic thin-film transistors and circuitry on one-micron-thick polymer films. 2182
- Figure 604. Types of PCBs after dismantling waste computers and monitors. 2193
- Figure 605. Global PCB revenues 2018-2035 (billions USD), by substrate types. 2199
- Figure 606. Global sustainable PCB revenues 2018-2035, by type (millions USD). 2201

- Figure 607. Global sustainable ICs revenues 2018-2035, by type (millions USD). 2203
- Figure 608. Piezotech FC. 2210
- Figure 609. PowerCoat paper. 2211
- Figure 610. BeFC biofuel cell and digital platform. 2212
- Figure 611. DPP-360 machine. 2216
- Figure 612. P-Flex Flexible Circuit. 2218
- Figure 613. Fairphone 4. 2220
- Figure 614. In2tec s fully recyclable flexible circuit board assembly. 2226
- Figure 615. C.L.A.D. system. 2228
- Figure 616. Soluboard immersed in water. 2230
- Figure 617. Infineon PCB before and after immersion. 2231
- Figure 618. Nano OPS Nanoscale wafer printing system. 2234
- Figure 619. Stora Enso lignin battery materials. 2246
- Figure 620. 3D printed electronics. 2249
- Figure 621. Tactotek IME device. 2250
- Figure 622. TactoTek IMSE SiP - System In Package. 2251
- Figure 623. Verde Bio-based resins. 2255
- Figure 624. Global market revenues for bio-based adhesives & sealants, by types, 2018-2035 (millions USD). 2264
- Figure 625. Global market revenues for bio-based adhesives & sealants, by market, 2018-2035 (millions USD). 2266
- Figure 626. sunliquid production process. 2274
- Figure 627. Spider silk production. 2284

I would like to order

Product name: The Global Market for Biobased and Sustainable Materials 2024-2035

Product link: <https://marketpublishers.com/r/G1971FE9D7A9EN.html>

Price: US\$ 1,266.00 (Single User License / Electronic Delivery)

If you want to order Corporate License or Hard Copy, please, contact our Customer Service:

info@marketpublishers.com

Payment

To pay by Credit Card (Visa, MasterCard, American Express, PayPal), please, click button on product page <https://marketpublishers.com/r/G1971FE9D7A9EN.html>

To pay by Wire Transfer, please, fill in your contact details in the form below:

First name:
Last name:
Email:
Company:
Address:
City:
Zip code:
Country:
Tel:
Fax:
Your message:

****All fields are required**

Customer signature _____

Please, note that by ordering from marketpublishers.com you are agreeing to our Terms & Conditions at <https://marketpublishers.com/docs/terms.html>

To place an order via fax simply print this form, fill in the information below and fax the completed form to +44 20 7900 3970