

The Global Market for Nanocellulose

Table of contents

1 EXECUTIVE SUMMARY.....	31
1.1 Applications.....	31
1.2 Market segmentation by type of nanocellulose.....	35
1.2.1 Cellulose nanofibers (CNF).....	36
1.2.2 MFC.....	37
1.2.3 Cellulose nanocrystals (CNC).....	38
1.3 Main opportunities in nanocellulose.....	38
1.4 Global production.....	41
1.4.1 Production plants and production status.....	42
1.5 Market trends.....	43
1.6 Market and technical challenges.....	44
1.7 Global nanocellulose market size.....	45
1.7.1 The market for nanocellulose in 2017.....	45
1.7.2 The market for nanocellulose in 2018.....	47
1.7.3 Nanocellulose demand in tons, 2015–2030.....	48
1.7.4 Nanocellulose market by region.....	49
1.7.4.1 Asia-Pacific.....	50
2 RESEARCH SCOPE AND METHODOLOGY.....	52

3	INTRODUCTION.....	58
3.1	Cellulose.....	58
3.2	Nanocellulose.....	58
3.3	Properties of nanocellulose.....	59
3.4	Advantages of nanocellulose.....	60
3.5	Manufacture of nanocellulose.....	60
3.6	Production methods.....	61
3.7	Types of nanocellulose.....	62
3.7.1	Microfibrillated cellulose (MFC).....	64
3.7.2	Cellulose nanofibers (CNF).....	64
3.7.2.1	Applications.....	64
3.7.2.2	Production methods of CNF producers.....	66
3.7.3	Cellulose nanocrystals (CNC).....	67
3.7.3.1	Properties.....	69
3.7.3.2	Applications.....	69
3.7.4	Bacterial Cellulose (BC).....	71
3.7.4.1	Applications.....	71
3.8	Synthesis.....	72
3.8.1	Microcrystalline cellulose (MC).....	72

3.8.2	Microfibrillated cellulose (MFC).....	72
3.8.3	Nanofibrillated cellulose (CNF).....	72
3.8.4	Cellulose nanocrystals (CNC).....	73
3.8.5	Bacterial cellulose particles (CNC).....	74
3.9	Nanocellulose structures.....	74
3.9.1	Films.....	74
3.9.2	Hydrogels and aerogels.....	75
3.9.3	Foams.....	75
4	MARKET STRUCTURE.....	76
4.1	Volume of industry demand for nanocellulose.....	76
4.2	Current end users for nanocellulose, by market and company.....	77
5	SWOT ANALYSIS FOR NANOCELLULOSE.....	80
6	REGULATIONS AND STANDARDS.....	82
7	REGIONAL INITIATIVES AND GOVERNMENT FUNDING.....	86
8	NANOCELLULOSE APPLICATIONS.....	87
9	NANOCELLULOSE TECHNOLOGY READINESS LEVEL (TRL)....	88
10	NANOCELLULOSE SUPPLY CHAIN.....	89
11	NANOCELLULOSE PRICES.....	91
12	NANOCELLULOSE PATENTS & PUBLICATIONS.....	93
13	COMPETITIVE MATERIALS.....	97
14	GLOBAL MARKETS FOR NANOCELLULOSE.....	101
14.1	COMPOSITES MARKET SUMMARY.....	101

14.1.1	Trends in the composites market and nanocellulose solutions.....	101
14.1.2	Comparison of nanocellulose to other composite materials.....	102
14.1.3	Applications.....	103
14.1.3.1	By cellulose type.....	103
14.1.3.2	Applications roadmap.....	104
14.2	PACKAGING.....	104
14.2.1	Market trends and nanocellulose solution.....	104
14.2.2	Applications.....	108
14.2.2.1	Anti-bacterial.....	109
14.2.2.2	Gas barrier.....	109
14.2.2.3	Anti-counterfeiting films.....	110
14.2.3	Nanocellulose market in packaging.....	110
14.2.3.1	Applications market readiness and market acceptability analysis.....	111
14.2.3.2	Global demand in tons for Nanocellulose in packaging.....	112
14.2.4	Market challenges.....	113
14.2.5	Product developer profiles.....	114
14.3	AIRCRAFT AND AEROSPACE.....	115
14.3.1	Market trends and Nanocellulose solution.....	115
14.3.2	Applications.....	116

14.3.2.1	Composites.....	116
14.3.3	Nanocellulose market in aircraft and aerospace.....	117
14.3.3.1	Applications market readiness and market acceptability analysis.....	117
14.3.3.2	Global demand in tons in aircraft and aerospace.....	118
14.3.4	Market challenges.....	119
14.3.5	Product developer profiles.....	119
14.4	AUTOMOTIVE.....	119
14.4.1	Market trends and Nanocellulose solution.....	119
14.4.2	Applications.....	122
14.4.2.1	Composites.....	123
14.4.3	Nanocellulose market in automotive.....	123
14.4.3.1	Polymer composites.....	123
14.4.3.2	Tires.....	125
14.4.4	Applications market readiness and market acceptability analysis.....	126
14.4.5	Global demand in tons in automotive.....	126
14.4.6	Market challenges.....	127
14.4.7	Product developer profiles.....	128
14.5	CONSTRUCTION.....	130

14.5.1	Market drivers and trends.....	130
14.5.2	Applications.....	131
14.5.3	Nanocellulose market in construction.....	132
14.5.3.1	Applications market readiness and market acceptability analysis.....	132
14.5.3.2	Global demand in tons in construction.....	133
14.5.4	Market challenges.....	134
14.5.5	Product developer profiles.....	135
14.6	PAPER AND BOARD.....	135
14.6.1	Market drivers and trends.....	135
14.6.2	Applications.....	136
14.6.3	Properties.....	136
14.6.3.1	Reinforcing agents.....	137
14.6.3.2	Transparency and flexibility.....	137
14.6.3.3	Paper packaging.....	137
14.6.3.4	Paper coatings.....	137
14.6.3.5	Anti-microbials.....	137
14.6.4	Nanocellulose market in paper & board.....	138
14.6.4.1	Applications market readiness and market acceptability analysis.....	138

14.6.4.2	Global demand in tons in paper & board.....	139
14.6.5	Market challenges.....	139
14.6.6	Product developer profiles.....	140
14.7	TEXTILES.....	142
14.7.1	Market drivers and trends.....	142
14.7.2	Applications.....	143
14.7.2.1	Turning pulp into textiles.....	143
14.7.2.2	Sanitary products.....	143
14.7.3	Nanocellulose market in textiles.....	144
14.7.3.1	Applications market readiness and market acceptability analysis.....	144
14.7.3.2	Global demand in tons in textiles.....	145
14.7.4	Market challenges.....	146
14.7.5	Product developer profiles.....	146
14.8	MEDICINE & HEALTHCARE.....	147
14.8.1	Market drivers and trends.....	147
14.8.2	Applications.....	148
14.8.2.1	Drug delivery.....	149
14.8.2.2	Medical implants.....	149

14.8.2.3	Tissue engineering.....	150
14.8.2.4	Wound dressings.....	150
14.8.2.5	Lateral flow immunoassay labels.....	150
14.8.3	Nanocellulose market in medical & healthcare.....	150
14.8.3.1	Applications market readiness and market acceptability analysis.....	150
14.8.3.2	Global demand in tons in medical & healthcare.....	151
14.8.4	Product developer profiles.....	152
14.9	COATINGS.....	153
14.9.1	Market drivers and trends.....	153
14.9.2	Applications.....	155
14.9.2.1	Abrasion and scratch resistance.....	156
14.9.2.2	Wood coatings.....	156
14.9.2.3	Anti-counterfeiting films.....	156
14.9.2.4	Gas barriers.....	156
14.9.3	Nanocellulose market in coatings.....	156
14.9.3.1	Applications market readiness and market acceptability analysis.....	158
14.9.3.2	Global demand in tons in paints and coatings.....	159

14.9.4	Market challenges.....	160
14.9.5	Product developer profiles.....	161
14.10	AEROGELS.....	162
14.10.1	Market drivers and trends.....	162
14.10.2	Applications.....	163
14.10.2.1	Thermal insulation.....	163
14.10.2.2	Shape memory.....	164
14.10.3	Nanocellulose market in aerogels.....	164
14.10.3.1	Global demand in tons in aerogels.....	164
14.10.4	Product developer profiles.....	165
14.11	OIL AND GAS EXPLORATION.....	165
14.11.1	Market drivers and trends.....	165
14.11.2	Applications.....	166
14.11.2.1	Oil and fracking drilling fluids.....	167
14.11.2.2	Extraction.....	169
14.11.3	Nanocellulose market in oil and gas.....	169
14.11.3.1	Market assessment for Nanocellulose in oil and gas.....	169
14.11.3.2	Global demand in tons in oil and gas.....	170

14.11.4	Market challenges.....	
172		
14.11.5	Product developer profiles.....	
172		
14.12	FILTRATION.....	173
14.12.1	Market drivers and trends.....	
173		
14.12.2	Applications.....	174
14.12.2.1	Nanomaterials in filtration.....	174
14.12.2.2	Nanocellulose membranes and filters.....	175
14.12.2.3	Water filtration.....	176
14.12.2.4	Air filtration.....	177
14.12.2.5	Virus filtration.....	178
14.12.3	Nanocellulose market in filtration and separation.....	
178		
14.12.3.1	Market assessment for Nanocellulose in filtration and separation.....	179
14.12.3.2	Global demand in tons in filtration.....	180
14.12.4	Market challenges.....	
181		
14.12.5	Product developer profiles.....	
182		
14.13	RHEOLOGY MODIFIERS.....	182
14.13.1	Applications.....	182
14.13.1.1	Food.....	183

14.13.1.2	Pharmaceuticals.....	183
14.13.1.3	Cosmetics.....	183
14.13.2	Product developer profiles.....	184
14.14	PRINTED AND FLEXIBLE ELECTRONICS.....	184
14.14.1	Market drivers and trends.....	184
14.14.2	Applications.....	186
14.14.2.1	Wearable electronics.....	187
14.14.2.2	Nanopaper.....	189
14.14.2.3	Paper memory.....	190
14.14.2.4	Conductive inks.....	191
14.14.3	Global market size and opportunity.....	191
14.14.3.1	Market assessment for Nanocellulose in printed and flexible electronics.....	193
14.14.4	Market challenges.....	195
14.14.5	Product developer profiles.....	196
14.15	3D PRINTING.....	197
14.15.1	Market drivers and trends.....	197
14.15.2	Applications.....	198
14.15.2.1	Cellulose nanocrystals 3D printing ink.....	198

14.15.2.2	Cellulose nanofibers.....	198
14.15.3	Global market size and opportunity.....	198
14.15.3.1	Market assessment for Nanocellulose in 3D printing.....	198
14.15.4	Market challenges.....	199
14.15.5	Product developer profiles.....	199
14.16	OTHER MARKETS.....	200
14.16.1	Rubber and tire additives.....	200
14.16.2	Colourants.....	200
15	NANOCELLULOSE COMPANY PROFILES.....	201-320 (80 company profiles)
16	MAIN NANOCELLULOSE RESEARCH CENTRES.....	321-329 (24 profiles)
17	REFERENCES.....	332

Tables

Table 1: Market summary for nanocellulose-Selling grade particle diameter, usage, advantages, average price/ton, market estimates, global consumption, main current applications, future applications.....	31
Table 2: Markets and applications for nanocellulose.....	33
Table 3: CNF producer capacities 2018.....	36
Table 4: MFC producer capacities 2018.....	37
Table 5: Cellulose nanocrystal producer capacities 2018.....	38
Table 6: Market opportunity assessment for nanocellulose, by application.....	38
Table 7: Nanocellulose (CNF, MFC, NCC) production plants worldwide and production status.....	42
Table 8: Market trends in nanocellulose.....	43

Table 9: Market and technical challenges in nanocellulose.....	44
Table 10: Properties and applications of nanocellulose.....	59
Table 11: Properties of cellulose nanofibrils relative to metallic and polymeric materials.....	61
Table 12: Types of nanocellulose.....	63
Table 13: Applications of cellulose nanofibers (CNF).....	65
Table 14: Production methods of main CNF producers.....	66
Table 15: CNC sources and scale.....	69
Table 16: CNC properties.....	69
Table 17: Applications of nanocrystalline cellulose (NCC).....	70
Table 18: Applications of bacterial cellulose (BC).....	71
Table 19: Microcrystalline cellulose (MCC) preparation methods, resulting materials and applications.....	72
Table 20: Microfibrillated cellulose (MFC) preparation methods, resulting materials and applications.....	72
Table 21: Nanofibrillated cellulose (CNF) preparation methods, resulting materials and applications.....	72
Table 22: Cellulose nanocrystals (MFC) preparation methods, resulting materials and applications.....	73
Table 23: Cellulose nanocrystals (MFC) preparation methods, resulting materials and applications.....	74
Table 24: Current and potential end users for nanocellulose, by market and company.....	77
Table 25: SWOT analysis of nanocellulose.....	80
Table 26: Safety of Micro/Nanofibrillated cellulose.....	83
Table 27: Identified applications of nanocellulose and their categorization.....	87
Table 28: Global nanocellulose market supply chain analysis.....	89
Table 29: Product/price/application matrix of nanocellulose producers.....	91
Table 30: Published patent publications for nanocellulose, 1997-2017.....	93
Table 31: Nanocellulose patents by organisation.....	94
Table 32: Nanocellulose patents by organisation.....	95

Table 33: Main patent assignees for NCC.....	95
Table 34: Main patent assignees for NFC.....	96
Table 35: Main patent assignees for BCC.....	96
Table 36: Price comparison of nanocellulose applications versus entry price of other materials in composites.....	97
Table 37. Main applications for carbon fibers, volumes, potential for CNF to gain market share.....	100
Table 38: Market drivers, trends and nanocellulose solutions in composites market.....	101
Table 39: Comparative properties of polymer composites reinforcing materials.....	102
Table 40: Applications of nanocellulose in polymer composites by cellulose type.....	103
Table 41: Nanocellulose applications timeline in the polymer composites market.....	104
Table 42: Examples of antimicrobial immobilization into cellulose nanofibers.....	108
Table 43: Oxygen permeability of nanocellulose films compared to those made form commercially available petroleum based materials and other polymers.....	110
Table 44: Market assessment for Nanocellulose in packaging.....	110
Table 45: Application markets, competing materials, Nanocellulose advantages and current market size in packaging.....	111
Table 46: Market opportunity assessment for Nanocellulose in biopackaging.....	111
Table 47: Demand for Nanocellulose in the packaging market, 2015-2030 (tons).....	113
Table 48: Market challenges rating for Nanocellulose in the biopackaging market.....	114
Table 49: Companies developing nanocellulose products in bio packaging, applications targeted and stage of commercialization.....	114
Table 50: Market drivers, trends and Nanocellulose solutions in aircraft and aerospace market.....	115
Table 51. Application of Nanocellulose in aircraft and aerospace composites-usage, motivating, competing materials, overall market size, potential market for CNF.....	116
Table 52: Market opportunity assessment for cellulose nanofibers in aircraft and aerospace.....	117
Table 53: Demand for Nanocellulose in the aerospace and aviation market, 2015-2030 (tons).....	118
Table 54: Market challenges rating for Nanocellulose in the aircraft and aerospace market.....	119

Table 55: Companies developing Nanocellulose products aircraft and aerospace, applications targeted and stage of commercialization.....	119
Table 56: Applications of natural fiber composites in vehicles by manufacturers.....	121
Table 57. Application of Nanocellulose in polymer composites in automotive.....	123
Table 58. Application of Nanocellulose in tires in automotive tyres.....	125
Table 59: Market opportunity assessment for Nanocellulose in the automotive industry.....	126
Table 60: Demand for Nanocellulose in the automotive market, 2015-2030 (tons).....	127
Table 61: Applications and commercialization challenges for Nanocellulose in the automotive market.....	127
Table 62: Market challenges rating for Nanocellulose in the automotive market.....	127
Table 63: Companies developing Nanocellulose products in the automotive industry, applications targeted and stage of commercialization.....	128
Table 64: Market drivers, trends and Nanocellulose solutions in construction market.....	130
Table 65: Comparison of nanocellulose with steel and other materials.....	131
Table 66: Market opportunity assessment for Nanocellulose in the construction industry.....	132
Table 67. Application of Nanocellulose in cement.....	132
Table 68. Application of Nanocellulose in ultra-high performance concrete.....	133
Table 69: Demand for Nanocellulose in the construction and building market, 2015-2030 (tons).....	134
Table 70: Market challenges rating for Nanocellulose in the construction, building protection and architectural exterior coatings market.....	134
Table 71: Nanocellulose in construction-Companies and products.....	135
Table 72: Market drivers, trends and Nanocellulose solutions in the paper and board market.....	135
Table 73: Nanocellulose applications timeline in the paper and board markets.....	136
Table 74: Market opportunity assessment for Nanocellulose in paper and board.....	138
Table 75: Demand for Nanocellulose in the paper and board market, 2015-2030 (tons).....	139
Table 76: Market challenges rating for Nanocellulose in the paper and board market.....	140

Table 77: Companies developing Nanocellulose products in paper and board, applications targeted and stage of commercialization.....	140
Table 78: Market drivers, trends and Nanocellulose solutions in the textiles market.....	142
Table 79: Market opportunity assessment for Nanocellulose in textiles.....	144
Table 80: Demand for Nanocellulose in the paper and board market, 2015-2030 (tons).....	145
Table 81: Market challenges rating for Nanocellulose in the textiles market.....	146
Table 82: Companies developing Nanocellulose products in textiles, applications targeted and stage of commercialization.....	146
Table 83: Market drivers, trends and Nanocellulose solutions in the medicine and healthcare market.....	147
Table 84: Nanocellulose applications timeline in the medicine and healthcare markets.....	148
Table 85: Market opportunity assessment for Nanocellulose in medicine and healthcare.....	151
Table 86: Demand for Nanocellulose in the medical and healthcare market, 2015-2030 (tons).....	152
Table 87: Nanocellulose product developers in medical and healthcare applications.....	152
Table 88: Market drivers, trends and Nanocellulose solutions in the coatings market.....	153
Table 89: Nanocellulose applications timeline in the coatings and paints markets.....	155
Table 90: Market assessment for Nanocellulose in coatings.....	157
Table 91: Application markets, competing materials, Nanocellulose advantages and current market size in coatings and films.....	157
Table 92: Market opportunity assessment for Nanocellulose in coatings.....	158
Table 93: Demand for Nanocellulose in the paint and coatings market, 2015-2030 (tons).....	159
Table 94: Market challenges for Nanocellulose in coatings.....	160
Table 95: Market challenges rating for Nanocellulose in the coatings and films market.....	161
Table 96: Companies developing Nanocellulose products in paper coatings and non-packaging coating products, applications targeted and stage of commercialization.....	161
Table 97: Market drivers, trends and Nanocellulose solutions in the aerogels market.....	162
Table 98: Nanocellulose applications timeline in the aerogels market.....	163

Table 99: Demand for Nanocellulose in the aerogels market, 2015-2030 (tons).....	164
Table 100: Nanocellulose product developers in aerogels.....	165
Table 101: Market drivers, trends and Nanocellulose solutions in the filtration market.....	165
Table 102: Nanocellulose applications timeline in the oil market.....	166
Table 103: Application markets, competing materials, Nanocellulose advantages and current market size in oil and gas.....	169
Table 104: Market assessment for Nanocellulose in oil and gas.....	169
Table 105: Nanocellulose in the oil and gas market-applications, stage of commercialization and estimated economic impact.....	170
Table 106: Demand for Nanocellulose in the oil and gas exploration market, 2015-2030 (tons).....	171
Table 107: Market challenges rating for Nanocellulose in the oil and gas exploration market.....	172
Table 108: Nanocellulose product developers in oil and gas exploration.....	172
Table 109: Market drivers, trends and Nanocellulose solutions in the filtration market.....	173
Table 110: Nanocellulose applications timeline in the filtration market.....	174
Table 111: Types of filtration.....	175
Table 112: CNF membranes.....	176
Table 113: Application markets, competing materials, Nanocellulose advantages and current market size in filtration.	178
Table 114: Market assessment for cellulose nanofibers in filtration.....	179
Table 115: Market opportunity assessment for Nanocellulose in the filtration industry.....	179
Table 116: Demand for Nanocellulose in the filtration market, 2015-2030 (tons).....	180
Table 117: Market challenges rating for Nanocellulose in the filtration market.....	181
Table 118: Companies developing Nanocellulose products in filtration, applications targeted and stage of commercialization.....	182
Table 119: Nanocellulose applications timeline in the rheology modifiers market.....	182
Table 120: Commercial activity in Nanocellulose rheology modifiers.....	184

Table 121: Market drivers, trends and Nanocellulose solutions in the printed and flexible electronics market.....	184
Table 122: Nanocellulose applications timeline in flexible electronics.....	186
Table 123: Properties of flexible electronics-cellulose nanofiber film (nanopaper).....	187
Table 124: Properties of flexible electronics cellulose nanofiber films.....	189
Table 125: Global market for wearables, 2014-2021, units and US\$.....	191
Table 126: Application markets, competing materials, Nanocellulose advantages and current market size in electronics.....	193
Table 127: Market assessment for Nanocellulose in the flexible and printed electronics sector.....	194
Table 128: Market opportunity assessment for Nanocellulose in flexible electronics.....	194
Table 129: Market challenges for use of Nanocellulose in printed and flexible electronics.....	195
Table 130: Market challenges rating for Nanocellulose in the printed and flexible electronics market.....	196
Table 131: Companies developing Nanocellulose products in paper electronics, applications targeted and stage of commercialization.....	196
Table 132: Market drivers, trends and Nanocellulose solutions in the 3D printing market.....	197
Table 133: Applications of CNF in 3D printing.....	198
Table 134. Application of Nanocellulose in 3D printing.....	198
Table 135: Market opportunity assessment for Nanocellulose in 3D printing.....	198
Table 136: Market challenges rating for Nanocellulose in the 3D printing market.....	199
Table 137: Companies developing Nanocellulose 3D printing products.....	199
Table 138: Nanocellulose producers and types of nanocellulose produced.....	201
Table 139: Target market, by nanocellulose producer.....	202
Table 140: Oji Holdings CNF products.....	245

Figures

Figure 1: Market segmentation by type of nanocellulose, capacities 2018.....	36
Figure 2: Market segmentation by type of nanocellulose, percentage.....	36

Figure 3: CNF wet powder.....	42
Figure 4: Cellulose nanofiber transparent sheet.....	45
Figure 5: Cellulose Nanofiber (CNF) composite with polyethylene (PE).....	46
Figure 6: CNF products.....	46
Figure 7: XCNF.....	47
Figure 8: CNF/MFC market value, by end user market demand, 2015–2030 (Tons).....	49
Figure 9: Nanocellulose market by region, 2017.....	50
Figure 10: Nanocellulose market by region, 2030.....	51
Figure 11: Schematic diagram of partial molecular structure of cellulose chain with numbering for carbon atoms and n= number of cellobiose repeating unit.....	58
Figure 12: Scale of cellulose materials.....	59
Figure 13: Types of nanocellulose.....	62
Figure 14: Relationship between different kinds of nanocelluloses.....	63
Figure 15: CNF gel.....	65
Figure 16: TEM image of cellulose nanocrystals.....	67
Figure 17: An iridescent biomimetic cellulose multilayer film remains after water that contains cellulose nanocrystals evaporates.....	68
Figure 18: Extracting CNC from trees.....	68
Figure 19: CNC slurry.....	70
Figure 20: Schematic of typical commercialization route for nanocellulose producer.....	76
Figure 21: Volume of industry demand for nanocellulose (external producer usage and external sales), 2017.....	77
Figure 22: Technology Readiness Level (TRL) for nanocellulose.....	88
Figure 23: Nanocellulose patents by field of application.....	94
Figure 24: Example process for producing NFC packaging film.....	107
Figure 25: Demand for Nanocellulose in the packaging market, 2015-2030 (tons).....	112

Figure 26: Demand for Nanocellulose in the aerospace and aviation market, 2015-2030 (tons).....	118
Figure 27: Nanomaterials-based automotive components.....	122
Figure 28: NFC composite.....	123
Figure 29: Demand for Nanocellulose in the automotive market, 2015-2030 (tons).....	127
Figure 30: Nanowood with hierarchically aligned cellulose nanofibrils for insulation.....	131
Figure 31: Demand for Nanocellulose in the construction and building market, 2015-2030 (tons).....	133
Figure 32: Demand for Nanocellulose in the paper and board market, 2015-2030 (tons).....	139
Figure 33: Cellulose nanocrystals on fabric create iridescent structural colour.....	143
Figure 34: CNF deodorant products.....	144
Figure 35: Demand for Nanocellulose in the textiles market, 2015-2030 (tons).....	145
Figure 36: Demand for Nanocellulose in the medical and healthcare market, 2015-2030 (tons).....	151
Figure 37: Demand for Nanocellulose in the paints and coatings market, 2015-2030 (tons).....	159
Figure 38: Demand for Nanocellulose in the aerogels market, 2015-2030 (tons).....	164
Figure 39: Nanocellulose sponge developed by EMPA for potential applications in oil recovery.....	167
Figure 40: Demand for Nanocellulose in the oil and gas exploration market, 2015-2030 (tons).....	171
Figure 41: Nanocellulose virus filter paper.....	178
Figure 42: Demand for Nanocellulose in the filtration market, 2015-2030 (tons).....	180
Figure 43: Electronic components using NFC as insulating materials.....	187
Figure 44: Cellulose nanofiber films.....	188
Figure 45: Nanocellulose photoluminescent paper.....	188
Figure 46: LEDs shining on circuitry imprinted on a 5x5cm sheet of CNF.....	189
Figure 47: Foldable nanopaper.....	190
Figure 48: Foldable nanopaper antenna.....	190
Figure 49: Paper memory (ReRAM).....	191

Figure 50: Global market revenues for smart wearable devices 2014-2021, in US\$.....	192
Figure 51: Global market revenues for nanotech-enabled smart wearable devices 2014-2021 in US\$, conservative estimate.....	193
Figure 52: Global market revenues for nanotech-enabled smart wearable devices 2014-2021 in US\$, optimistic estimate.....	193
Figure 53: 3D printed CNFS in Paper Microfluidics devices.....	197
Figure 54. American Process, Inc. CNF production process.....	205
Figure 55: Asahi Kasei CNF fabric sheet.....	207
Figure 56: Properties of Asahi Kasei cellulose nanofiber nonwoven fabric.....	207
Figure 57: CNF nonwoven fabric.....	208
Figure 58: Ashai Kasei CNF production process.....	209
Figure 59. Borregaard Chemcell CNF production process.....	212
Figure 60. Chuetsu Pulp & Paper CNF production process.....	217
Figure 61. Daicel Corporation CNF production process.....	219
Figure 62. CNF-reinforced PP compounds.....	221
Figure 63. Kirekiral toilet wipes.....	222
Figure 64. Daio Paper CNF production process.....	223
Figure 65. DIC Products CNF production process.....	225
Figure 66: Rheocrysta spray.....	227
Figure 67. DKS Co. Ltd. CNF production process.....	228
Figure 68. Imerys CNF production process.....	231
Figure 69: Innventia AB movable nanocellulose demo plant.....	233
Figure 70. Innventia CNF production process.....	234
Figure 71. Kruger Biomaterials, Inc. CNF production process.....	236
Figure 72: Hydrophobization facilities for raw pulp.....	238

Figure 73: Mixing facilities for CNF-reinforced plastic.....	238
Figure 74. Nippon Paper CNF production process.....	240
Figure 75: Nippon Paper Industries' adult diapers.....	241
Figure 76: CNF wet powder.....	242
Figure 77: CNF transparent film.....	242
Figure 78. Oji Paper CNF production process.....	244
Figure 79. Performance Biofilaments CNF production process.....	247
Figure 80. Seiko PMC CNF production process.....	249
Figure 81. Stora Enso CNF production process.....	251
Figure 82: Silk nanofiber (right) and cocoon of raw material.....	253
Figure 83. BiNF-i-s Dry Powder.....	253
Figure 84. BiNF-i-s Dry Powder and Propylene (PP) Complex Pellet.....	253
Figure 85. Sugino Machine CNF production process.....	254
Figure 86. University of Maine CNF production process.....	257
Figure 87. UPM-Kymmene CNF production process.....	259
Figure 88. US Forest Service Products Laboratory CNF production process.....	262
Figure 89: Flexible electronic substrate made from CNF.....	262
Figure 90. VTT 100% bio-based stand-up pouches.....	263
Figure 91. VTT CNF production process.....	265
Figure 92: Bio-based barrier bags prepared from Tempo-CNF coated bio-HDPE film.....	266
Figure 93. Zelfo Technology GmbH CNF production process.....	268
Figure 94: 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:.....	273
Figure 95: NCCTM Process.....	273

Figure 96: Plantrose process..... 279

Figure 97: CNF gel..... 291

Figure 98: Block nanocellulose material..... 291

Figure 99: CNF products developed by Hokuetsu..... 292

Figure 100: 0.3% aqueous dispersion of sulfated esterified CNF and dried transparent film (front side)..... 295

Figure 101: Fluorene cellulose ® powder..... 299

Figure 102: Silver / CNF composite dispersions..... 306

Figure 103: CNF/nanosilver powder..... 306

Figure 104: CNF resin products..... 307