

## TABLE OF CONTENTS

<b>1 EXECUTIVE SUMMARY</b>	<b>28</b>
1.1 The market for nanocellulose	30
1.2 Nanocellulose industry developments 2020-22	32
1.3 Market outlook in 2022 and beyond	34
1.4 Global production of nanocellulose	36
1.4.1 Global nanocellulose production capacities 2021, by type	36
1.4.2 Cellulose nanofibers (CNF) production capacities 2022, in metric tons by producer	37
1.4.3 Microfibrillated cellulose (MFC) production capacities 2022	38
1.4.4 Cellulose nanocrystals (CNC) production capacities 2022	41
1.5 Market challenges for nanocellulose	43
1.6 Nanocellulose commercial products	45
1.7 Nanocellulose market by region	53
1.7.1 Japan	55
1.7.2 China	56
1.7.3 Malaysia	57
1.7.4 Western Europe	57
1.7.5 North America	58
1.8 Global government funding	59
<b>2 OVERVIEW OF NANOCELLULOSE</b>	<b>60</b>
2.1 Cellulose	60
2.2 Nanocellulose	61
2.3 Properties of nanocellulose	62
2.4 Feedstocks	63
2.5 Advantages of nanocellulose	65
2.6 Synthesis and Production methods	66
2.6.1 Acid hydrolysis	70

---

2.6.2	TEMPO oxidation.....	70
2.6.3	Ammonium persulfate (APS) oxidation.....	70
2.6.4	Ball milling.....	71
2.6.5	Cryocrushing.....	71
2.6.6	High-shear grinding.....	71
2.6.7	Green production methods.....	72
2.6.7.1	Ultrasonication .....	72
2.6.7.2	High-pressure homogenization.....	72
2.6.8	Recent methods.....	73
2.6.8.1	Microwave irradiation .....	73
2.6.8.2	Enzymatic processing .....	73
2.6.8.3	Deep eutectic solvents (DESs).....	74
2.6.8.4	Pulsed electric field .....	75
2.6.8.5	Electron beam irradiation .....	75
2.7	Types of nanocellulose .....	77
2.7.1	Microfibrillated cellulose (MFC) .....	80
2.7.2	Cellulose nanofibers (CNF) .....	81
2.7.2.1	Applications.....	81
2.7.3	Cellulose nanocrystals (CNC) .....	82
2.7.3.1	Synthesis .....	83
2.7.3.2	Properties .....	85
2.7.3.3	Production.....	86
2.7.3.4	Applications.....	87
2.7.4	Bacterial Nanocellulose (BNC) .....	88
2.7.4.1	Production.....	88
2.7.4.2	Applications.....	91
<b>3</b>	<b>MARKET OPPORTUNITIES IN NANOCELLULOSE.....</b>	<b>93</b>
<b>4</b>	<b>REGULATIONS AND STANDARDS .....</b>	<b>96</b>
4.1	Standards .....	96

---

4.1.1	International Standards Organization (ISO).....	96
4.1.2	American National Standards.....	96
4.1.3	CSA Group.....	96
4.2	Toxicity.....	97
4.3	Regulation.....	99
<b>5</b>	<b>NANOCELLULOSE SUPPLY CHAIN .....</b>	<b>100</b>
<b>6</b>	<b>NANOCELLULOSE PRICING .....</b>	<b>103</b>
6.1	Cellulose nanofiber (CNF).....	103
6.2	Cellulose nanocrystal (CNC) .....	104
6.3	Bacterial nanocellulose (BNC) .....	105
<b>7</b>	<b>MARKETS FOR NANOCELLULOSE.....</b>	<b>106</b>
7.1	Composites.....	106
7.1.1	Market overview.....	106
7.1.2	Applications.....	112
7.1.2.1	Automotive composites .....	113
7.1.2.2	Biocomposite films & packaging.....	113
7.1.2.3	Barrier packaging.....	113
7.1.2.4	Thermal insulation composites.....	113
7.1.2.5	Construction composites.....	114
7.1.3	Global market in tons to 2033 .....	114
7.1.4	Product developers .....	115
7.2	Automotive.....	118
7.2.1	Market overview.....	118
7.2.2	Applications.....	122
7.2.2.1	Composites.....	122
7.2.2.2	Air intake components.....	128
7.2.2.3	Tires.....	128
7.2.3	Global market in tons to 2033 .....	129

---

7.2.4	Product developers .....	130
7.3	Buildings and construction .....	133
7.3.1	Market overview.....	133
7.3.2	Applications.....	137
7.3.2.1	Sandwich composites .....	137
7.3.2.2	Cement additives .....	137
7.3.2.3	Pump primers.....	138
7.3.2.4	Thermal insulation and damping .....	138
7.3.3	Global market in tons to 2033 .....	139
7.3.4	Product developers .....	140
7.4	Paper and board packaging .....	142
7.4.1	Market overview.....	142
7.4.2	Applications.....	148
7.4.2.1	Reinforcement and barrier.....	148
7.4.2.2	Biodegradable food packaging foil and films .....	149
7.4.2.3	Paperboard coatings .....	149
7.4.3	Global market in tons to 2033 .....	150
7.4.4	Product developers .....	151
7.5	Textiles and apparel.....	152
7.5.1	Market overview.....	152
7.5.2	Applications.....	156
7.5.2.1	CNF deodorizer and odour reducer (antimicrobial) in adult and child diapers.....	157
7.5.2.2	Footwear.....	157
7.5.3	Global market in tons to 2033 .....	157
7.5.4	Product developer profiles.....	159
7.6	Biomedicine and healthcare .....	160
7.6.1	Market overview.....	160
7.6.2	Applications.....	167
7.6.2.1	Wound dressings .....	167

---

7.6.2.2	Drug delivery stabilizers .....	168
7.6.2.3	Tissue engineering scaffolds .....	168
7.6.3	Global market in tons to 2033 .....	169
7.6.4	Product developers .....	170
7.7	Hygiene and sanitary products .....	173
7.7.1	Market overview .....	173
7.7.2	Applications .....	173
7.7.3	Global market in tons to 2033 .....	173
7.7.4	Product developers .....	175
7.8	Paints and coatings .....	176
7.8.1	Market overview .....	176
7.8.2	Applications .....	180
7.8.3	Global market in tons to 2033 .....	180
7.8.4	Product developers .....	182
7.9	Aerogels .....	184
7.9.1	Market overview .....	184
7.9.2	Global market in tons to 2033 .....	187
7.9.3	Product developers .....	188
7.10	Oil and gas .....	190
7.10.1	Market overview .....	190
7.10.2	Applications .....	193
7.10.2.1	Oil recovery applications (fracturing fluid) .....	193
7.10.2.2	CNF Membranes for separation .....	193
7.10.2.3	Oil and gas fluids additives .....	194
7.10.3	Global market in tons to 2033 .....	194
7.10.4	Product developers .....	195
7.11	Filtration .....	197
7.11.1	Market overview .....	197
7.11.2	Applications .....	202

7.11.2.1	Membranes for selective absorption.....	203
7.11.3	Global market in tons to 2033 .....	203
7.11.4	Product developers .....	204
7.12	Rheology modifiers.....	206
7.12.1	Market overview.....	206
7.12.2	Applications.....	209
7.12.2.1	Food additives.....	209
7.12.2.2	Pickering stabilizers .....	210
7.12.2.3	Hydrogels.....	210
7.12.2.4	Cosmetics and skincare .....	211
7.12.3	Global market in tons to 2033 .....	211
7.12.4	Product developers .....	212
7.13	Other markets.....	215
7.13.1	Printed, stretchable and flexible electronics.....	215
7.13.1.1	Market assessment .....	215
7.13.1.2	Product developers .....	218
7.13.2	3D printing.....	220
7.13.2.1	Market assessment .....	220
7.13.2.2	Product developers .....	222
7.13.3	Aerospace.....	223
7.13.3.1	Market assessment.....	223
7.13.3.2	Product developers .....	224
7.13.4	Batteries.....	225
7.13.4.1	Market assessment .....	225

**8 CELLULOSE NANOFIBER COMPANY PROFILES..... 226**

8.1	██████████.....	226
8.2	██████████.....	226
8.3	██████████.....	228
8.4	██████████.....	233

---

8.5	.....	233
8.6	.....	234
8.7	.....	235
8.8	.....	236
8.9	.....	237
8.10	.....	238
8.11	.....	239
8.12	.....	240
8.13	.....	241
8.14	.....	244
8.15	.....	245
8.16	.....	247
8.17	.....	248
8.18	.....	252
8.19	.....	253
8.20	.....	254
8.21	.....	255
8.22	.....	259
8.23	.....	260
8.24	.....	261
8.25	.....	263
8.26	.....	266
8.27	.....	267
8.28	.....	269
8.29	.....	269
8.30	.....	271
8.31	.....	272
8.32	.....	273
8.33	.....	274

---

8.34	.....	276
8.35	.....	276
8.36	.....	277
8.37	.....	280
8.38	.....	281
8.39	.....	283
8.40	.....	283
8.41	.....	284
8.42	.....	284
8.43	.....	285
8.44	.....	286
8.45	.....	288
8.46	.....	289
8.47	.....	289
8.48	.....	290
8.49	.....	290
8.50	.....	291
8.51	.....	291
8.52	.....	294
8.53	.....	296
8.54	.....	298
8.55	.....	299
8.56	.....	300
8.57	.....	301
8.58	.....	302
8.59	.....	303
8.60	.....	306
8.61	.....	306
8.62	.....	308



---

8.63	████████████████████	308
8.64	████████████████████	309
8.65	████████████████████	310
8.66	████████████████████	310
8.67	████████████████████	311
8.68	████████████████████	312
8.69	████████████████████	313
8.70	████████████████████	319
8.71	████████████████████	320
8.72	████████████████████	321
8.73	████████████████████	321
8.74	████████████████████	322
8.75	████████████████████	323
8.76	████████████████████	323
8.77	████████████████████	330
8.78	████████████████████	331
8.79	████████████████████	332
8.80	████████████████████	334
8.81	████████████████████	334
8.82	████████████████████	336
8.83	████████████████████	336
8.84	████████████████████	338
8.85	████████████████████	339
8.86	████████████████████	340
8.87	████████████████████	341
8.88	████████████████████	344
8.89	████████████████████	345
8.90	████████████████████	345
8.91	████████████████████	346

---

8.92	.....	348
8.93	.....	353
8.94	.....	354
8.95	.....	354
8.96	.....	355
8.97	.....	355
8.98	.....	356
8.99	.....	356
8.100	.....	357
8.101	.....	358
8.102	.....	359
8.103	.....	360
8.104	.....	361
8.105	.....	362
8.106	.....	363
8.107	.....	363
8.108	.....	364
8.109	.....	366
8.110	.....	369
8.111	.....	372
8.112	.....	372
8.113	.....	373
8.114	.....	373
8.115	.....	377
8.116	.....	378
8.117	.....	380
8.118	.....	380
8.119	.....	381
8.120	.....	383

8.121	.....	384
8.122	.....	384

**9 CELLULOSE NANOCRYSTAL (CNC) PRODUCER ANALYSIS ... 386**

**10 CELLULOSE NANOCRYSTAL (CNC) COMPANY PROFILES..... 388**

10.1	.....	388
10.2	.....	389
10.3	.....	391
10.4	.....	394
10.5	.....	395
10.6	.....	395
10.7	.....	396
10.8	.....	399
10.9	.....	400
10.10	.....	400
10.11	.....	401
10.12	.....	405
10.13	.....	405
10.14	.....	406
10.15	.....	406
10.16	.....	409
10.17	.....	411
10.18	.....	412
10.19	.....	412
10.20	.....	414
10.21	.....	416

**11 BACTERIAL NANOCELLULOSE (BNC) COMPANY PROFILES.. 418**

11.1	.....	418
11.2	.....	419

11.3	.....	420
11.4	.....	421
11.5	.....	421
11.6	.....	422
11.7	.....	423
11.8	.....	423
11.9	.....	424
11.10	.....	425
11.11	.....	426
11.12	.....	427
11.13	.....	428
11.14	.....	429
11.15	.....	430
11.16	.....	431
11.17	.....	432
11.18	.....	432
11.19	.....	433
11.20	.....	434
<b>12 RESEARCH SCOPE AND METHODOLOGY</b>	<b>.....</b>	<b>435</b>
12.1	Report scope .....	435
12.2	Research methodology.....	435
<b>13 REFERENCES</b>	<b>.....</b>	<b>437</b>

## List of 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. ....	29
Table 2. Markets and applications for nanocellulose.....	30

---

Table 3. The nanocellulose market 2020-2022-industry product and production activity.....	32
Table 4. Classification of nanocellulose applications by type of industrial product ranged in terms of their potential of consumption. ....	35
Table 5. CNF production capacities (by type, wet or dry) and production process, by producer, metric tons. ....	37
Table 6. MFC production capacities in metric tons and production process, by producer, metric tons. ....	38
Table 7. Global demand for cellulose nanofibers/MFC by market in metric tons, 2018-2033. ....	39
Table 8: Cellulose nanocrystal capacities (by type, wet or dry) and production process, by producer, metric tons.....	41
Table 9. Global demand for cellulose nanocrystals by market, 2018-2033 (metric tons).....	41
Table 10. Market and technical challenges in nanocellulose.....	43
Table 11. Nanocellulose -based commercial products.....	45
Table 12. Regional demand for nanocellulose, 2021, tons (total excludes MFC). ....	54
Table 13. Nanocellulose producers and product developers in Japan. ....	55
Table 14. Nanocellulose research centres, universities and companies in China.....	56
Table 15. Nanocellulose producers and product developers in Europe.....	57
Table 16. Nanocellulose producers and product developers in North America. ....	58
Table 17. Properties and applications of nanocellulose. ....	62
Table 18. Properties of nanocellulose, by type. ....	63
Table 19. Chemical composition of different lignocellulosic feedstocks used for nanocellulose production (% dry basis). ....	64
Table 20. Properties of cellulose nanofibrils relative to metallic and polymeric materials. ....	65
Table 21. Extraction of nanocellulose (NC) from various lignocellulosic sources using different conventional technologies.....	69
Table 22. Types of nanocellulose. ....	77
Table 23. Types of nanocellulose. ....	79
Table 24. Applications of cellulose nanofibers (CNF).....	81
Table 25. Synthesis methods for cellulose nanocrystals (CNC).....	84
Table 26. CNC sources, size and yield.....	85
Table 27. CNC properties.....	85
Table 28. Mechanical properties of CNC and other reinforcement materials.....	86

---

---

Table 29. Applications of nanocrystalline cellulose (NCC). .....	87
Table 30. Applications of bacterial nanocellulose (BNC). .....	91
Table 31. Market opportunity assessment for nanocellulose, by application. ....	93
Table 32. Safety of Micro/Nanofibrillated cellulose. ....	97
Table 33. Global nanocellulose market supply chain analysis. ....	100
Table 34: Product/price/application matrix of cellulose nanofiber producers. ....	103
Table 35: Product/price/application matrix of cellulose nanocrystal producers. ....	104
Table 36: Product/price/application matrix of bacterial nanocellulose producers. ....	105
Table 37. Market overview for nanocellulose in composites. ....	106
Table 38. Comparative properties of polymer composites reinforcing materials. ....	107
Table 39. Scorecard for nanocellulose in composites. ....	107
Table 40. Market assessment for nanocellulose in composites-application, key benefits and motivation for use, megatrends, market drivers, technology drawbacks, competing materials, material loading, main global composites OEMs. ....	108
Table 41. Global market demand for nanocellulose in composites, 2018-2033 (metric tons). ....	114
Table 42. Companies developing nanocellulose in composites. ....	115
Table 43. Market overview for nanocellulose in automotive. ....	118
Table 44. Scorecard for nanocellulose in automotive. ....	119
Table 45. Market assessment for nanocellulose in automotive-application, key benefits and motivation for use, megatrends, market drivers, technology drawbacks, competing materials, material loading, main global automotive OEMs. ....	119
Table 46. Components featured in the NCV. ....	123
Table 47. Global market demand for nanocellulose in the automotive sector 2018-2033 (metric tons). ....	129
Table 48. Companies developing nanocellulose products in the automotive industry. ....	130
Table 49. Market overview for nanocellulose in building and construction. ....	133
Table 50. Scorecard for nanocellulose in building and construction. ....	133
Table 51. Comparison of CNC with steel and other materials. ....	134
Table 52. Market assessment for nanocellulose in building and construction-application, key benefits and motivation for use, megatrends, market drivers, technology drawbacks, competing materials, material loading, main global construction OEMs. ....	135
Table 53: Market demand for nanocellulose in building and construction, 2018-2033 (tons). ....	139

---

---

Table 54. Companies developing nanocellulose in building and construction. ....	140
Table 55. Oxygen permeability of nanocellulose films compared to those made from commercially available petroleum-based materials and other polymers.....	142
Table 56. Scorecard for nanocellulose in paper and board packaging. ....	142
Table 57. Market assessment for nanocellulose in paper and board packaging-application, key benefits and motivation for use, megatrends, market drivers, technology drawbacks, competing materials, material loading, main global paper and board packaging OEMs.....	143
Table 58. Global demand for nanocellulose in paper & board packaging, 2018-2033 (tons).....	150
Table 59. Companies developing nanocellulose products in paper and board.....	151
Table 60. Market overview for nanocellulose in textiles and apparel.....	152
Table 61. Scorecard for nanocellulose in textiles and apparel. ....	152
Table 62. Market assessment for nanocellulose in textiles and apparel-application, key benefits and motivation for use, megatrends, market drivers, technology drawbacks, competing materials, material loading, main global textiles and apparel OEMs. ....	153
Table 63. Demand for nanocellulose in textiles, 2018-2033 (tons).....	157
Table 64. Companies developing nanocellulose products in textiles and apparel. ....	159
Table 65. Market overview for cellulose nanofibers in medicine and healthcare. ....	160
Table 66. Scorecard for nanocellulose in medicine and healthcare.....	161
Table 67. Market assessment for nanocellulose in medicine and healthcare-application, key benefits and motivation for use, megatrends, market drivers, technology drawbacks, competing materials, material loading, main global medicine and healthcare OEMs. ....	162
Table 68. Global demand for nanocellulose in medical and healthcare, 2018-2033 (tons).....	169
Table 69. Nanocellulose product developers in medicine and healthcare. ....	170
Table 70. Market overview for nanocellulose in the hygiene and sanitary products market.....	173
Table 71. Global demand for nanocellulose in hygiene and absorbents, 2018-2033 (tons).....	173
Table 72. Nanocellulose product developers in hygiene and sanitary products. ....	175
Table 73. Market overview for nanocellulose in paints and coatings. ....	176
Table 74. Scorecard for nanocellulose in paints and coatings.....	176
Table 75. Market assessment for nanocellulose 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. ....	177
Table 76. Global demand for nanocellulose in paint and coatings, 2018-2033 (tons).....	180

---

Table 77. Companies developing nanocellulose products in paints and coatings, applications targeted and stage of commercialization.....	182
Table 78. Market overview for nanocellulose in aerogels.....	184
Table 79. Scorecard for cellulose nanofibers in aerogels.....	184
Table 80. Market assessment for nanocellulose in aerogels-application, key benefits and motivation for use, megatrends, market drivers, technology drawbacks, competing materials, material loading, main global aerogels OEMs. ....	185
Table 81. Global demand for nanocellulose in aerogels, 2018-2033 (tons).....	187
Table 82. Nanocellulose in product developers in aerogels. ....	188
Table 83. Market overview for nanocellulose in in oil and gas.....	190
Table 84. Scorecard for nanocellulose in in oil and gas. ....	190
Table 85. Market assessment for nanocellulose in in oil and gas-application, key benefits and motivation for use, megatrends, market drivers, technology drawbacks, competing materials, material loading, main global oil and gas OEMs. ....	191
Table 86. Global demand for nanocellulose in the oil and gas market, 2018-2033 (tons).....	194
Table 87. Nanocellulose product developers in oil and gas exploration. ....	195
Table 88. CNF membranes. ....	198
Table 89. Market overview for nanocellulose in filtration.....	198
Table 90. Scorecard for nanocellulose in filtration.....	199
Table 91. Market assessment for nanocellulose in filtration-application, key benefits and motivation for use, megatrends, market drivers, technology drawbacks, competing materials, material loading, main global filtration OEMs. ....	199
Table 92: Global demand for nanocellulose in the filtration market, 2018-2033 (tons). ....	203
Table 93. Companies developing nanocellulose products in filtration. ....	204
Table 94. Market overview for nanocellulose in rheology modifiers. ....	206
Table 95. Scorecard for nanocellulose in rheology modifiers.....	207
Table 96. Market assessment for nanocellulose in rheology modifiers-application, key benefits and motivation for use, megatrends, market drivers, technology drawbacks, competing materials, material loading, main global rheology modifier OEMs. ....	207
Table 97. Global demand for nanocellulose in the rheology modifiers market, 2018-2033 (tons).....	211
Table 98. Commercial activity in nanocellulose rheology modifiers.....	212
Table 99. Properties of flexible electronics-cellulose nanofiber film (nanopaper). ....	215



Table 100. Market assessment for nanocellulose in printed, stretchable and flexible electronics-application, key benefits and motivation for use, megatrends, market drivers, technology drawbacks, competing materials, material loading, main global printed, flexible and stretchable electronics OEMs. ....	216
Table 101. Companies developing nanocellulose products in printed, stretchable and flexible electronics. ....	218
Table 102. Market assessment for nanocellulose in 3D printing-application, key benefits and motivation for use, megatrends, market drivers, technology drawbacks, competing materials, material loading, main global 3D printing OEMs. ....	220
Table 103. Companies developing nanocellulose printing products. ....	222
Table 104. Market assessment for nanocellulose in aerospace-application, key benefits and motivation for use, megatrends, market drivers, technology drawbacks, competing materials, material loading. ....	223
Table 105: Companies developing nanocellulose products in aircraft and aerospace. ....	224
Table 106. Market assessment for nanocellulose in Batteries-application, key benefits and motivation for use, megatrends, market drivers, technology drawbacks. ....	225
Table 107: Granbio Nanocellulose Processes. ....	278
Table 108. Nippon Paper commercial CNF products. ....	318
Table 109. Oji Holdings CNF products. ....	328
Table 110: CNC producers and production capacities. ....	386
Table 111. Target market, by cellulose nanocrystal producer. ....	387
Table 112. Fibnano properties. ....	427

## List of Figures

Figure 1. CNF nameplate. ....	32
Figure 2. Market segmentation by type of nanocellulose, capacities and demand 2021, metric tons. ....	35
Figure 3. Market segmentation by type of nanocellulose, capacities and demand 2021, metric tons. ....	37
Figure 4. Global demand for cellulose nanofibers/MFC in metric tons by market, 2018-2033. ....	40
Figure 5. Global demand for cellulose nanocrystals by market, 2018-2033 (metric tons). ....	43
Figure 6. Aruba 23. ....	45
Figure 7. Dorayaki. ....	46
Figure 8. ENASAVE NEXT. ....	46

Figure 9. Flat4-KAEDE. ....	47
Figure 10. GEL-KAYANO™.....	47
Figure 11. Hada care acty®.....	48
Figure 12. Hiteeth All in One Mouth Gel. ....	48
Figure 13. HYPERNANO X series. ....	48
Figure 14. Kirekira! toilet wipes.....	49
Figure 15. ONKYO® Scepter SC-3(B) 2-way Speaker System.....	49
Figure 16. Pioneer® SE-MONITOR5 Headphones.....	49
Figure 17. "Poise" series Super strong deodorant sheet.....	50
Figure 18. RUBURI Precursor Lubris for raw concrete pumping. ....	50
Figure 19. SC-3 (B) speakers. ....	51
Figure 20. SE-MONITOR5 headphones. ....	51
Figure 21. "Skin Care Acty" series Adult diapers. ....	51
Figure 22. "SURISURI" Lotion. ....	52
Figure 23. X9400 series.....	52
Figure 24. X Premium Sound Speaker Alps Alpine.....	53
Figure 25. Regional demand for nanocellulose, 2021. ....	54
Figure 26. Schematic diagram of partial molecular structure of cellulose chain with numbering for carbon atoms and n= number of cellobiose repeating unit. ....	60
Figure 27. Scale of cellulose materials. ....	61
Figure 28. Nanocellulose preparation methods and resulting materials. ....	67
Figure 29. Production of nanocellulose from lignocellulosic biomass using enzymatic treatment (endoglucanases and xylanases) followed by mechanical treatment.....	74
Figure 30. EBI pretreatment combined with HPH for CNC production. ....	76
Figure 31. Types of nanocellulose. ....	78
Figure 32. Relationship between different kinds of nanocelluloses. ....	78
Figure 33. Various preparation methods for nanocellulose. ....	80
Figure 34. CNF gel. ....	81
Figure 35. TEM image of cellulose nanocrystals.....	83
Figure 36. CNC preparation.....	83

Figure 37. Extracting CNC from trees.....	85
Figure 38. CNC slurry.....	87
Figure 39. Bacterial nanocellulose shapes.....	90
Figure 40. Applications of nanocellulose in composites.....	112
Figure 41. Global market demand for nanocellulose in composites, 2018-2033 (metric tons).....	115
Figure 42. CNF mixed PLA (Poly Lactic Acid).....	116
Figure 43. CNF resin products.....	117
Figure 44. Interior of NCV concept car.....	118
Figure 45. Applications of nanocellulose in automotive.....	122
Figure 46. Interior of the NCV prototype.....	123
Figure 47. Global demand for nanocellulose in the automotive sector, 2018-2033 (metric tons).....	129
Figure 48: Daio Paper's cellulose nanofiber material in doors and hood of race car.....	130
Figure 49: CNF composite.....	131
Figure 50: Engine cover utilizing Kao CNF composite resins.....	131
Figure 51. CNF car engine cover developed in Japan Ministry of the Environment's (MOE) Nano Cellulose Vehicle (NCV) Project.....	132
Figure 52. Comparison of nanofillers with supplementary cementitious materials and aggregates in concrete.....	134
Figure 53. Applications of nanocellulose in building and construction.....	137
Figure 54. Demand for nanocellulose in construction, 2018-2033 (tons).....	140
Figure 55. Applications of nanocellulose in paper and board packaging.....	148
Figure 56. Global demand for nanocellulose in the paper & board/packaging, 2018-2033 (tons).....	151
Figure 57. Applications of nanocellulose in textiles and apparel.....	157
Figure 58. Asics GEL-KAYANO™ 25 running shoe.....	157
Figure 59. Demand for nanocellulose in the textiles, 2018-2033 (tons).....	158
Figure 60. CNF deodorant products.....	159
Figure 61. Applications of nanocellulose in medicine and healthcare.....	167
Figure 62. Global demand for nanocellulose in medical and healthcare, 2018-2033 (tons).....	170
Figure 63. Fibnano.....	171
Figure 64. Global demand for nanocellulose in hygiene and absorbents, 2018-2033 (tons).....	174

---

Figure 65. Applications of nanocellulose in paints and coatings.....	180
Figure 66. Global demand for nanocellulose in paint and coatings, 2018-2033 (tons). ....	181
Figure 67. Hefcel-coated wood (left) and untreated wood (right) after 30 seconds flame test. ....	183
Figure 68: Global demand for nanocellulose in in aerogels, 2018-2033 (tons).....	188
Figure 69. Global demand for nanocellulose in the oil and gas market, 2018-2033 (tons). ....	195
Figure 70. Nanocellulose sponge developed by EMPA for potential applications in oil recovery.....	196
Figure 71. Applications of nanocellulose in filtration.....	202
Figure 72. Global demand for nanocellulose in the filtration market, 2018-2033 (tons). ....	204
Figure 73. Multi-layered cross section of CNF-nw.....	205
Figure 74. Applications of nanocellulose in rheology modifiers. ....	209
Figure 75. Global demand for nanocellulose in the rheology modifiers market, 2018-2033 (tons).....	212
Figure 76. "SURISURI" products. ....	213
Figure 77. Foldable nanopaper antenna. ....	216
Figure 78: Flexible electronic substrate made from CNF. ....	218
Figure 79. Oji CNF transparent sheets. ....	218
Figure 80. Electronic components using NFC as insulating materials. ....	219
Figure 81: Anpoly cellulose nanofiber hydrogel. ....	227
Figure 82. MEDICELLU™. ....	227
Figure 83: Ashai Kasei CNF production process.....	229
Figure 84: Asahi Kasei CNF fabric sheet. ....	230
Figure 85: Properties of Asahi Kasei cellulose nanofiber nonwoven fabric.....	230
Figure 86. CNF nonwoven fabric. ....	231
Figure 87. Borregaard Chemcell CNF production process.....	237
Figure 88. Celfion membrane. ....	239
Figure 89. nanoforest products.....	248
Figure 90. Chuetsu Pulp & Paper CNF production process. ....	249
Figure 91. nanoforest-S.....	250
Figure 92. nanoforest-PDP.....	250
Figure 93. nanoforest-MB.....	251

---

Figure 94. Daicel Corporation CNF production process.....	253
Figure 95. Celish. ....	254
Figure 96: Trunk lid incorporating CNF.....	255
Figure 97. Daio Paper CNF production process. ....	256
Figure 98. ELLEX products.....	258
Figure 99. CNF-reinforced PP compounds. ....	258
Figure 100. Kirekira! toilet wipes.....	258
Figure 101. Color CNF.....	260
Figure 102. DIC Products CNF production process. ....	262
Figure 103. DKS Co. Ltd. CNF production process.....	264
Figure 104: Rheocrysta spray.....	265
Figure 105. DKS CNF products. ....	265
Figure 106: CNF based on citrus peel. ....	267
Figure 107. Citrus cellulose nanofiber.....	268
Figure 108. Imerys CNF production process.....	270
Figure 109. Filler Bank CNC products. ....	272
Figure 110: Cellulose Nanofiber (CNF) composite with polyethylene (PE).....	274
Figure 111: CNF products from Furukawa Electric. ....	275
Figure 112. Granbio CNF production process.....	279
Figure 113: Cutlery samples (spoon, knife, fork) made of nano cellulose and biodegradable plastic composite materials. ....	282
Figure 114. Non-aqueous CNF dispersion "Senaf" (Photo shows 5% of plasticizer).....	284
Figure 115: CNF gel. ....	286
Figure 116: Block nanocellulose material. ....	287
Figure 117: CNF products developed by Hokuetsu.....	287
Figure 118. Kami Shoji CNF products.....	291
Figure 119. Dual Graft System. ....	292
Figure 120: Engine cover utilizing Kao CNF composite resins.....	293
Figure 121. Acrylic resin blended with modified CNF (fluid) and its molded product (transparent film), and image obtained with AFM (CNF 10wt% blended). ....	294

---

---

Figure 122: 0.3% aqueous dispersion of sulfated esterified CNF and dried transparent film (front side)...	295
Figure 123. Kruger Biomaterials, Inc. CNF production process.....	297
Figure 124. CNF deodorant.....	298
Figure 125. Chitin nanofiber product.....	299
Figure 126. Marusumi Paper cellulose nanofiber products.....	301
Figure 127. FibriMa cellulose nanofiber powder.....	302
Figure 128. Cellulomix production process.....	304
Figure 129. Nanobase versus conventional products.....	304
Figure 130. Uni-ball Signo UMN-307.....	305
Figure 131: CNF slurries.....	307
Figure 132. Range of CNF products.....	307
Figure 133: Nanocell serum product.....	311
Figure 134. Vatensel® product.....	312
Figure 135: Hydrophobization facilities for raw pulp.....	314
Figure 136: Mixing facilities for CNF-reinforced plastic.....	314
Figure 137. Nippon Paper CNF production process.....	317
Figure 138: Nippon Paper Industries' adult diapers.....	318
Figure 139. All-resin forceps incorporating CNF.....	320
Figure 140. CNF paint product.....	322
Figure 141. CNF wet powder.....	324
Figure 142. CNF transparent film.....	324
Figure 143. Transparent CNF sheets.....	325
Figure 144. Oji Paper CNF production process.....	326
Figure 145. CNF clear sheets.....	328
Figure 146. Oji Holdings CNF polycarbonate product.....	330
Figure 147. Fluorene cellulose ® powder.....	331
Figure 148. A vacuum cleaner part made of cellulose fiber (left) and the assembled vacuum cleaner.....	332
Figure 149. Performance Biofilaments CNF production process.....	333
Figure 150. XCNF.....	335

---

Figure 151. Innventia CNF production process.....	337
Figure 152: Innventia AB movable nanocellulose demo plant.....	338
Figure 153. CNF insulation flat plates.....	339
Figure 154. Seiko PMC CNF production process.....	342
Figure 155. Manufacturing process for STARCEL.....	343
Figure 156. Rubber soles incorporating CNF.....	345
Figure 157. CNF dispersion and powder from Starlite.....	346
Figure 158. Stora Enso CNF production process.....	347
Figure 159. Sugino Machine CNF production process.....	349
Figure 160. High Pressure Water Jet Process.....	349
Figure 161. 2 wt.% CNF suspension.....	350
Figure 162. BiNF-i-s Dry Powder.....	350
Figure 163. BiNF-i-s Dry Powder and Propylene (PP) Complex Pellet.....	351
Figure 164. Silk nanofiber (right) and cocoon of raw material.....	351
Figure 165. SVELOSA AD CNC products.....	353
Figure 166. Silver / CNF composite dispersions.....	358
Figure 167. CNF/nanosilver powder.....	359
Figure 168: Comparison of weight reduction effect using CNF.....	361
Figure 169: CNF resin products.....	364
Figure 170. University of Maine CNF production process.....	365
Figure 171. UPM-Kymmene CNF production process.....	367
Figure 172. FibDex® wound dressing.....	368
Figure 173. US Forest Service Products Laboratory CNF production process.....	370
Figure 174: Flexible electronic substrate made from CNF.....	371
Figure 175. VTT 100% bio-based stand-up pouches.....	374
Figure 176. VTT CNF production process.....	375
Figure 177: HefCel-coated wood (left) and untreated wood (right) after 30 seconds flame test.....	376
Figure 178: Bio-based barrier bags prepared from Tempo-CNF coated bio-HDPE film.....	377
Figure 179. S-CNF in powder form.....	379

---

Figure 180. Zelfo Technology GmbH CNF production process.....	382
Figure 181. R3TM process technology. ....	391
Figure 182. Blue Goose CNC Production Process.....	392
Figure 183: Celluforce production process.....	397
Figure 184: NCC™ Process.....	398
Figure 185: 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:.....	398
Figure 186. Filler Bank CNC products. ....	400
Figure 187. Melodea CNC barrier coating packaging. ....	404
Figure 188. Plantrose process. ....	407
Figure 189. CNC solution. ....	411
Figure 190. University of Maine CNF production process. ....	413
Figure 191. US Forest Service Products Laboratory CNF production process.....	415
Figure 192. Jelly-like seaweed-based nanocellulose hydrogel.....	418
Figure 193. Cellugy materials. ....	425
Figure 194: Bacterial cellulose face mask sheet. ....	426
Figure 195. TransLeather. ....	429