

TABLE OF CONTENTS

1 RESEARCH METHODOLOGY	17
1.1 Investment analysis.....	19
1.2 Market impediment analysis	21
2 EXECUTIVE SUMMARY	24
2.1 Main markets and applications	25
2.2 Main opportunities in nanocellulose.....	28
2.3 Production in 2017.....	31
2.4 The market for nanocellulose in 2017.....	33
2.5 Nanocellulose market by region	38
2.6 The market for nanocellulose in 2018.....	42
2.7 Japan market leads the way	43
3 TYPES OF COMMERCIALY AVAILABLE NANOCELLULOSE	44
3.1 Microfibrillated cellulose	47
3.2 NanoFibrillar Cellulose (NFC/CFC)	48
3.2.1 Nanofibrillated cellulose production methods.....	48
3.2.2 Applications.....	48
3.3 NanoCrystalline Cellulose (NCC/CNC).....	51
3.3.1 Applications.....	52
3.3.2 Nanocrystalline cellulose production methods	53
3.4 Bacterial Cellulose (BCC).....	54
3.4.1 Applications.....	54
4 NANOCELLULOSE MARKET STRUCTURE AND ROUTES TO COMMERCIALIZATION	55
5 COMMERCIAL OPPORTUNITES IN NANOCELLULOSE	59

5.1	Volume of industry demand for nanocellulose by nanocellulose producer sales.....	59
5.2	Current end users for nanocellulose, by market and company.....	60
6	NANOCELLULOSE PRODUCERS AND PRODUCTION CAPACITIES, CURRENT AND PLANNED	63
6.1	Cellulose nanofiber production.....	63
6.2	Cellulose nanocrystal production.....	64
7	NANOCELLULOSE PRICING	65
7.1	Cellulose nanofiber Gel/ Cellulose nanofiber Slurry/MFC pricing.....	65
7.2	NCC pricing	67
7.3	Bulk supply	67
7.4	Commoditisation.....	68
8	COMMERCIAL OPPORTUNITES IN NANOCELLULOSE	69
8.1	Short-term growth.....	69
8.2	Medium-term growth.....	70
8.3	Opportunities in printed and flexible electronics	70
8.4	COMPOSITES	73
8.4.1	Applications.....	73
8.4.2	Current and planned commercial activity	75
8.4.3	Nanocellulose market opportunity	77
8.4.4	Market impediments.....	80
8.5	BIOPACKAGING	81
8.5.1	Applications.....	81
8.5.2	Current and planned commercial activity	82
8.5.3	Nanocellulose market opportunity	83
8.5.4	Market impediments.....	87
8.6	PAPER & BOARD	88
8.6.1	Applications.....	89

8.6.2	Current and planned commercial activity	91
8.6.3	Nanocellulose market opportunity	92
8.6.4	Market impediments	94
8.7	AEROSPACE AND AVIATION	95
8.7.1	Applications	95
8.7.2	Current and planned commercial activity	97
8.7.3	Nanocellulose market opportunity	97
8.7.4	Market impediments	99
8.8	AUTOMOTIVE	100
8.8.1	Applications	100
8.8.2	Current and planned commercial activity	102
8.8.3	Nanocellulose market opportunity	103
8.8.4	Market impediments	108
8.9	CONSTRUCTION AND BUILDING	109
8.9.1	Applications	109
8.9.2	Current and planned commercial activity	109
8.9.3	Nanocellulose market opportunity	113
8.9.4	Market impediments	115
8.10	TEXTILES AND CLOTHING	116
8.10.1	Applications	116
8.10.2	Current and planned commercial activity	117
8.10.3	Nanocellulose market opportunity	117
8.10.4	Market impediments	119
8.11	MEDICAL & HEALTHCARE	120
8.11.1	Applications	120
8.11.2	Current and planned commercial activity	122
8.11.3	Nanocellulose market opportunity	124
8.11.4	Market impediments	126

8.12	COATINGS AND PAINTS	126
8.12.1	Applications.....	127
8.12.2	Current and planned commercial activity	129
8.12.3	Nanocellulose market opportunity.....	130
8.12.4	Market impediments.....	134
8.13	AEROGELS	136
8.13.1	Applications.....	136
8.13.2	Current and planned commercial activity	138
8.13.3	Nanocellulose market opportunity.....	138
8.13.4	Market impediments.....	140
8.14	OIL AND GAS EXPLORATION.....	140
8.14.1	Applications.....	140
8.14.2	Current and planned commercial activity	142
8.14.3	Nanocellulose market opportunity.....	142
8.14.4	Market impediments.....	146
8.15	FILTRATION AND SEPARATION.....	146
8.15.1	Applications.....	146
8.15.2	Current and planned commercial activity	150
8.15.3	Nanocellulose market opportunity.....	151
8.15.4	Market impediments.....	154
8.16	RHEOLOGY MODIFIERS	155
8.16.1	Applications.....	155
8.16.2	Current and planned commercial activity	157
8.16.3	Nanocellulose market opportunity.....	157
8.16.4	Market impediments.....	157
8.17	PRINTABLE, STRETCHABLE AND FLEXIBLE ELECTRONICS.....	158
8.17.1	Applications.....	158
8.17.2	Current and planned commercial activity	162

8.17.3	Nanocellulose market opportunity	162
8.17.4	Market impediments.....	167
8.18	3D PRINTING.....	168
8.18.1	Applications.....	168
8.18.2	Current and planned commercial activity	169
8.18.3	Nanocellulose market opportunity.....	170
8.18.4	Market impediments.....	171
8.19	OTHER MARKETS	172
8.19.1	Rubber and tire additives	172
8.19.2	Colourants.....	172
9	NANOCELLULOSE PRODUCERS	174
9.1	Producers and types of nanocellulose produced (NCF, NCC, BCC).....	174
9.2	Target markets for producers	175
9.3	Nanocellulose producer production capacities, prices and target markets.....	177
9.3.1	American Process, Inc.	177
9.3.2	Ashai Kasei Chemicals Corporation.....	179
9.3.3	Blue Goose Biorefineries, Inc.....	182
9.3.4	Borregaard Chemcell	183
9.3.5	Cellucomp Ltd.	185
9.3.6	Celluforce, Inc.	186
9.3.7	Chuetsu Pulp & Paper Co., Ltd.	188
9.3.8	Daicel Corporation	189
9.3.9	Daio Paper Corporation	190
9.3.10	DIC Products, Inc.....	192
9.3.11	DKS Co. Ltd.....	193
9.3.12	Hattori Shoten Co., Ltd.	195
9.3.13	Imerys	195

9.3.14	Innventia AB.....	196
9.3.15	Kruger Biomaterials, Inc.....	197
9.3.16	Melodea/Holmen.....	198
9.3.17	Nippon Paper Group, Inc.	199
9.3.18	Oji Paper Company Ltd.....	203
9.3.19	Paperlogic.....	207
9.3.20	Performance BioFilaments Inc.....	208
9.3.21	Renmatrix, Inc.....	209
9.3.22	Seiko PMC Corporation	209
9.3.23	Stora Enso Ltd.	210
9.3.24	Sugino Machine Limited.....	212
9.3.25	University of Maine	213
9.3.26	UPM-Kymmene.....	214
9.3.27	US Forest Service Forest Products Laboratory.....	215
9.3.28	VTT Technical Research Centre.....	217
9.3.29	Zelfo Technology GmbH.....	220
10	REFERENCES	222

TABLES

Table 1:	Markets and applications for nanocellulose.	25
Table 2:	Market opportunity assessment for nanocellulose, by application.	28
Table 3:	Nanocellulose production plants worldwide and production status.	31
Table 4:	Current and planned production capacities, by major suppliers, pilot/pre-commercial and commercial volumes.	33
Table 5:	Nanocellulose products in Japan.	34
Table 6:	SWOT analysis of nanocellulose.	40

Table 7: Properties and applications of nanocellulose	46
Table 8: Nanofibrillated cellulose production methods.....	48
Table 9: Applications of nanofibrillar cellulose (NFC).....	49
Table 10: Production methods of NFC producers.....	50
Table 11: Applications of nanocrystalline cellulose (NCC).....	53
Table 12: Cellulose nanocrystals (NCC) production methods.....	53
Table 13: Applications of bacterial cellulose (BC).....	54
Table 14: Nanocellulose market structure.....	55
Table 15: Current and potential end users for nanocellulose, by market and company.....	60
Table 16: Production capacities of CNF producers per annum in tons, current and planned.	63
Table 17: Production capacities of CNC producers per annum in tons, current and planned.	64
Table 18: Cellulose nanofiber producers, prices/kg and main target markets.....	65
Table 19: NCC producers, prices/kg and main target markets.....	67
Table 20: Properties of flexible electronics cellulose nanofiber films.	72
Table 21: Equivalent cost of nanocellulose and competitive materials in polymer composites.....	74
Table 22: Applications of nanocellulose in polymer composites by cellulose type.....	74
Table 23: Nanocellulose applications timeline in the polymer composites market.....	75
Table 24: Companies developing nanocellulose products in paper and board, applications targeted and stage of commercialization.....	75
Table 25: Market assessment for nanocellulose in composites.....	77
Table 26: Market opportunity assessment for nanocellulose in composites.	77
Table 27: Application markets, competing materials, nanocellulose advantages and current market size in composites.....	78
Table 28: Demand for nanocellulose in the composites market, 2015-2027 (tons).....	80
Table 29: Market impediments for nanocellulose in composites.....	80
Table 30: Companies developing nanocellulose products in bio packaging, applications targeted and stage of commercialization.....	82
Table 31: Market assessment for nanocellulose in biopackaging.....	83

Table 32: Application markets, competing materials, nanocellulose advantages and current market size in packaging.	84
Table 33: Market opportunity assessment for nanocellulose in biopackaging.	86
Table 34: Demand for nanocellulose in the biopackaging market, 2015-2027 (tons).....	87
Table 35: Market impediments for nanocellulose in the biopackaging market.	88
Table 36: Nanocellulose applications timeline in the paper and board markets.....	89
Table 37: Nanocellulose in construction-Companies and products.....	91
Table 38: Market opportunity assessment for nanocellulose in paper and board.	92
Table 39: Demand for nanocellulose in the paper and board market, 2015-2027 (tons).	93
Table 40: Market impediments for nanocellulose in the paper and board market.	94
Table 41: Applications in aerospace composites.	95
Table 42: Market size for nanocellulose in aerospace and aviation.	98
Table 43: Demand for nanocellulose in the aerospace and aviation market, 2015-2027 (tons).....	99
Table 44: Market impediments for nanocellulose in the aerospace market.	100
Table 45: Companies developing Nanocellulose products in the automotive industry, applications targeted and stage of commercialization.....	102
Table 46: Application markets, competing materials, Nanocellulose advantages and current market size in the automotive sector.....	104
Table 47: Market assessment for nanocellulose in the automotive sector.	105
Table 48: Market opportunity assessment for nanocellulose in the automotive industry.....	105
Table 49: Market size for nanocellulose in the automotive industry.	106
Table 50: Demand for nanocellulose in the automotive market, 2015-2027 (tons).	107
Table 51: Applications and commercialization challenges in the automotive market.....	108
Table 52: Market impediments for nanocellulose in the automotive market.....	108
Table 53: Comparison of nanocellulose with steel and other materials.	109
Table 54: Nanocellulose in construction-Companies and products.....	109
Table 55: Market size for nanocellulose in construction and civil engineering.	114
Table 56: Demand for nanocellulose in the construction and building market, 2015-2027 (tons).115	

Table 57: Market impediments in the construction, building protection and architectural exterior coatings market.....	116
Table 58: Companies developing nanocellulose products in textiles, applications targeted and stage of commercialization.....	117
Table 59: Market opportunity assessment for nanocellulose in textiles and clothing.	117
Table 60: Potential volume estimates (tons) and penetration of nanocellulose into textiles and clothing.....	118
Table 61: Market assessment for nanocellulose in textiles and clothing.....	118
Table 62: Market impediments for nanocellulose in the textiles and clothing market.....	119
Table 63: Nanocellulose applications timeline in the medical and healthcare markets.	120
Table 64: Nanocellulose product developers in medical and healthcare applications.....	122
Table 65: Applications of nanocellulose in medical and healthcare.	125
Table 66: Demand for nanocellulose in the medical and healthcare market, 2015-2027 (tons)...	125
Table 67: Market impediments for nanocellulose in the medical and healthcare market.	126
Table 68: Nanocellulose applications timeline in the coatings and paints markets.	127
Table 69: Companies developing nanocellulose products in coatings and paints, applications targeted and stage of commercialization.....	129
Table 70: Market assessment for nanocellulose in coatings and paints.	131
Table 71: Application markets, competing materials, nanocellulose advantages and current market size in coatings and films.	132
Table 72: Market opportunity assessment for nanocellulose in coatings and films.	133
Table 73: Demand for nanocellulose in the paint and coatings market, 2015-2027 (tons).....	134
Table 74: Market impediments for nanocellulose in the coatings and films market.....	136
Table 75: Nanocellulose applications timeline in the aerogels market.	136
Table 76: Nanocellulose product developers in aerogels.....	138
Table 77: Demand for nanocellulose in the aerogels market, 2015-2027 (tons).....	139
Table 78: Market impediments for nanocellulose in the aerogels market.	140
Table 79: Nanocellulose applications timeline in the oil market.	140
Table 80: Nanocellulose product developers in oil and gas exploration.....	142

Table 81: Application markets, competing materials, nanocellulose advantages and current market size in oil and gas.	143
Table 82: Market assessment for nanocellulose in oil and gas.	143
Table 83: Nanocellulose in the oil and gas market-applications, stage of commercialization and estimated economic impact.....	144
Table 84: Demand for nanocellulose in the oil and gas exploration market, 2015-2017 (tons)....	145
Table 85: Market impediments for nanocellulose in the oil and gas exploration market.	146
Table 86: Nanocellulose applications timeline in the filtration market.	146
Table 87: Companies developing NFC products in filtration, applications targeted and stage of commercialization.	150
Table 88: Application markets, competing materials, nanocellulose advantages and current market size in filtration.	151
Table 89: Market assessment for nanocellulose in filtration.....	152
Table 90: Market opportunity assessment for nanocellulose in the filtration industry.....	153
Table 91: Demand for nanocellulose in the filtration market, 2015-2027 (tons).	154
Table 92: Market impediments for nanocellulose in the filtration market.....	154
Table 93: Nanocellulose applications timeline in the rheology modifiers market.....	155
Table 94: Commercial activity in nanocellulose rheology modifiers.	157
Table 95: Market impediments for nanocellulose in the rheology modifiers market.	157
Table 96: Nanocellulose applications timeline in flexible electronics.	158
Table 97: Properties of flexible electronics cellulose nanofiber films.	161
Table 98: Companies developing Nanocellulose products in flexible and stretchable electronics, applications targeted and stage of commercialization.....	162
Table 99: Global market for wearables, 2014-2021, units and US\$.	163
Table 100: Application markets, competing materials, Nanocellulose advantages and current market size in electronics.....	165
Table 101: Market assessment for nanocellulose in the flexible and printed electronics sector. .	165
Table 102: Market opportunity assessment for Nanocellulose in flexible electronics.....	166
Table 103: Market impediments for nanocellulose in the printed and flexible electronics market.	168

Table 104: Companies developing nanocellulose 3D printing products,.....	169
Table 105: Application markets, competing materials, nanocellulose advantages and current market size in 3D printing.....	170
Table 106: Market assessment for nanocellulose in 3D printing.....	170
Table 107: Market opportunity assessment for nanocellulose in 3D printing.	171
Table 108: Market impediments for nanocellulose in the 3D printing market.....	172
Table 109: Nanocellulose producers and types of nanocellulose produced.	174
Table 110: Target market, by nanocellulose producer.	175

FIGURES

Figure 1: CNF wet powder.	31
Figure 2: Running shoes incorporating cellulose nanofibers.....	34
Figure 3: Ballpoint pen incorporating cellulose nanofibers.....	34
Figure 4: Onkyo speakers, incorporating CNF.....	35
Figure 5: Daio Paper toilet wipes.	36
Figure 6: Cellulose Nanofiber (CNF) composite with polyethylene (PE).	36
Figure 7: Nanocellulose market, by type, 2015–2027 (Tons).....	38
Figure 8: Nanocellulose market by region, 2017.....	39
Figure 9: Nanocellulose market by region, 2027.....	40
Figure 10: Polycarbonate (left); Composite of Polycarbonate and CNF.....	42
Figure 11: Schematic diagram of partial molecular structure of cellulose chain with numbering for carbon atoms and n= number of cellobiose repeating unit.....	44
Figure 12: Scale of cellulose materials.	45
Figure 13: Schematic of typical commercialization route for nanocellulose producer.	55
Figure 14: Volume of industry demand for nanocellulose by nanocellulose producer sales, 2016.	60
Figure 15: Nanocellulose photoluminescent paper.	71
Figure 16: Foldable nanopaper.....	72
Figure 17: Foldable nanopaper antenna.....	73

Figure 18: Demand for nanocellulose in the composites market, 2015-2027 (tons).	79
Figure 19: Demand for nanocellulose in the biopackaging market, 2015-2027 (tons).	87
Figure 20: Demand for nanocellulose in the paper and board market, 2015-2027 (tons).	93
Figure 21: Demand for nanocellulose in the aerospace and aviation market, 2015-2027 (tons). ..	99
Figure 22: NFC composite.	102
Figure 23: Demand for nanocellulose in the automotive market, 2015-2027 (tons).	107
Figure 24: Demand for nanocellulose in the construction and building market, 2015-2027 (tons).	115
Figure 25: Demand for nanocellulose in the medical and healthcare market, 2015-2027 (tons). ..	125
Figure 26: Global Paints and Coatings Market, share by end user market.	130
Figure 27: Demand for nanocellulose in the paints and coatings market, 2015-2027 (tons).	134
Figure 28: Demand for nanocellulose in the aerogels market, 2015-2027 (tons).	139
Figure 29: Nanocellulose sponge developed by EMPA for potential applications in oil recovery. ..	141
Figure 30: Demand for nanocellulose in the oil and gas exploration market, 2015-2017 (tons)... ..	145
Figure 31: Nanocellulose virus filter paper.	150
Figure 32: Demand for nanocellulose in the filtration market, 2015-2027 (tons).	153
Figure 33: Electronic components using NFC as insulating materials.	159
Figure 34: Cellulose nanofiber films.	160
Figure 35: LEDs shining on circuitry imprinted on a 5x5cm sheet of CNF.	160
Figure 36: Paper memory (ReRAM).	161
Figure 37: Global market revenues for smart wearable devices 2014-2021, in US\$.	163
Figure 38: Global market revenues for nanotech-enabled smart wearable devices 2014-2021 in US\$, conservative estimate.	164
Figure 39: Global market revenues for nanotech-enabled smart wearable devices 2014-2021 in US\$, optimistic estimate.	164
Figure 40: Jawbone 3D printed with cellulose ink.	169
Figure 41: Asahi Kasei CNF fabric sheet.	179
Figure 42: Properties of Asahi Kasei cellulose nanofiber nonwoven fabric.	180

Figure 43: Nonwoven fabric made from CNF.....	181
Figure 44: 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:.....	186
Figure 45: Rheocrysta spray.....	193
Figure 46: Hydrophobization facilities for raw pulp.....	200
Figure 47: Mixing facilities for CNF-reinforced plastic.....	201
Figure 48: Nippon Paper Industries’ adult diapers.....	202
Figure 49: CNF transparent film.....	204
Figure 50: CNF wet powder.....	204
Figure 51: Flexible electronic substrate made from CNF.....	217
Figure 52: Bio-based barrier bags prepared from Tempo-CNF coated bio-HDPE film.....	219

1 RESEARCH METHODOLOGY

The report covers the known nanocellulose suppliers and product developers. End user markets and applications are also outlined and forecast.

The following methodology was utilized:

1. Identification of companies in the nanocellulose sector, and companies developing products thereof. This was mainly accrued from Future Markets, Inc. existing information database and proprietary information on nanomaterials companies. This was also supplemented with a search of the literature on companies producing relevant nanomaterials. Secondary sources included journals and related books, trade literature, marketing literature, technology roadmaps, other product/promotional literature, annual reports, analyst reports, conference proceedings and other publications.

2. A series of interviews was conducted via email with relevant nanocellulose company representatives to gauge production volumes and end user's markets products are sold to.

The market was then quantified for relevant application impact and the main prerequisites for commercial success were identified including performance of the technology, supplier distribution, legislation, pricing of competing products, sale of complementary products, industry environment and demographics of the customer. Market revenues were forecast based on current revenues generated by companies marketing nanomaterials products, market penetrations in key end user markets of these products and future estimated growth in these markets.

Production volumes are in metric tons unless stated otherwise. The report refers to all types of chemical species of each nanomaterial type unless stated otherwise.

The overall study objective was to help accelerate the identification, development and commercialization of nanocellulose technologies, specifically cellulose nanofibers (CNF), cellulose nanocrystals (CNC) and bacterial cellulose (BC). Competitive analysis was compiled on the following producers:

CNF producers

- American Process, Inc.
- Asahi Kasei
- Borregaard Chemcell
- Cellucomp
- Chuetsu Pulp and Paper
- Daicel Corporation
- DaiNippon Ink and Chemicals (DIC) Corporation

- DKS Co. Ltd.
- Greencore Composites
- Imerys
- Invention AB
- Kruger Bioproducts, Inc.
- Nippon Paper Industries
- Oji Holdings
- Paperlogic
- SAPPI
- Seiko PMC Corporation.
- Story Enso
- Suina Machine
- University of Maine
- UPM-Kymani Corporation
- US Forest Service-Forest Products Laboratory
- VTT.
- Zelfo Technology.

CNC producers

- Blue Goose Biorefineries
- Cellulforce, Inc.
- Elodea
- More Research.

BC producers/application developers

- Exelon Biopolymers Corporation
- BC Technologies
- Bowil Biotech
- Depuy Synthes Biomaterials

The following information was included on each organization for CNF and CNC:

- Products
- Scale of production
- Production process
- Prices of NFC
- Extent of commercial development
- Advantages of NFC produced
- Target markets