

The Global Market for Carbon Nanotubes

Table of contents

1	RESEARCH METHODOLOGY.....	22
2	EXECUTIVE SUMMARY.....	29
2.1	Exceptional properties.....	30
2.2	Market developments 2018-2019.....	32
2.3	Products and applications.....	32
2.4	SWCNTs.....	36
2.4.1	Market developments 2018-2019.....	36
2.5	Competition from graphene.....	37
2.6	Production.....	39
2.6.1	Multi-walled carbon nanotube (MWCNT) production.....	39
2.6.2	Single-walled nanotube (SWCNT) production.....	40
2.6.3	Boron nitride nanotubes (BNNT) production.....	41
2.7	Global demand for carbon nanotubes, HISTORICAL AND FORECAST TO 2030.....	42
2.7.1	MWCNTs.....	42
2.7.2	SWCNTs.....	44
2.7.3	Current products.....	47
2.7.4	Future products.....	47
2.8	Market drivers and trends.....	48
2.9	Market and production challenges.....	53
3	INTRODUCTION.....	55

3.1	Properties of nanomaterials.....	55
3.2	Categorization.....	56
3.3	CARBON NANOTUBES.....	57
3.3.1	Multi-walled nanotubes (MWCNT).....	58
3.3.1.1	Properties.....	58
3.3.1.2	Applications.....	59
3.3.2	Single-wall carbon nanotubes (SWCNT).....	61
3.3.2.1	Properties.....	62
3.3.2.2	Applications.....	62
3.3.3	Comparison between MWCNTs and SWCNTs.....	65
3.3.4	Double-walled carbon nanotubes (DWNTs).....	65
3.3.4.1	Properties.....	65
3.3.4.2	Applications.....	66
3.3.5	Few-walled carbon nanotubes (FWNTs).....	66
3.3.5.1	Properties.....	66
3.3.5.2	Applications.....	66
3.4	Carbon Nanohorns (CNHs).....	66
3.4.1	Properties.....	66
3.4.2	Applications.....	67
3.5	Carbon Onions.....	67

3.5.1	Properties.....	67
3.5.2	Applications.....	68
3.6	Fullerenes.....	68
3.6.1	Properties.....	68
3.6.2	Applications.....	69
3.7	Boron Nitride nanotubes (BNNTs).....	70
3.7.1	Properties.....	70
3.7.1.1	Applications.....	70
4	CARBON NANOTUBE SYNTHESIS.....	71
5	CARBON NANOTUBES MARKET STRUCTURE.....	78
6	REGULATIONS AND STANDARDS.....	80
7	CARBON NANOTUBES PATENTS.....	85
8	CARBON NANOTUBES TECHNOLOGY READINESS LEVEL.....	89
9	CARBON NANOTUBES END USER MARKET SEGMENT ANALYSIS.....	91
9.1	The market for MWCNTs.....	91
9.1.1	MWCNT producer production capacities.....	92
9.2	The market for SWCNTs.....	95
9.2.1	SWCNT producer production capacities.....	96
9.3	Regional demand for carbon nanotubes.....	97
9.4	Main MWCNT producers.....	99
9.5	Price of carbon nanotubes-MWCNTs, SWCNTs and FWNTs.....	100
9.5.1	MWCNTs.....	100
9.5.2	SWCNTs.....	100

9.6	APPLICATIONS.....	101
10	END USER MARKET ANALYSIS FOR CARBON NANOTUBES.....	103
10.1	3D PRINTING.....	103
10.1.1	MARKET DRIVERS AND TRENDS.....	103
10.1.2	APPLICATIONS.....	104
10.1.2.1	3D printing filaments.....	104
10.1.3	MARKET SIZE AND OPPORTUNITY.....	105
10.1.4	MARKET CHALLENGES.....	105
10.1.5	PRODUCT DEVELOPERS.....	106
10.2	ADHESIVES.....	107
10.2.1	MARKET DRIVERS AND TRENDS.....	107
10.2.2	APPLICATIONS.....	108
10.2.2.1	Conductive adhesives.....	108
10.2.2.2	Thermal management adhesives.....	108
10.2.3	MARKET SIZE AND OPPORTUNITY.....	109
10.2.4	MARKET CHALLENGES.....	111
10.2.5	PRODUCT DEVELOPERS.....	111
10.3	AEROSPACE AND AVIATION.....	112

10.3.1	MARKET DRIVERS AND TRENDS.....	112
10.3.2	APPLICATIONS.....	113
10.3.2.1	Composites.....	114
10.3.2.2	Coatings.....	116
10.3.3	MARKET SIZE AND OPPORTUNITY.....	119
10.3.4	MARKET CHALLENGES.....	122
10.3.5	PRODUCT DEVELOPERS.....	123
10.4	AUTOMOTIVE.....	124
10.4.1	MARKET DRIVER AND TRENDS.....	125
10.4.2	APPLICATIONS.....	126
10.4.2.1	Composites.....	127
10.4.2.2	Thermally conductive additives.....	127
10.4.2.3	Tires.....	127
10.4.2.4	Heat dissipation in electric vehicles.....	127
10.4.2.5	In-vehicle and seat heaters.....	129
10.4.3	MARKET SIZE AND OPPORTUNITY.....	129
10.4.4	MARKET CHALLENGES.....	132

10.4.5	PRODUCT DEVELOPERS.....	132
10.5	COATINGS.....	133
10.5.1	MARKET DRIVERS AND TRENDS.....	134
10.5.2	APPLICATIONS.....	136
10.5.3	MARKET SIZE AND OPPORTUNITY.....	141
10.5.3.1	Thermal barrier coatings.....	144
10.5.3.2	Barrier coatings.....	144
10.5.3.3	Anti-microbial coatings.....	145
10.5.3.4	De-icing or anti-icing coatings.....	145
10.5.3.5	Abrasion and wear resistant coatings.....	145
10.5.3.6	Anti-corrosion coatings.....	145
10.5.4	MARKET CHALLENGES.....	146
10.5.5	PRODUCT DEVELOPERS.....	147
10.6	COMPOSITES.....	147
10.6.1	MARKET DRIVERS AND TRENDS.....	148
10.6.2	APPLICATIONS.....	149
10.6.2.1	Polymer composites.....	149

10.6.2.2	Barrier packaging.....	152
10.6.2.3	Electrostatic discharge (ESD) and electromagnetic interference (EMI) shielding.....	152
10.6.2.4	Wind turbines.....	152
10.6.2.5	Ballistic protection.....	153
10.6.3	MARKET SIZE AND OPPORTUNITY.....	153
10.6.4	MARKET CHALLENGES.....	156
10.6.5	PRODUCT DEVELOPERS.....	156
10.7	ELECTRONICS.....	158
10.7.1	FLEXIBLE ELECTRONICS, CONDUCTIVE FILMS AND DISPLAYS.....	159
10.7.1.1	MARKET DRIVERS AND TRENDS.....	159
10.7.1.2	APPLICATIONS.....	161
10.7.1.3	MARKET SIZE AND OPPORTUNITY.....	169
10.7.1.4	MARKET CHALLENGES.....	173
10.7.1.5	PRODUCT DEVELOPERS.....	175
10.7.2	CONDUCTIVE INKS.....	177
10.7.2.1	MARKET DRIVERS AND TRENDS.....	177
10.7.2.2	APPLICATIONS.....	178

10.7.2.3	MARKET SIZE AND OPPORTUNITY.....	183
10.7.2.4	MARKET CHALLENGES.....	187
10.7.2.5	PRODUCT DEVELOPERS.....	188
10.7.3	TRANSISTORS, INTEGRATED CIRCUITS AND OTHER COMPONENTS.....	188
10.7.3.1	APPLICATIONS.....	189
10.7.3.2	MARKET SIZE AND OPPORTUNITY.....	192
10.7.3.3	MARKET CHALLENGES.....	194
10.7.3.4	PRODUCT DEVELOPERS.....	196
10.7.4	MEMORY DEVICES.....	196
10.7.4.1	MARKET DRIVERS AND TRENDS.....	196
10.7.4.2	APPLICATIONS.....	197
10.7.4.3	MARKET SIZE AND OPPORTUNITY.....	199
10.7.4.4	MARKET CHALLENGES.....	200
10.7.4.5	PRODUCT DEVELOPERS.....	201
10.7.5	PHOTONICS.....	204
10.7.5.1	MARKET DRIVERS.....	204
10.7.5.2	APPLICATIONS.....	204

10.7.5.3	MARKET SIZE AND OPPORTUNITY.....	205
10.7.5.4	MARKET CHALLENGES.....	205
10.8	ENERGY STORAGE AND CONVERSION.....	206
10.8.1	BATTERIES.....	206
10.8.1.1	MARKET DRIVERS AND TRENDS.....	206
10.8.1.2	APPLICATIONS.....	209
10.8.1.3	MARKET SIZE AND OPPORTUNITY.....	211
10.8.1.4	MARKET CHALLENGES.....	214
10.8.2	SUPERCAPACITORS.....	215
10.8.2.1	MARKET DRIVERS AND TRENDS.....	215
10.8.2.2	APPLICATIONS.....	216
10.8.2.3	MARKET SIZE AND OPPORTUNITY.....	217
10.8.2.4	MARKET CHALLENGES.....	218
10.8.3	PHOTOVOLTAICS.....	219
10.8.3.1	MARKET DRIVERS AND TRENDS.....	219
10.8.3.2	APPLICATIONS.....	220
10.8.3.3	MARKET SIZE AND OPPORTUNITY.....	222

10.8.3.4	MARKET CHALLENGES.....	223
10.8.4	FUEL CELLS AND HYDROGEN STORAGE.....	224
10.8.4.1	MARKET DRIVERS.....	224
10.8.4.2	APPLICATIONS.....	226
10.8.4.3	MARKET SIZE AND OPPORTUNITY.....	226
10.8.4.4	MARKET CHALLENGES.....	228
10.9	FILTRATION AND SEPARATION.....	231
10.9.1	MARKET DRIVERS AND TRENDS.....	231
10.9.2	APPLICATIONS.....	232
10.9.2.1	Water filtration.....	234
10.9.2.2	Gas separation.....	235
10.9.3	MARKET SIZE AND OPPORTUNITY.....	235
10.9.4	MARKET CHALLENGES.....	237
10.9.5	PRODUCT DEVELOPERS.....	238
10.10	LIFE SCIENCES AND BIOMEDICAL.....	239
10.10.1	MARKET DRIVERS AND TRENDS.....	239
10.10.2	APPLICATIONS.....	240
10.10.2.1	Implants.....	241

10.10.2.2	Tissue engineering.....	241
10.10.2.3	Therapeutics.....	242
10.10.2.4	Biosensors.....	243
10.10.2.5	X-ray sources.....	243
10.10.2.6	Vaccine development & immunotherapy.....	245
10.10.3	MARKET SIZE AND OPPORTUNITY.....	245
10.10.4	MARKET CHALLENGES.....	247
10.10.5	PRODUCT DEVELOPERS.....	249
10.11	LUBRICANTS.....	250
10.11.1	MARKET DRIVERS AND TRENDS.....	250
10.11.2	APPLICATIONS.....	251
10.11.2.1	Lubricant additives.....	251
10.11.3	MARKET SIZE AND OPPORTUNITY.....	252
10.11.4	MARKET CHALLENGES.....	253
10.11.5	PRODUCT DEVELOPERS.....	254
10.12	OIL AND GAS.....	254
10.12.1	MARKET DRIVERS AND TRENDS.....	255

10.12.2	APPLICATIONS.....	
255		
10.12.2.1	Sensing and reservoir management.....	255
10.12.2.2	Coatings.....	
. 256		
10.12.2.3	Drilling fluids.....	256
10.12.2.4	Sorbent materials.....	256
10.12.3	MARKET SIZE AND OPPORTUNITY.....	
256		
10.12.4	MARKET CHALLENGES.....	
258		
10.13	RUBBER AND TIRES.....	259
10.13.1	APPLICATIONS.....	
259		
10.13.1.1	Rubber additives.....	260
10.13.1.2	Shape memory elastomers.....	260
10.13.1.3	Tire additives.....	260
10.13.2	GLOBAL MARKET SIZE AND OPPORTUNITY.....	
261		
10.13.3	MARKET CHALLENGES.....	
261		
10.13.4	PRODUCT DEVELOPERS.....	
262		
10.14	SENSORS.....	263
10.14.1	MARKET DRIVERS AND TRENDS.....	
263		

10.14.2	APPLICATIONS.....	264
10.14.2.1	Biosensors.....	265
10.14.2.2	Gas sensors.....	266
10.14.2.3	Infrared (IR) sensors.....	266
10.14.2.4	Pressure sensors.....	267
10.14.2.5	Strain sensors.....	267
10.14.3	MARKET SIZE AND OPPORTUNITY.....	268
10.14.4	MARKET CHALLENGES.....	270
10.14.5	PRODUCT DEVELOPERS.....	271
10.15	SMART TEXTILES AND APPAREL.....	272
10.15.1	MARKET DRIVERS AND TRENDS.....	272
10.15.2	APPLICATIONS.....	275
10.15.2.1	Electrically conductive textiles.....	277
10.15.2.2	Flame retardant textiles.....	278
10.15.2.3	Wearable sensors.....	279
10.15.3	MARKET SIZE AND OPPORTUNITY.....	279
10.15.4	MARKET CHALLENGES.....	283

10.15.5	PRODUCT DEVELOPERS.....	284
11	MULTI-WALLED CARBON NANOTUBES COMPANY PROFILES.....	285
	(100 COMPANY PROFILES)	
12	SINGLE-WALLED CARBON NANOTUBES COMPANY PROFILES.....	342 (8
	COMPANY PROFILES)]
13	REFERENCES.....	349

Tables

Table 1: Market summary for carbon nanotubes-Selling grade particle diameter, usage, advantages, average price/ton, high volume applications, low volume applications and novel applications.....	29
Table 2: Properties of CNTs and comparable materials.....	31
Table 3: Notable events in the MWCNTs market in 2018.....	32
Table 4: Market opportunity assessment for SWCNTs in order of opportunity from high to low.....	33
Table 5. Comparative properties of MWCNT and SWCNT.....	36
Table 6: Notable events in the SWCNTs market in 2018.....	37
Table 7: Competitive analysis of Carbon nanotubes and graphene by application area and potential impact by 2025.	37
Table 8: Annual production capacity of MWCNT producers 2018.....	39
Table 9: SWCNT producers production capacities 2018.....	40
Table 10: Production volumes of MWCNTs (tons), 2010-2030.....	42
Table 11. Market trends impacting the market for SWCNTs.....	48
Table 12: Categorization of nanomaterials.....	56
Table 13: Properties of carbon nanotubes.....	57

Table 14: Applications of multi-walled carbon nanotubes.....	59
Table 15: Markets, benefits and applications of Single-Walled Carbon Nanotubes.....	63
Table 16: Comparison between single-walled carbon nanotubes and multi-walled carbon nanotubes.....	65
Table 17: Markets, benefits and applications of fullerenes.....	69
Table 18: SWCNT synthesis methods.....	72
Table 19: Carbon nanotubes market structure.....	79
Table 20: National nanomaterials registries in Europe.....	81
Table 21: Nanomaterials regulatory bodies in Australia.....	85
Table 22. Location of MWCNT patent filings 2008-2018.....	86
Table 23. Main MWCNT patent assignees.....	86
Table 24. Location of SWCNT patent filings 2008-2018.....	87
Table 25. Main SWCNT patent assignees.....	88
Table 26: Production volumes of carbon nanotubes (tons), 2010-2030.....	91
Table 27: Annual production capacity of MWCNT producers.....	93
Table 28: SWCNT capacities, by producers.....	96
Table 29: Example carbon nanotubes prices.....	101
Table 30: Markets, benefits and applications of Carbon Nanotubes.....	101
Table 31: Market drivers for use of CNTs in 3D printing.....	103
Table 32: Applications and benefits of CNTs in 3D printing.....	104
Table 33: Market size for CNTs in 3D printing.....	105
Table 34: Market opportunity assessment for CNTs in 3D printing.....	105
Table 35: Market challenges for CNTs in 3D printing.....	105
Table 36: Market challenges rating for CNTs in the 3D printing market.....	106
Table 37: Carbon nanotubes product and application developers in the 3D printing industry.....	106

Table 38: Market drivers for use of carbon nanotubes in adhesives.....	107
Table 39: Applications and benefits of carbon nanotubes in adhesives.....	108
Table 40: Market size for carbon nanotubes in adhesives.....	109
Table 41: Market opportunity assessment for CNTs in adhesives.....	109
Table 42: Market challenges rating for CNTs in the adhesives market.....	111
Table 43: Carbon nanotubes product and application developers in the adhesives industry.....	111
Table 44: Market drivers for use of CNTs in aerospace.....	112
Table 45: Applications and benefits of CNTs in aerospace.....	113
Table 46: Applications in aerospace composites, by nanomaterials type and benefits thereof.....	115
Table 47: Types of nanocoatings utilized in aerospace and application.....	117
Table 48: Market size for CNTs in aerospace.....	120
Table 49: Market opportunity assessment for CNTs in aerospace.....	120
Table 50: Market challenges rating for CNTs in the aerospace market.....	122
Table 51: Carbon nanotubes product and application developers in the aerospace industry.....	123
Table 52: Market drivers for use of CNTs in automotive.....	125
Table 53: Applications and benefits of CNTs in automotive.....	128
Table 54: Market size for CNTs in automotive.....	129
Table 55: Market opportunity assessment for CNTs in automotive.....	130
Table 56: Applications and commercialization challenges for CNTs in the automotive market.....	132
Table 57: Market challenges rating for CNTs in the automotive market.....	132
Table 58: Carbon nanotubes product and application developers in the automotive industry.....	132
Table 59: Markets for nanocoatings.....	142
Table 60: Carbon nanotubes in the coatings market-applications, stage of commercialization and addressable market size.....	145

Table 61: Market challenges rating for CNTs in the coatings market.....	146
Table 62: Carbon nanotubes product and application developers in the coatings industry.....	147
Table 63: Market drivers for use of CNTs in composites.....	148
Table 64: Comparative properties of polymer composites reinforcing materials.....	149
Table 65: Applications and benefits of SWCNTs in composites.....	150
Table 66: Market size for CNTs in composites.....	153
Table 67: Market opportunity assessment for CNTs in composites.....	154
Table 68: Applications and commercialization challenges for CNTs in composites.....	156
Table 69: Market challenges rating for CNTs in the composites market.....	156
Table 70: Carbon nanotubes product and application developers in the composites industry.....	156
Table 71: Market drivers for use of CNTs in flexible electronics and conductive films.....	159
Table 72: Applications and benefits of CNTs in flexible electronics and conductive films.....	162
Table 73: Comparison of ITO replacements.....	164
Table 74: Wearable electronics devices and stage of development.....	166
Table 75: Market size for CNTs in flexible electronics and conductive films.....	169
Table 76: Market opportunity assessment for CNTs in flexible electronics and conductive films.....	170
Table 77: Global market for wearable electronics, 2015-2030, by application, billions \$.....	172
Table 78: Applications and commercialization challenges for CNTs in flexible electronics and conductive films.....	173
Table 79: Market challenges rating for CNTs in the flexible electronics and conductive films market.....	174
Table 80: Carbon nanotubes product and application developers in transparent conductive films and displays.....	175
Table 81: Market drivers for use of CNTs in conductive inks.....	177
Table 82: Comparative properties of conductive inks.....	178
Table 83: Opportunities for advanced materials in printed electronics.....	180

Table 84: Applications in flexible and stretchable batteries, by nanomaterials type and benefits thereof.....	182
Table 85: Market opportunity assessment for CNTs in conductive inks.....	183
Table 86: Conductive inks in the flexible and stretchable electronics market 2017-2030 revenue forecast (million \$), by ink types.....	186
Table 87: Market challenges for CNTs in conductive inks.....	187
Table 88: Market challenges rating for CNTs in the conductive inks market.....	187
Table 89: Carbon nanotubes product and application developers in conductive inks.....	188
Table 90: Market drivers for use of CNTs in transistors, integrated circuits and other components.....	188
Table 91: Applications and benefits of CNTs in transistors, integrated circuits and other components.....	191
Table 92: Market size for CNTs in transistors, integrated circuits and other components.....	192
Table 93: Market opportunity assessment for CNTs in transistors, integrated circuits and other components.....	193
Table 94: Applications and commercialization challenges for CNTs in the transistors, integrated circuits and other components market.....	194
Table 95: Market challenges rating for CNTs in the transistors, integrated circuits and other components market....	195
Table 96: Carbon nanotubes product and application developers in transistors, integrated circuits and other components.....	196
Table 97: Market drivers for use of CNTs in memory devices.....	196
Table 98: Applications and benefits of CNTs in memory devices.....	198
Table 99: Market size for CNTs in memory devices.....	199
Table 100: Market opportunity assessment for CNTs in memory devices.....	200
Table 101: Market challenges rating for CNTs in the memory devices market.....	201
Table 102: Carbon nanotubes product and application developers in memory devices.....	203
Table 103: Market drivers for use of CNTs in photonics.....	204
Table 104: Applications and benefits of CNTs in photonics.....	204
Table 105: Market size for CNTs in photonics.....	205
Table 106: Market challenges rating for CNTs in the photonics market.....	205

Table 107: Market drivers for use of CNTs in batteries.....	207
Table 108: Applications and benefits of CNTs in batteries.....	209
Table 109: Market size for CNTs in batteries.....	211
Table 110: Potential addressable market for thin film, flexible and printed batteries.....	212
Table 111: Market challenges in CNT batteries.....	214
Table 112: Market challenges rating for CNTs in the batteries market.....	215
Table 113: Market drivers for use of CNTs in supercapacitors.....	215
Table 114: Applications and benefits of CNTs in supercapacitors.....	216
Table 115: Properties of carbon materials in high-performance supercapacitors.....	217
Table 116: Market size for CNTs in supercapacitors.....	217
Table 117: Market opportunity assessment for CNTs in supercapacitors.....	218
Table 118: Market challenges in supercapacitors.....	218
Table 119: Market challenges rating for CNTs in the supercapacitors market.....	219
Table 120: Market drivers for use of CNTs in photovoltaics.....	219
Table 121: Applications and benefits of CNTs in photovoltaics.....	221
Table 122: Market size for CNTs in photovoltaics.....	222
Table 123: Market size for CNTs in photovoltaics.....	222
Table 124: Potential addressable market for CNTs in photovoltaics.....	223
Table 125: Market challenges for CNTs in solar.....	223
Table 126: Market challenges rating for C NTs in the solar market.....	224
Table 127: Market drivers for use of CNTs in fuel cells and hydrogen storage.....	224
Table 128: Applications and benefits of CNTs in fuel cells and hydrogen storage.....	226
Table 129: Electrical conductivity of different catalyst supports compared to carbon nanotubes.....	226
Table 130: Market size for CNTs in fuel cells and hydrogen storage.....	227

Table 131: Market opportunity assessment for CNTs in fuel cells and hydrogen storage.....	227
Table 132: Market challenges rating for CNTs in the fuel cells and hydrogen storage market.....	228
Table 133: Carbon nanotubes product and application developers in the energy storage, conversion and exploration industries.....	228
Table 134: Market drivers for use of CNTs in filtration.....	231
Table 135: Comparison of CNT membranes with other membrane technologies.....	233
Table 136: Applications and benefits of CNTs in filtration and separation.....	235
Table 137: Market size for CNTs in filtration.....	235
Table 138: Market opportunity assessment for CNTs in filtration.....	236
Table 139: Market challenges for CNTs in filtration.....	237
Table 140: Market challenges rating for CNTs in the filtration market.....	237
Table 141: Carbon nanotubes product and application developers in the filtration industry.....	238
Table 142: Market drivers for use of CNTs in the life sciences and medical market.....	239
Table 143: CNTs in life sciences and biomedicine.....	242
Table 144: Applications and benefits of CNTs in life sciences and medical.....	243
Table 145: Market size for CNTs in life sciences and medical.....	245
Table 146: Potential addressable market for smart textiles and wearables in medical and healthcare.....	246
Table 147: Market opportunity assessment for CNTs in life sciences and medical.....	247
Table 148: Applications and commercialization challenges for CNTs in life sciences and medical.....	247
Table 149: Market challenges rating for CNTs in the life sciences and medical.....	249
Table 150: Carbon nanotubes product and application developers in the medical and healthcare industry.....	249
Table 151: Market drivers for use of CNTs in lubricants.....	250
Table 152: Applications of carbon nanotubes in lubricants.....	251
Table 153: Applications in lubricants, by nanomaterials type and benefits thereof.....	252

Table 154: Market size for CNTs in lubricants.....	252
Table 155: Market opportunity assessment for CNTs in lubricants.....	253
Table 156: Market challenges rating for CNTs in the lubricants market.....	253
Table 157: Carbon nanotubes product and application developers in the lubricants industry.....	254
Table 158: Market drivers for carbon nanotubes in oil and gas.....	255
Table 159: Market summary and revenues for CNTs in the oil and gas market.....	257
Table 160: Investment opportunity assessment for CNTs in the oil and gas market.....	257
Table 161: Market challenges rating for carbon nanotubes in the oil and gas exploration market.....	258
Table 162: Applications of CNTs in rubber and tires.....	259
Table 163: Market summary and revenues for CNTs in the rubber and tires market.....	261
Table 164: Investment opportunity assessment for CNTs in the rubber and tires market.....	261
Table 165: Market challenges for CNTs in rubber and tires.....	261
Table 166: Companies developing graphene-based products in rubber and tires.....	262
Table 167: Market drivers for use of CNTs in sensors.....	263
Table 168: Applications and benefits of CNTs in sensors.....	264
Table 169: Market size for CNTs in sensors.....	268
Table 170: Market opportunity assessment for CNTs in sensors.....	269
Table 171: Market challenges for CNTs in sensors.....	270
Table 172: Market challenges rating for CNTs in the sensors market.....	270
Table 173: Carbon nanotubes product and application developers in the sensors industry.....	271
Table 174: Types of smart textiles.....	273
Table 175: Smart textile products.....	273
Table 176: Market drivers for use of CNTs in smart textiles and apparel.....	274
Table 177: Desirable functional properties for the textiles industry afforded by the use of nanomaterials.....	275

Table 178: Applications and benefits of CNTs in textiles and apparel.....	276
Table 179: Global smart clothing, interactive fabrics and apparel market.....	280
Table 180: Market opportunity assessment for CNTs in smart textiles and apparel.....	283
Table 181: Applications and commercialization challenges for CNTs in smart textiles and apparel.....	283
Table 182: Market challenges rating for CNTs in the smart textiles and apparel market.....	284
Table 183: Carbon nanotubes product and application developers in the textiles industry.....	284
Table 184: CNT producers and companies they supply/licence to.....	285

Figures

Figure 1: Molecular structures of SWNT and MWCNT.....	31
Figure 2: Global demand for MWCNTs (tons), 2010-2030.....	43
Figure 3: Demand for MWCNTs, by market in 2017, total.....	44
Figure 4: Demand for single-walled carbon nanotubes, by market, 2017, based on target market analysis from SWCNT producers.....	45
Figure 5: Production capacities for SWCNTs in kilograms, 2005-2018.....	46
Figure 6: Demand for SWCNTs in tons, 2018-2030.....	46
Figure 7: Schematic of single-walled carbon nanotube.....	62
Figure 8: TIM sheet developed by Zeon Corporation.....	63
Figure 9: Double-walled carbon nanotube bundle cross-section micrograph and model.....	66
Figure 10: Schematic representation of carbon nanohorns.....	67
Figure 11: TEM image of carbon onion.....	68
Figure 12: Fullerene schematic.....	69
Figure 13: Schematic of Boron Nitride nanotubes (BNNTs). Alternating B and N atoms are shown in blue and red....	70
Figure 14: Schematic representation of methods used for carbon nanotube synthesis (a) Arc discharge (b) Chemical vapor deposition (c) Laser ablation (d) hydrocarbon flames.....	72
Figure 15: Arc discharge process for CNTs.....	74

Figure 16: Schematic of thermal-CVD method.....	74
Figure 17: Schematic of plasma-CVD method.....	75
Figure 18: CoMoCAT® process.....	76
Figure 19: Schematic for flame synthesis of carbon nanotubes (a) premixed flame (b) counter-flow diffusion flame (c) co-flow diffusion flame (d) inverse diffusion flame.....	77
Figure 20: Schematic of laser ablation synthesis.....	78
Figure 21: MWCNT patents filed 2000-2017.....	86
Figure 22. SWCNT patent applications 2001-2018.....	87
Figure 23: Technology Readiness Level (TRL) for Carbon Nanotubes.....	90
Figure 24: Global demand for carbon nanotubes (tons), 2010-2030.....	92
Figure 25: Demand for carbon nanotubes, by market in 2018, total.....	94
Figure 26: Demand for single-walled carbon nanotubes, by market, 2018.....	95
Figure 27: Demand for single-walled carbon nanotubes, by market, 2030.....	96
Figure 28: Production volumes of Carbon Nanotubes 2017, by region.....	97
Figure 29: 3D Printed tweezers incorporating Carbon Nanotube Filament.....	104
Figure 30: Potential addressable market for CNTs in adhesives, USD.....	110
Figure 31: Carbon nanotube Composite Overwrap Pressure Vessel (COPV) developed by NASA.....	114
Figure 32: Veelo carbon fiber nanotube sheet.....	115
Figure 33: HeatCoat CNT anti-icing coatings.....	118
Figure 34: Potential addressable market for CNTs in aerospace.....	121
Figure 35: Potential addressable market for CNTs in aerospace, USD.....	122
Figure 36: Schematic of CNTs as heat-dissipation sheets.....	128
Figure 37: Potential addressable market for CNTs in the automotive sector.....	131
Figure 38: Potential addressable market for CNTs in automotive, USD.....	132

Figure 39: Global Paints and Coatings Market, share by end user market.....	141
Figure 40: Potential addressable market for CNTs in the coatings market.....	145
Figure 41: CNT anti-icing coating for wind turbines.....	153
Figure 42: Potential addressable market for CNTs in composites.....	154
Figure 43: Potential addressable market for CNTs in composites, USD.....	155
Figure 44: Carbon nanotube thin-film transistors and integrated circuits on a flexible and transparent substrate.....	161
Figure 45: 3D printed carbon nanotube sensor.....	163
Figure 46: Carbon nanotube-based color active matrix electrophoretic display (EPD) e-paper.....	165
Figure 47: Covestro wearables.....	166
Figure 48: LG Innotek flexible textile pressure sensor.....	168
Figure 49: C2Sense flexible sensor.....	169
Figure 50: Potential addressable market for CNTs in flexible electronics, conductive films and displays.....	171
Figure 51: Global market for wearable electronics, 2015-2030, by application, billions \$.....	172
Figure 52: Global transparent conductive electrodes market forecast by materials type, 2012-2030, millions \$.....	173
Figure 53: Nanotube inks.....	178
Figure 54: Flexible RFID tag.....	180
Figure 55: Enfucell Printed Battery.....	183
Figure 56: Potential addressable market for CNTs in conductive inks, USD.....	185
Figure 57: Conductive inks in the flexible and stretchable electronics market 2017-2030 revenue forecast (million \$), by ink types.....	186
Figure 58: Emerging logic devices.....	190
Figure 59: Thin film transistor incorporating CNTs.....	190
Figure 60: Potential addressable market for CNTs in transistors and integrated circuits.....	193
Figure 61: Potential addressable market for CNTs in transistors, integrated circuits and other components, USD....	194

Figure 62: Carbon nanotubes NRAM chip..... 198

Figure 63: Stretchable SWCNT memory and logic devices for wearable electronics..... 198

Figure 64: Schematic of NRAM cell..... 203

Figure 65: Energy densities and specific energy of rechargeable batteries..... 209

Figure 66: Nano Lithium X Battery..... 211

Figure 67: Potential addressable market for CNTs in batteries, USD..... 214

Figure 68: Suntech/TCNT nanotube frame module..... 221

Figure 69: CARESTREAM DRX-Revolution Nano Mobile X-ray System..... 241

Figure 70: Potential addressable market for CNTs in sensors, USD..... 270

Figure 71: Global smart clothing, interactive fabrics and apparel market 2013-2030 revenue forecast (million \$).....
280

Figure 72 Global smart clothing, interactive fabrics and apparel sales by market segment, 2016..... 281

Figure 73: Global market revenues for nanotech-enabled smart clothing and apparel 2014-2021, in US\$, conservative
estimate..... 282

Figure 74: Global market revenues for nanotech-enabled smart clothing and apparel 2014-2021, in US\$, optimistic
estimate..... 282