

TABLE OF CONTENTS

TOPIC	PAGE NO.
CHAPTER 1 INTRODUCTION	1
MOTIVATION	1
OBJECTIVES AND PURPOSE OF THIS REPORT	1
SCOPE OF REPORT	1
CONTRIBUTION OF THE STUDY AND TARGET AUDIENCE	2
METHODOLOGY AND SOURCES OF INFORMATION	2
AUTHOR'S CREDENTIALS	3
RELATED BCC REPORTS AND PUBLICATIONS	3
REPORTS	3
MONTHLY NEWSLETTER	3
BCC ONLINE SERVICES	3
DISCLAIMER	4
CHAPTER 2 EXECUTIVE SUMMARY	6
<i>SUMMARY TABLE GLOBAL MARKET REVENUES FOR CNT GRADES BASED ON COMMITTED PRODUCTION ESTIMATES, THROUGH 2016 (\$ MILLIONS)</i>	6
<i>SUMMARY FIGURE GLOBAL MARKET FOR CNT GRADES BASED ON COMMITTED PRODUCTION, 2011-2016 (\$ MILLIONS)</i>	7
CHAPTER 3 TECHNOLOGY OVERVIEW	9
WHAT ARE CNTS?	9
<i>FIGURE 1 FORMATION OF A SWNT STRUCTURE</i>	9
<i>FIGURE 2 CNT STRUCTURES</i>	10
A BRIEF HISTORY OF NANOTUBES	10
<i>TABLE 1 CHRONOLOGY OF SOME CNT LANDMARK DEVELOPMENTS, 1953-2012</i>	11
COMPARISON OF CARBON COMPOUNDS	12
<i>TABLE 2 SOME COMPARATIVE PROPERTIES OF CARBON ALLOTROPES</i>	12
DIAMOND	13
Diamondoids	13
Nanocrystalline Diamond and CNT Hybrid Films	14
GRAPHITE	14
FULLERENES	15
Spherical Form: Buckminsterfullerene	15
Cylindrical Form: CNTs	16
Hybrid Forms: Carbon Nanobuds and Graphene Nanoribbons	16
Linear Form: Carbynes	16
CARBON NANOFIBERS	17
CARBON NANOSPHERES	17
CARBIDE-DERIVED MESOPOROUS CARBON	18
PROPERTIES OF CNTS	18
<i>TABLE 3 SOME CHARACTERISTIC PROPERTIES OF CNTS</i>	19
<i>TABLE 4 COMPARATIVE PROPERTIES OF DIFFERENT CNTS AND CFS</i>	20
APPLICATIONS OF CNTS	20
<i>TABLE 5 DIVERSE RANGE OF INDUSTRIAL APPLICATIONS FOR CNTS</i>	20
<i>TABLE 6 SOME EXAMPLES OF OPTIMUM FORMS OF CNTS REQUIRED FOR DIFFERENT APPLICATIONS</i>	21

TOPIC	PAGE NO.
OTHER TYPES OF NANOTUBE COMPOUNDS	21
SYNTHETIC INORGANIC NANOTUBES	21
<i>TABLE 7 PROPERTIES AND APPLICATIONS OF SOME INORGANIC NANOTUBES</i>	23
NATURAL INORGANIC NANOTUBES	24
ORGANIC NANOTUBES	25
NANOTUBE PRODUCTION	25
<i>TABLE 8 COMPARISON OF THE MOST COMMON TYPES OF CNT BATCH PRODUCTION TECHNOLOGIES</i>	26
ARC DISCHARGE	26
LASER ABLATION	26
CVD	27
SYNTHETIC PROCESS FACTORS AFFECTING GROWTH	27
<i>TABLE 9 SYNTHETIC PROCESS FACTORS AFFECTING CNT GROWTH</i>	28
CONTINUOUS SCALABLE PRODUCTION	28
<i>TABLE 10 COMPARATIVE ADVANTAGES AND DISADVANTAGES OF CNT PROCESSES</i>	29
<i>TABLE 11 COMPARISON OF SWNT CONTINUOUS PRODUCTION TECHNOLOGIES</i>	29
CVD	30
Flame Combustion	31
Plasma Torch	32
Other Developments	33
Catalyst-Free SWNTs	33
Chiral-Specific Growth	34
Nonmetallic Catalysts	35
Natural Lava Catalysts	36
Pulsed Laser Vaporization (PLV)	36
Purer and Controlled Diameter SWNTs	37
Separation and Sorting	37
Varying Carbon Feedstock	37
PURIFICATION AND PRODUCT QUALITY CONTROL	38
<i>TABLE 12 COMMON CNT CHEMICAL PURIFICATION PROCESSES, OUTCOMES AND DISADVANTAGES</i>	39
<i>TABLE 13 HISTORICAL DEVELOPMENT IN SEPARATION, PURIFICATION, CAPPING AND UNCAPPING OF CNTS BASED ON U.S. PATENTS</i>	40
CNT APPLICATIONS INTEGRATION	40
<i>TABLE 14 LEADING U.S. RESEARCH ORGANIZATIONS SPEARHEADING CNT SYNTHESIS AND APPLICATIONS DEVELOPMENT</i>	41
SURFACE CHEMICAL FUNCTIONALIZATION	41
<i>TABLE 15 RECENT DEVELOPMENTS IN CHEMICAL FUNCTIONALIZATION OF CNTS AND POSSIBLE APPLICATIONS</i>	42
<i>TABLE 16 EXEMPLARY U.S. PATENTS RELATING TO CNT CHEMICAL FUNCTIONALIZATION</i>	43
<i>TABLE 17 ORGANIZATIONS OFFERING SURFACE FUNCTIONALIZED CNT DISPERSIONS AND THEIR APPLICATIONS</i>	43
SEPARATING ELECTRONIC STRUCTURES	44
<i>TABLE 18 NOTABLE DEVELOPMENTS IN SORTING ELECTRONIC GRADE CNTS</i>	44
CNT GROWTH AND DEVICE FABRICATION	46
<i>TABLE 19 EXEMPLARY U.S. PATENTS RELATING TO SELF-ASSEMBLY AND ORGANIZATION OF CNTS</i>	46
<i>TABLE 20 SCALABLE DEVICE INTEGRATION OF CNTS</i>	47
OTHER FORM FACTORS	48

TOPIC	PAGE NO.
<i>TABLE 21 EXEMPLARY U.S. PATENTS RELATING TO THE USE OF CNTS AS NANOTEMPLATES</i>	48
DWNTS AND BUCKYPAPER	48
TWNTS	50
SWNT-BASED PEAPODS OR NANO TEST TUBES	50
MWNT-BASED MICROCAPSULES	50
OTHER FORMS OF CNTS	50
<i>TABLE 22 RECENT RESEARCH DEVELOPMENTS IN OTHER CNT VARIANTS</i>	51
DRY SPINNING OF CNT FIBERS AND SHEET FORMING YARNS	51
THREE-DIMENSIONAL CNT ARCHITECTURES	53
WET SPINNING OF SWNTS	53
CONTINUOUSLY GROWN SWNT FIBERS	54
CONTINUOUSLY GROWN SWNT NONWOVEN TRANSPARENT FILMS	55
CNT-REINFORCED POLYMER FIBERS	55
CHAPTER 4 PATENT ANALYSIS	57
RATIONALE AND METHODOLOGY	57
U.S. PATENTS ISSUED	58
CHRONOLOGICAL GROWTH TRENDS IN PATENT ACTIVITY	58
<i>FIGURE 3 CNT PATENTS ISSUED, 1994-2011 (CUMULATIVE TOTAL: 7,726)</i>	58
PATENT ACTIVITY CLASSIFIED BY INDUSTRIAL APPLICATION SECTOR	59
<i>FIGURE 4 BREAKDOWN OF THE MAIN INDUSTRY/APPLICATION SECTORS DERIVED FROM U.S. CNT ISSUED PATENTS, 1994-2004</i>	59
<i>TABLE 23 INDUSTRIAL SECTORS AND EXEMPLARY APPLICATIONS EMERGING FROM ISSUED U.S. CNT PATENTS, 1994-2009</i>	60
<i>FIGURE 5 BREAKDOWN OF THE MAIN INDUSTRY/APPLICATION SECTORS FROM U.S. CNT ISSUED PATENTS, 2007-JUNE 30, 2009 (%)</i>	60
<i>FIGURE 6 U.S. AND FOREIGN CNT PATENTS ISSUED, CLASSIFIED ACCORDING TO INDUSTRIAL/APPLICATIONS SECTORS, 1994-2002 (COMBINED TOTAL: 415)</i>	62
<i>FIGURE 7 U.S. AND FOREIGN CNT PATENTS ISSUED, CLASSIFIED ACCORDING TO INDUSTRIAL/APPLICATION SECTOR, 2003-2004 (COMBINED TOTAL 480)</i>	63
<i>FIGURE 8 U.S. AND FOREIGN CNT PATENTS ISSUED, CLASSIFIED ACCORDING TO INDUSTRIAL/APPLICATION SECTOR, 2007 TO JUNE 30, 2009 (COMBINED TOTAL 1,987)</i>	64
Comparison of U.S. Patent Activity with Asian, European and Other Countries	65
1994 to 2004	65
<i>FIGURE 9 U.S. VERSUS ASIAN CNT PATENTS ISSUED, 1994-2004 (COMBINED TOTAL 679)</i>	65
<i>FIGURE 10 EUROPEAN AND OTHER COUNTRIES WITH U.S. CNT ISSUED PATENTS, 1994-2004 (COMBINED TOTAL 51)</i>	66
2007 to June 30, 2009	67
<i>FIGURE 11 U.S. CNT PATENTS ISSUED: ASIA, 2007-JUNE 30, 2009</i>	67
<i>FIGURE 12 U.S. CNT PATENTS ISSUED: EUROPEAN AND OTHER COUNTRIES, 2007-JUNE 30, 2009 (NUMBER)</i>	68
2010 to 2011	69
<i>FIGURE 13 U.S. CNT PATENTS ISSUED: ASIA, 2011-2012 (NUMBER)*</i>	69
<i>FIGURE 14 U.S. CNT PATENTS ISSUED: EUROPEAN AND OTHER COUNTRIES, 2010-2011 (NUMBER)*</i>	70
Domestic Patent Activity	71
<i>FIGURE 15 LEADING U.S. STATES WITH U.S. CNT ISSUED PATENTS, 2009-NOVEMBER 21, 2011 (NUMBER)*</i>	71
Small Businesses	72

TOPIC	PAGE NO.
<i>TABLE 24 LEADING SMALL U.S. BUSINESSES WITH CNT ISSUED AND PENDING PATENT APPLICATIONS, 2010-NOVEMBER 22, 2011 (NUMBER)*</i>	72
<i>TABLE 25 OTHER SMALL U.S. BUSINESSES WITH MULTIPLE CNT ISSUED AND PENDING PATENT APPLICATIONS, 2010-NOVEMBER 22, 2011 (NUMBER)*</i>	73
Large Businesses	74
<i>TABLE 26 LEADING LARGE U.S. BUSINESSES WITH CNT ISSUED AND PENDING PATENT APPLICATIONS, 2010-NOVEMBER 22, 2011 (NUMBER)*</i>	74
<i>TABLE 27 OTHER LARGE U.S. BUSINESSES WITH MULTIPLE CNT ISSUED AND PENDING PATENT APPLICATIONS, 2010-NOVEMBER 22, 2011 (NUMBER)*</i>	75
Academic Institutions	76
<i>TABLE 28 CNT ISSUED AND PENDING PATENT APPLICATIONS AMONG LEADING U.S. ACADEMIC INSTITUTIONS, 2010-NOVEMBER 1, 2011 (NUMBER)*</i>	76
Government and Other Research Institutions	77
<i>TABLE 29 U.S. GOVERNMENT AND OTHER RESEARCH INSTITUTIONS WITH CNT ISSUED AND PENDING PATENT APPLICATIONS, 2010-NOVEMBER 24, 2011 (NUMBER)*</i>	77
U.S. Patent Activity According to Foreign Ownership	78
Leading Japanese Companies	78
<i>TABLE 30 CNT ISSUED AND PENDING PATENT APPLICATIONS FOR LEADING JAPANESE ORGANIZATIONS, 2010-NOVEMBER 24, 2011 (NUMBER)*</i>	78
Leading Korean, Taiwanese and Chinese Organizations	79
<i>TABLE 31 U.S. CNT ISSUED AND PENDING PATENT APPLICATIONS FOR LEADING KOREAN, TAIWANESE AND CHINESE ORGANIZATIONS, 2010-NOVEMBER 24, 2011 (NUMBER)**</i>	79
Leading Organizations in European and Other Countries	80
<i>TABLE 32 CNT ISSUED AND PENDING PATENTS FOR LEADING ORGANIZATIONS IN EUROPE AND OTHER COUNTRIES, 2010 TO NOVEMBER 24, 2011 (NUMBER)****</i>	80
U.S. PATENTS PENDING	81
<i>FIGURE 16 GROWTH AND BACKLOG IN U.S. PATENTS FILED 2001-DECEMBER 29, 2011 (NUMBER)*</i>	81
CHALLENGES IN PATENTING NANOTECHNOLOGY	82
PATENT BACKLOG	82
WHO OWNS WHAT?	83
QUALITY VERSUS QUANTITY	83
A NEW BREED OF PATENT BROKERAGE COMPANIES	83
PATENT TROLL	84
CHAPTER 5 INDUSTRY STRUCTURE AND COMPETITIVE ANALYSIS	86
OVERVIEW	86
INDUSTRY STRUCTURE	86
NANOTUBE PRODUCERS	86
<i>TABLE 33 INFLUENTIAL PLAYERS INVOLVED IN LARGE-SCALE CNT PRODUCTION AND MARKET EXPLOITATION</i>	87
<i>TABLE 34 INFLUENTIAL PLAYERS INVOLVED IN SMALL-SCALE CNT PRODUCTION AND/OR SPECIALIZED MARKET EXPLOITATION</i>	88
MARKET SEGMENTATION	89
<i>TABLE 35 MARKET SEGMENTATION OF CNT INDUSTRY</i>	89
COMPANY PROFILES: CNT PRODUCERS	89
Arkema	89
Bayer MaterialScience AG	91
<i>TABLE 36 RECENT DEVELOPMENTS IN COMMERCIALIZING BAYER MATERIALSCIENCE MWNTS</i>	92

TOPIC	PAGE NO.
Canatu, Ltd.	93
Catalytic Materials, LLC/Catalyx Nanotech	94
CNano Technology, Ltd.	95
Fullerene International Corp.	96
Hanwha Nanotech Corp.	97
Haydale Limited	97
Hitachi Chemical Co. Ltd.	98
Hodogaya Chemical Co. Ltd./Mitsui & Co.	98
Hyperion Catalysis Int'l Inc.	99
MER Corp.	101
Nanocyl S.A.	101
NanoIntegris, Inc.	102
Nanoledge, Inc.	103
Nanotailor, Inc.	104
Nanothinx S.A.	105
Pyrograph Products, Inc.	106
Raymor Industries, Inc.	106
Selah Technologies, LLC	108
Shenzhen Nanotech Port Co., Ltd.	108
Showa Denko KK	109
SouthWest NanoTechnologies (SWeNT), Inc.	109
<i>TABLE 37 SWENT'S LATEST COMMERCIAL SWNT DEVELOPMENTS: OCTOBER 2009-OCTOBER 2011</i>	111
Thomas Swan & Co., Ltd.	112
Unidym, Inc.	113
<i>TABLE 38 UNIDYM'S LATEST COMMERCIAL BUSINESS DEVELOPMENTS: 2010-2011</i>	115
Xintek, Inc.	116
COMPANY PROFILES: CNT SPECIALTY AND ANCILLARY PRODUCTS	117
Applied Nanotech Holdings, Inc.	117
Brewer Science, Inc.	118
Carbon Solutions, Inc.	118
Eikos, Inc.	119
First Nano, Inc.	119
NanoComposites, Inc.	120
Nanocomp Technologies, Inc.	120
Nanomix, Inc.	121
Q-Flo, Ltd.	122
Zyvex Technologies	123
<i>TABLE 39 ZYVEX TECHNOLOGIES COMMERCIAL DEVELOPMENTS IN CNT POLYMER COMPOSITES, 2007-2011</i>	124
COMPANY PROFILES: LARGE U.S. CORPORATIONS	125
<i>TABLE 40 LARGE U.S. CORPORATIONS LEADING IN U.S. CNT PATENT ACTIVITY* (TOTAL NUMBER OF PATENTS 579)</i>	125
DuPont Co.	126
General Electric Company	126
GM Corporation	127
Intel Corp.	127
IBM Corporation	127

TOPIC	PAGE NO.
Micron Technology	128
Shell Oil Company	128
Xerox Corp.	128
COMPANY PROFILES: LARGE FOREIGN CORPORATIONS	129
CHALLENGES AND ISSUES FACING THE CNT INDUSTRY	129
Industry Driving Forces	129
<i>TABLE 41 EXEMPLARY COMPANIES LEADING THE CNT INDUSTRY EVOLUTION</i>	129
Nanotube Consumers and the Evolving Grade Structure	129
<i>TABLE 42 DIVERSITY IN CNT CONSUMER MARKET PRODUCTS</i>	130
Cost/Performance Balance	130
Competition	131
<i>TABLE 43 COMPETITIVE MATERIAL ALTERNATIVES TO CNTS FOR CERTAIN APPLICATIONS</i>	131
Toxicity	132
<i>TABLE 44 PROGRESS IN IDENTIFYING AND RESOLVING CNT TOXICOLOGICAL BEHAVIOR, 2005-2007</i>	132
<i>TABLE 45 PROGRESS IN IDENTIFYING AND RESOLVING CNT TOXICOLOGICAL BEHAVIOR, 2008-2011</i>	133
Environmental Safety	135
NANOTECHNOLOGY RISKS AND REGULATORY CONTROL	136
Asian Initiatives	136
Canadian Government	136
European Commission	136
International Organization for Standardization (ISO)	138
U.S. Led Nanotechnology Regulatory Control Initiatives	138
SouthWest NanoTechnologies (SWeNT), Inc.	139
Thomas Swan & Co., Ltd. (U.K.)	139
CBEN at Rice University	139
City of Berkeley, Calif., Nanomaterials Ordinance	139
EPA	140
Nanoethics and Social Advocacy Groups	140
Woodrow Wilson International Center for Scholars	140
CHAPTER 6 MARKETS BY APPLICATION	143
COMPOSITES	143
<i>TABLE 46 MECHANICAL PROPERTIES OF CNTS COMPARED WITH OTHER FIBERS</i>	143
<i>TABLE 47 CNT COMPOSITES: RANGE OF POSSIBLE APPLICATIONS</i>	144
<i>TABLE 48 CNT COMPOSITES: PROPERTIES ENDOWED</i>	144
<i>TABLE 49 MECHANICAL PROPERTY ENHANCEMENTS IN VARIOUS CNT COMPOSITES</i>	145
CEMENT MATRIX	145
CERAMIC MATRIX	147
<i>TABLE 50 ENHANCEMENTS CLAIMED IN VARIOUS CNT CERAMIC SYSTEMS</i>	147
DIAMOND COMPOSITES	151
GLASS MATRIX	151
METAL MATRIX	152
<i>TABLE 51 SOME EXAMPLES OF CNT-METAL COMPOSITES</i>	152
POLYMER MATRIX	154
<i>TABLE 52 EXAMPLES OF CNT-POLYMER COMPOSITE MATRIX SYSTEMS AMENABLE TO COMMERCIAL PROCESSING AND APPLICATION</i>	154

TOPIC	PAGE NO.
<i>TABLE 53 SOME EXAMPLES OF CNT-POLYMER COMPOSITES</i>	155
<i>TABLE 54 VARIOUS PROCESSING STRATEGIES USED TO MANUFACTURE POLYMER-CNT COMPOSITES</i>	156
Electrical Conductivity Properties of Polymer-CNT Composites	156
Mechanical Properties of Polymer-CNT Composites	157
<i>TABLE 55 ULTIMATE MECHANICAL PROPERTIES OF CNT FIBERS AND EXAMPLES OF THEIR ENHANCEMENT IN VARIOUS POLYMER COMPOSITE SYSTEMS</i>	157
<i>TABLE 56 KEY PROPERTIES CONTROLLING ULTIMATE REINFORCING AND CONDUCTIVITY POTENTIAL OF SWNTS IN A POLYMER MATRIX</i>	158
Thermal Conductivity Properties of Polymer-CNT Composites	158
Commercial Product Applications of Polymer-CNT Composites	159
<i>TABLE 57 POLYMER COMPOSITE CNT PRODUCTS CURRENTLY MANUFACTURED OR UNDER COMMERCIAL DEVELOPMENT</i>	159
<i>TABLE 58 LEADING COMPANIES INVOLVED IN THE COMMERCIAL DEVELOPMENT OF CNT-POLYMER COMPOSITES</i>	160
<i>TABLE 59 MOST ACTIVE COMPANIES ACCORDING TO CNT-POLYMER COMPOSITE U.S. PATENTS, 2007-DECEMBER 29, 2011 (TOTAL NUMBER OF PATENTS 607)</i>	161
<i>TABLE 60 OTHER ACTIVE ORGANIZATIONS ACCORDING TO U.S. CNT-POLYMER COMPOSITE PATENTS, 2007-DECEMBER 29, 2011</i>	162
Automotive Applications	162
<i>TABLE 61 EXAMPLES OF READY-TO-MOLD HYPERION AUTOMOTIVE MWNT-RESIN COMPOUNDS</i>	163
<i>TABLE 62 COMPARATIVE PERFORMANCE FOR HYPERION CONDUCTIVE AUTOMOTIVE MWNT-RESIN COMPOUNDS</i>	163
<i>TABLE 63 ADVANTAGES OF MWNTS COMPARED WITH CONVENTIONAL CONDUCTIVE FILLERS USED IN MOLDED AUTOMOTIVE PLASTICS</i>	164
<i>TABLE 64 CLASSIFICATION OF CONDUCTIVE MOLDED PLASTICS ACCORDING TO FILLER LOADING AND ELECTRICAL PROPERTIES</i>	165
<i>TABLE 65 VARIOUS APPLICATIONS OF MWNTS IN ELECTROSTATICALLY DISSIPATIVE PLASTIC AUTO COMPONENTS</i>	165
<i>TABLE 66 ADVANCES IN IMPROVING THE STRENGTH AND CONDUCTIVITY OF POLYMER-CNT COMPOSITES, 2007-2009</i>	168
Aeronautical Applications	168
<i>TABLE 67 RECENT DEVELOPMENTS IN AEROSPACE CF COMPOSITES INDUSTRY</i>	171
Electronic Applications	171
<i>TABLE 68 VARIOUS ELECTRONIC APPLICATIONS OF MWNTS IN MOLDED PLASTIC ELECTRONIC COMPONENTS</i>	171
Flame-Retardant Applications	172
Military Applications	173
<i>TABLE 69 CNT COMPOSITE COMPANIES ATTRACTING MILITARY AND OTHER CIVILIAN APPLICATIONS DEVELOPMENT</i>	174
Space Applications	174
<i>TABLE 70 FUTURE SPACE APPLICATIONS FOR CNTS</i>	175
Sporting Goods Applications	175
<i>TABLE 71 SPORTING GOODS PROTOTYPES BASED ON MWNT-PLASTIC COMPOSITES</i>	176
Other Applications and Important Property Considerations	177
Biocatalytic Films	177
Biomedical Composites	177
Conventional Adhesives	178
Dry Adhesives	178

TOPIC	PAGE NO.
<i>TABLE 72 RECENT PATENT ACTIVITY IN CNT DRY ADHESIVE SYSTEMS*</i>	179
Polymer Composite Coatings and Inks	179
<i>TABLE 73 ORGANIZATIONS EXPLORING CNT-BASED OR OTHER CARBON-BASED INKS AND SMART COATINGS</i>	179
<i>TABLE 74 COMPARATIVE PROPERTY PERFORMANCE OF CONDUCTIVE TRANSPARENT COMPOSITE COATINGS</i>	181
Sensor Networks for Ongoing Composite Structural Diagnostics and Repair	184
Surface Chemical Functionalization and Form Factor	185
ELECTRONIC APPLICATIONS	186
<i>TABLE 75 U.S. ORGANIZATIONS LEADING THE ELECTRONICS SECTOR WITH CNT PATENTS, 2010-DECEMBER 29, 2011 (NUMBER)*</i>	186
<i>TABLE 76 LEADING ASIAN AND EUROPEAN ORGANIZATIONS HOLDING ELECTRONICS CNT PATENTS, 2010-DECEMBER 29, 2011 (NUMBER)**</i>	187
ELECTRONIC COMPONENTS	188
Emergence of Nanoelectronics	188
<i>TABLE 77 KEY CNT PROPERTIES ATTRACTING FUTURE ELECTRONIC APPLICATIONS</i>	190
CNT Electronic Components Development	190
Synthesis and Characterization of Electronic-Grade SWNTs	192
Electronic Device Integration and Self-Assembly	195
Competition-Silicon Nanowires	196
Connectivity, Large-Scale Integration and Potential Replacement for Copper	197
Thermal Management (Solid-Based)	200
<i>TABLE 78 ORGANIZATIONS INVOLVED IN CNT ELECTRONIC THERMAL MANAGEMENT APPLICATIONS</i>	200
California Institute of Technology	201
CAT Science/University of Copenhagen (Denmark)	201
Fujitsu, Ltd. (Japan)	201
IBM (Yorktown Heights, N.Y.)	202
Koila, Inc. (Sunnyvale, Calif.)	202
LG Electronics (Korea)	202
Molecular Nanosystems, Inc. (Palo Alto, Calif.)	202
Nanoconduction, Inc. (Sunnyvale, Calif.)/NASA Ames Research Center	203
National Renewable Energy Laboratory (Golden, Colo.)	203
Nextreme Thermal Solutions (Research Triangle Park, N.C.)	203
OCZ Technology (Sunnyvale, Calif.)	203
Purdue University	203
Rensselaer Polytechnic Institute	204
University of California, Berkeley	204
University of Colorado	204
Thermal Management (Liquid-Based)	204
Cooligy, Inc. (Mountain View, Calif.)	205
Seoul National University, Korea	205
University of Leeds/Institute of Particle Science and Engineering, U.K.	205
Beyond the CMOSFET Paradigm	205
Current Industry FET Development	206
<i>TABLE 79 LEADING COMPANIES WITH CNTFET PATENT INTEREST</i>	206
GE Global Research Center	207
IBM Optoelectronic Applications	207

TOPIC	PAGE NO.
Infineon Technologies, Germany	208
Development of Other CNT Nanoelectronic Components	208
FE DISPLAYS AND RELATED DEVICES	209
What is FE?	209
Why CNTs are Attractive Material Candidates?	209
<i>TABLE 80 ADVANTAGES OF CNTS AS A COLD FE CATHODE</i>	209
FE Applications	210
FE Displays	211
Fabrication	211
How CNT-FEDs Compare with Other Display Technologies	211
<i>TABLE 81 ADVANTAGES OF FE DISPLAYS OVER LCDS</i>	212
Major Factors Dictating CNT-FED Development	212
<i>TABLE 82 MAJOR FACTORS DICTATING EMERGENCE OF CNT-BASED TECHNOLOGY IN FPD MARKETPLACE</i>	212
Leading Organizations Involved in FED Development	213
<i>TABLE 83 LEADING U.S. ORGANIZATIONS INVOLVED IN U.S. CNT FED-DISPLAY PATENT ACTIVITY, 2000-DECEMBER 29, 2011 (NUMBER)</i>	213
<i>TABLE 84 LEADING FOREIGN COUNTRIES INVOLVED IN U.S. CNT-FED DISPLAY PATENT ACTIVITY, 2000-DECEMBER 29, 2011 (NUMBER)</i>	213
<i>TABLE 85 MAJOR PLAYERS AND ANCILLIARY GROUPS/COMPANIES INVOLVED IN CNT-FED HISTORY AND DEVELOPMENT</i>	214
<i>TABLE 86 ORGANIZATIONS ACTIVELY INVOLVED IN CNT-FED PROTOTYPES, 2000-2011</i>	215
Canon KK (Japan)	215
cDream Corp. (San Jose, Calif.)	216
CEA/LETI (France)	216
CopyTele, Inc. (Melville, N.Y.)	217
Futaba Corp. (Japan)	218
Japan, Inc.	219
Motorola Laboratories (Tempe, Ariz.)	219
<i>TABLE 87 ADVANTAGES AND CHALLENGES OF MOTOROLA'S CNT-BASED FED COMPARED WITH EXISTENT FPD TECHNOLOGIES</i>	220
Nano-Proprietary/Applied Nanotech, Inc. (Austin, Texas)	220
Noritake Itron Corp./Ise Electronics (Japan)	222
<i>Printable Field Emitters, Ltd. (U.K.)</i>	223
Samsung (Korea)	223
Taiwan, Inc.	224
OTHER FED APPLICATIONS	225
<i>TABLE 88 EXAMPLES OF OTHER FED APPLICATIONS</i>	226
Light Bulbs and Light Sources	226
<i>TABLE 89 ADVANTAGES OF FE-CNT FLUORESCENT WHITE LIGHT SOURCE OVER CONVENTIONAL LAMPS</i>	227
<i>TABLE 90 RATIONALIZING CNT SYNTHESIS WITH END-USE FE PERFORMANCE REQUIREMENTS</i>	228
Applications of CNT-Based FE Light Sources	228
<i>TABLE 91 ORGANIZATIONS WITH U.S. PATENT ACTIVITY RELATING TO CNT-BASED FE LIGHT-SOURCES</i>	228
Advance Nanotech, Inc./University of Bristol	229
Ahwahnee Technology (San Jose, Calif.)	229
Delta Optoelectronics, Inc. (Taiwan)	230

TOPIC	PAGE NO.
Dialight Japan Co., Ltd.	230
EPFL/NanoLight Int'l, Ltd. (Switzerland)	230
Electrovac AG (Austria)	231
Foxconn/Hon Hai Precision Industry Co., Ltd. (Taiwan)	231
Hanwha Chemical Co./Iljin Nanotech (Korea)	232
IBM/Thomas J. Watson Research Center	232
Korea Advanced Institute of Science and Technology (KAIST)	233
Nanoexa (Burlingame, Calif.)	233
Nano-Proprietary/Advanced Nanotech Holdings, Inc. (Austin, Texas)	233
Samsung Electronics Co., Ltd. (Korea)	234
Taitung University, Taiwan	234
University of Surrey/Advanced Technology Institute (U.K.)	235
FLEXIBLE DISPLAYS AND ELECTRONICS	235
<i>TABLE 92 LEADING ORGANIZATIONS INVOLVED IN THE APPLICATION OF CNTS IN FLEXIBLE ELECTRONICS AND DISPLAYS</i>	<i>237</i>
Advance Nanotech, Inc. (New York, N.Y.)/Cambridge University, (U.K.)	238
Advanced Technology Institute/University of Surrey/Surrey Nanosystems, Ltd.	239
Aneve Nanotechnologies, LLC (Los Angeles, Calif.)	239
Arrowhead Research (Pasadena, Calif.)/University of Florida	239
DuPont Electronic Technologies (Hayward, Calif.)	240
Eikos, Inc. (Franklin, Mass.)	241
NanoIntegris, Inc. (Skokie, Ill.)	241
NEC Corp. (Tokyo, Japan)	241
Rennselaer Polytechnic Institute	241
Unidym, Inc. (Menlo Park, Calif.)	242
University of Illinois/Semprius, Inc. (Durham, N.C.)	243
MEMORY APPLICATIONS	244
<i>TABLE 93 ATTRACTIVE PROPERTIES OF CNTS FOR MEMORY APPLICATIONS</i>	<i>244</i>
<i>TABLE 94 LEADING COMMERCIAL PLAYERS IN CNT-MEMORY INITIATIVES BASED ON U.S. PATENTS, 1997-DECEMBER 29, 2011</i>	<i>246</i>
Nantero, Inc. (Woburn, Mass.)	246
SanDisk 3D LLC (Santa Clara, Calif.)	248
OTHER ELECTRONIC APPLICATIONS	248
<i>TABLE 95 RECENT DEVELOPMENTS IN OTHER APPLICATIONS OF CNTS USED IN ELECTRONIC DEVICES</i>	<i>248</i>
ENERGY CONVERSION AND STORAGE	249
BATTERIES	249
Lead-acid Batteries	249
Lithium-Ion Batteries	250
Lithium Polymer Batteries	251
CNT Commercial Battery Developments	252
<i>TABLE 96 LEADING PLAYERS IN CNT-BASED BATTERY TECHNOLOGY ACCORDING TO U.S. PATENT ACTIVITY, 2004-DECEMBER 29, 2011</i>	<i>253</i>
Micro Bubble Technologies, Inc. (South Korea)/Next Alternative, Inc. (Canada)	253
FUEL CELLS	254
<i>TABLE 97 CNTS ENDEARING PROPERTIES USED IN FUEL CELL APPLICATIONS</i>	<i>255</i>
Hydrogen Fuel Cells	255
<i>TABLE 98 KEY PROPERTIES AFFECTING FUEL CELL PERFORMANCE</i>	<i>256</i>

TOPIC	PAGE NO.
Direct Methanol Fuel Cell (DMFC)	256
Substitution of CNTs in MEA Materials	257
CNTs Used in Hydrogen and DMFCs	257
Optimizing Catalyst Loading and Retention	257
CNT-Based MEAs	258
Critical Fuel Cell Components	258
Gas Diffusion Layers (GDLs)	258
Surface Wettability	259
Early Commercial Applications and Development of Fuel Cells	260
<i>TABLE 99 LEADING ORGANIZATIONS PATENTING U.S. CNT FUEL CELL ENHANCEMENTS, 2002-DECEMBER 30, 2006</i>	260
More Recent Patent Activity and Commercial Developments in Fuel Cells	261
<i>TABLE 100 PATENT ACTIVITY IN CNT-BASED FUEL CELL APPLICATIONS AMONG U.S. ORGANIZATIONS, 2007-DECEMBER 29, 2011</i>	261
<i>TABLE 101 PATENT ACTIVITY IN U.S. CNT-BASED FUEL CELL APPLICATIONS AMONG FOREIGN ORGANIZATIONS, 2007-DECEMBER 29, 2011</i>	262
Angstrom Power, Inc. (Vancouver, Canada)	262
Intematix Corp. (Fremont, Calif.)	263
Japan, Inc.	263
Motorola, Inc. (Tempe, Ariz.)	264
MTI MicroFuel Cells, Inc. (Albany, N.Y.)	265
Neah Power Systems, Inc. (Bothel, Wash.)	265
Pacific Fuel Cell Corp. (Riverside, Calif.)	266
Samsung SDI (Korea)	266
Showa Denko KK (Japan)	266
Toyota (Japan)	267
UltraCell Corp. (Livermore, Calif.)	267
HYDROGEN STORAGE	267
Carbon Nanostructures	268
Underlying System Properties	269
Commercial Development and Patent Activity	270
<i>TABLE 102 EARLY PATENT ACTIVITY IN U.S. CNT-BASED HYDROGEN STORAGE APPLICATIONS, 1997-APRIL 2006</i>	270
<i>TABLE 103 LEADING U.S. AND FOREIGN PATENT ACTIVITY IN U.S. CNT-BASED HYDROGEN STORAGE APPLICATIONS, 2007-DECEMBER 29, 2011</i>	271
Nanomix, Inc.	271
Motorola, Inc.	272
Sony Corporation	272
SUPERCAPACITORS	272
Basic Characteristics	272
<i>TABLE 104 PERFORMANCE COMPARISON OF ENERGY STORAGE DEVICES</i>	273
<i>TABLE 105 ADVANTAGES OF SUPERCAPACITOR ELECTRICAL STORAGE DEVICES COMPARED WITH BATTERIES</i>	273
<i>TABLE 106 COMPARATIVE PERFORMANCE OF BATTERIES VERSUS CAPACITORS</i>	274
Electric Double Layer Capacitor (EDLC)	274
Research Activities in CNT-Based EDLCs	275
Georgia Institute of Technology Textile and Fiber Engineering	275
INRS (Quebec, Canada)	275
MIT Laboratory for Electromagnetic and Electronic Systems (LEES)	276

TOPIC	PAGE NO.
NASA Johnson Space Center	276
National Institute of AIST (Japan)	277
Rice University	277
Stanford University/UCLA	277
Tsinghua-Foxconn Nanotechnology Research Center (China)	278
University of California, Davis	278
University of California, San Diego	279
University of Cambridge/Department of Engineering (U.K.)	279
University of Southern California (USC)	280
University of Texas at Austin	280
University of Texas at Dallas/NanoTech Institute	280
Early Patent Activity and Commercial Development in CNT-Based EDLCs	281
GSI Creos Corp., Asahi Glass and TDK (Japan)	281
<i>TABLE 107 U.S. PATENT ACTIVITY IN U.S. CNT-BASED EDL CAPACITORS AND APPLICATIONS, 1997-DECEMBER 30, 2006</i>	281
Hyperion Catalysis International	282
Iljin Nanotech (Korea)	282
Recent Patent Activity and Commercial Development in CNT-Based EDLCs	282
<i>TABLE 108 LEADING ORGANIZATIONS INVOLVED IN U.S. CNT-BASED EDL CAPACITOR PATENT ACTIVITY, 2007-DECEMBER 29, 2011</i>	283
Arrowhead Research Corp./Agonn Systems, Inc. (Pasadena, Calif.)	284
Kemet Corp. (Greenville, S.C.)	284
Nisshinbo Holdings, Inc. (Tokyo, Japan)	284
Honda Motor Co., Ltd. (Tokyo, Japan)	285
SOLAR/PV CELLS	285
Basic Characteristics	285
Academic Research	286
<i>TABLE 109 ACADEMIC RESEARCH ACTIVITIES IN CNT-BASED SOLAR CELLS</i>	286
<i>TABLE 110 MORE RECENT DEVELOPMENTS IN CNT-BASED SOLAR CELLS, 2010 TO 2012</i>	287
Commercial Development	288
<i>TABLE 111 CNT PATENT ACTIVITY IN SOLAR CELL APPLICATIONS, 1997-DECEMBER 30, 2006 (NUMBER)</i>	288
<i>TABLE 112 PATENT ACTIVITY LEADERS IN CNT-BASED SOLAR CELL APPLICATIONS, 2007-DECEMBER 29, 2011 (NUMBER)</i>	289
Ambit Corp. (Ashland, Mass.)	290
Arrowhead Research Corp./Nan Polaris (Pasadena, Calif.)	290
BP Solar North America (Frederick, Mass.)	291
DuPont (Wilmington, Del.)	291
Dow Corning Corp. (Midland, Mich.)	292
Eikos, Inc. (Franklin, Mass.)	292
First Solar, LLC (Phoenix, Ariz.)	293
HelioVolt Corp. (Austin, Texas)	293
Innovalight, Inc. (Sunnyvale, Calif.)	294
Konarka Technologies (Lowell, Mass.)	294
Miasolé (San Jose, Calif.)	295
Nanosolar, Inc. (Palo Alto, Calif.)	295
Natcore Technogy (Red Bank, N.J.)	295
Plextronics, Inc. (Pittsburg, Pa.)	296

TOPIC	PAGE NO.
Wakonda Technologies, Inc/RIT	296
OTHER ENERGY CONVERSION SYSTEMS	297
<i>TABLE 113 PATENT ACTIVITY IN U.S. CNT-BASED APPLICATIONS USED IN OTHER ENERGY CONVERSION SYSTEMS, 2007-DECEMBER 29, 2011 (NUMBER)</i>	297
Mechanical Energy Storage	298
Thermionic Power	298
Thermal Rectifiers	299
Thermocells	299
Thermoelectric Power	299
Thermopower Wave	300
MEMBRANES: FILTRATION AND SEPARATION MEDIA	300
<i>TABLE 114 ATTRACTIVE PROPERTIES OF CNTS AS SEPARATION MEMBRANES DEVELOPMENTS AND APPLICATIONS</i>	301
<i>TABLE 115 ORGANIZATIONS WITH U.S. PATENT ACTIVITY IN CNT MEMBRANES, FILTRATION AND SEPARATION MEDIA, 2007-DECEMBER 29, 2011</i>	301
<i>TABLE 116 RESEARCH AND COMMERCIAL PROTOTYPE DEVELOPMENTS OF VARIOUS CNT-BASED MEMBRANE SEPARATION TECHNOLOGIES</i>	302
Biosource, Inc./Voltea, Ltd. (London, U.K.)	303
Clemson University	303
Cnanoz, Inc (Research Triangle Park, N.C.)	304
Covalent Industrial Technologies, LLC (Hayward, Calif.)	304
Lawrence Livermore National Laboratory (LLNL)	305
NanOasis Technologies (Richmond, Calif.)	306
Philip Morris USA Research Center	306
Procter & Gamble Co.	307
Rensselaer Polytechnic Institute	307
Seldon Laboratories, LLC	308
University of Kentucky, Center for Applied Energy Research	308
Velocys, Inc. (Plain City, Ohio)/Oxford Catalysts Group plc (Oxford, U.K.)	309
SENSORS	310
TYPES OF SENSORS	310
<i>TABLE 117 TYPES OF CNT SENSORS</i>	310
Biosensors	310
<i>TABLE 118 RECENT TYPES OF CNT BIOSENSOR SYSTEMS</i>	311
Chemical Sensors	312
<i>TABLE 119 KEY PROPERTIES OF CNTS EXPLOITED IN SENSOR APPLICATIONS</i>	312
Physical Sensors and Actuators	313
RECENT PATENT ACTIVITY IN SENSORS	314
<i>TABLE 120 LEADING ORGANIZATIONS INVOLVED IN U.S. CNT-SENSOR PATENT ACTIVITY, 2007-DECEMBER 29, 2011 (NUMBER)</i>	315
COMMERCIAL PROTOTYPE DEVELOPMENTS	315
Applied Nanotech Holdings, Inc. (Austin, Texas)	315
Enzyme Coated CNT Sensor	315
Gated Metal Oxide Sensor	315
Palladium Nanoparticle Hydrogen Sensor	316
Photoacoustic Sensor (PAS)	316
Other Recent Sensor and Detector-Related Developments	316
Honeywell Int'l, Inc. (Morristown, N.J.)	317

TOPIC	PAGE NO.
Motorola Laboratories (Tempe, Ariz.)	317
Nano Engineered Applications, Inc. (Riverside, Calif.)	318
Nanomix, Inc. (Emeryville, Calif.)	318
Nanosensors, Inc. (Santa Clara, Calif.)	320
Pacific Northwest National Laboratory, Richland, Wash.	320
YTC America, Inc. (Camarillo, Calif.)	321
OTHER APPLICATIONS	322
BIOSENSORS	322
Alpha Szenszor, Inc. (Worcester, Mass.)	322
Applied Nanotech Holdings, Inc. (Austin, Texas)	322
Nanomix, Inc. (Emeryville, Calif.)/MysticMD, Inc. (Groton, Conn.)	323
BIOMEDICAL DEVELOPMENTS	323
<i>TABLE 121 POTENTIAL USES OF CNTS IN THE BIOMEDICAL AREA</i>	323
<i>TABLE 122 RESEARCH DEVELOPMENTS IN CNT BIOMEDICAL APPLICATIONS, PRIOR TO 2007</i>	323
<i>TABLE 123 RESEARCH DEVELOPMENTS IN CNT BIOMEDICAL APPLICATIONS, 2007-2009</i>	324
<i>TABLE 124 RESEARCH DEVELOPMENTS IN CNT BIOMEDICAL APPLICATIONS, 2010-2011</i>	326
Potential Commercial CNT Biomedical Developments	326
Cromoz, Inc. (Research Triangle Park, N.C.)	326
Ensysce Biosciences, Inc., (Houston, Texas)	327
Intel Corp. (Santa Clara, Calif.)	327
XinRay Systems, LLC (Research Triangle Park, N.C.)	327
CATALYST SUPPORTS	328
Industrial Chemical Process Synthesis	328
<i>TABLE 125 U.S. PATENT ACTIVITY LEADERS IN CNT CATALYST SUPPORTS, 2007-DECEMBER 29, 2011 (NUMBER)</i>	329
BTU Int'l, Inc. (North Billerica, Mass.)	329
Headwaters Technology Innovation, Inc. (Lawrenceville, N.J.)	330
Hyperion Catalysis Int'l, Inc. (Cambridge, Mass.)	330
Electrocatalysis	330
Photocatalytic Support Systems	330
<i>TABLE 126 APPLICATIONS OF CNTS IN PHOTOCATALYTIC SYSTEMS</i>	331
ELECTROPHOTOGRAPHY	331
Xerox Corp. (Stamford, Conn.)	331
INSTRUMENTS: ACTUATORS, MANIPULATORS AND PROBES	332
<i>TABLE 127 U.S. CNT PATENT ACTIVITY INVOLVING ACTUATORS, INSTRUMENTS AND MANIPULATORS, 2009-DECEMBER 29, 2011 (NUMBER)</i>	332
Commercial Developments in SPM/AFM CNT Probes	332
Carbon Design Innovations (Burlingame, Calif.)	333
Carbon Nanoprobes, Inc. (White Plains, N.Y.)	333
Xidex Corp. (Austin, Texas)	334
OIL RECOVERY	334
<i>TABLE 128 U.S. PATENT ACTIVITY IN CNT ENHANCEMENTS IN OIL RECOVERY, 2010-DECEMBER 29, 2011 (NUMBER)</i>	335
SECURITY	336
<i>TABLE 129 LEADING ORGANIZATIONS INVOLVED IN VARIOUS CNT-BASED SECURITY APPLICATIONS</i>	336
Bioterrorism and Explosives Detection	336

TOPIC	PAGE NO.
Stanford University	337
MIT	337
Body Armor and Smart Textiles	337
National Research Council Canada (Ottawa, Canada)	338
Nanocomp Technologies, Inc. (Concord, N.H.)	338
Q-Flo, Ltd. (Cambridge, U.K.)	339
Nico Technologies (Ann Arbor, Mich.)	339
Radio Frequency Identification (RFID) Tags	339
Alien Technology Corp. (Morgan Hills, Calif.)	340
Ambient Systems, B.V. (Enschede, Netherlands)	340
AMBIT Corporation (Ashland, Mass.)	341
Nantero Inc. (Woburn, Mass.)/HP Specialty Printing Systems (San Diego, Calif.)	341
X-Ray Detection	342
American Science and Engineering, Inc. (Billerica, Mass.)	342
XinRay Systems, LLC (Research Triangle Park, N.C.)	342
POLISHING	343
Applied Materials, Inc. (Santa Clara, Calif.)	343
CHAPTER 7 GLOBAL MARKET ANALYSIS	345
TECHNOLOGY PUSH	345
CNT COMMERCIAL PRODUCTION AND ESTIMATED SALES REVENUES	345
MWNTs	345
<i>TABLE 130 GLOBAL MARKET FORECAST FOR MWNT ANNUAL PRODUCTION AND REVENUES: TIER 1 COMPANIES, THROUGH 2016 (\$ MILLIONS)</i>	345
SWNTs	346
<i>TABLE 131 GLOBAL ANNUAL PRODUCTION COMMITMENT FOR COMMERCIAL SWNTS AND REVENUES: TIER 1 COMPANIES, THROUGH 2016 (KG/YEAR, \$ MILLIONS)</i>	347
Few-Walled Grades (FWNTs)	347
<i>TABLE 132 FORECAST FOR SPECIALTY FWNTS PRODUCTION AND REVENUES, THROUGH 2016</i>	347
MARKET PULL	348
COMPOSITES: POLYMER	348
<i>TABLE 133 COMMERCIAL PROTOTYPE DEVELOPMENTS IN CNT POLYMER COMPOSITES</i>	348
COMPOSITES: OTHER MATRIX MATERIALS	349
<i>TABLE 134 COMMERCIAL PROTOTYPE DEVELOPMENTS IN OTHER MATRIX COMPOSITES</i>	349
ELECTRONICS	350
<i>TABLE 135 COMMERCIAL PROTOTYPE DEVELOPMENTS IN ELECTRONICS</i>	350
ENERGY	350
<i>TABLE 136 COMMERCIAL PROTOTYPE DEVELOPMENTS IN ENERGY</i>	350
OTHER APPLICATIONS	351
<i>TABLE 137 COMMERCIAL PROTOTYPE DEVELOPMENTS IN OTHER APPLICATIONS</i>	351
CHAPTER 8 NORTH AMERICAN MARKET ANALYSIS	353
CNT COMMERCIAL PRODUCTION AND ESTIMATED SALES REVENUES	353
MWNTS	353
<i>TABLE 138 ANNUAL PRODUCTION COMMITMENT AND REVENUES FOR U.S. COMMERCIAL MWNT PRODUCERS: TIER 1 COMPANIES, THROUGH 2016 (METRIC TONS, \$ MILLIONS)</i>	353

TOPIC	PAGE NO.
SWNTS	354
<i>TABLE 139 ANNUAL PRODUCTION COMMITMENT AND REVENUES OF U.S. COMMERCIAL SWNT PRODUCERS: TIER 1 COMPANIES, THROUGH 2016 (KG/YEAR, \$ MILLIONS)</i>	354
FEW-WALLED GRADES (FWNTS)	355
<i>TABLE 140 FORECAST FOR NORTH AMERICAN SPECIALTY FWNTS PRODUCTION: REVENUES, THROUGH 2016</i>	355
OTHER COMPANIES INFLUENCING CNT EXPLOITATION	355
<i>TABLE 141 OTHER COMPANIES AIDING GLOBAL CNT COMMERCIALIZATION</i>	356
Brewer Science, Inc.	357
Carbon Solutions, Inc.	357
NanoIntegris, Inc.	357
CHAPTER 9 EUROPEAN MARKET ANALYSIS	359
CNT COMMERCIAL PRODUCTION AND ESTIMATED SALES REVENUES	359
MWNTS	359
<i>TABLE 142 EUROPEAN PRODUCTION COMMITMENT AND REVENUES OF COMMERCIAL MWNTS: TIER 1 COMPANIES, THROUGH 2016 (METRIC TONNES, \$ MILLIONS)</i>	359
SWNTS	360
<i>TABLE 143 EUROPEAN ANNUAL PRODUCTION COMMITMENT OF COMMERCIAL SWNTS AND REVENUES: TIER 1 THOMAS SWAN, THROUGH 2016 (KG/YEAR, \$ MILLIONS)</i>	360
CHAPTER 10 ASIAN MARKET ANALYSIS	362
CNT COMMERCIAL PRODUCTION AND ESTIMATED SALES REVENUES	362
MWNTS	362
<i>TABLE 144 JAPANESE ANNUAL COMMERCIAL PRODUCTION COMMITMENT AND REVENUES FOR MWNTS: TIER 1 SHOWA DENKO COMPANY, THROUGH 2016 (METRIC TONNES, \$ MILLIONS)</i>	362
<i>TABLE 145 UNCONFIRMED ANNUAL PRODUCTION COMMITMENT OF COMMERCIAL MWNTS: TIER 2 ASIAN COMPANIES, 2011-2016 (METRIC TONS)</i>	363
SWNTS	363
<i>TABLE 146 UNCONFIRMED ASIAN COMMERCIAL SWNT PRODUCTION COMMITMENT: TIER 2 COMPANIES, 2011-2016 (KG)</i>	364
FEW-WALLED GRADES (FWNTS)	364
CHAPTER 11 MARKET PULL: PROGNOSIS FOR GLOBAL CNT APPLICATIONS	366
POLYMER COMPOSITES	366
AERONAUTICAL APPLICATIONS	366
AUTOMOTIVE APPLICATIONS	367
ELECTRONIC PACKAGING APPLICATIONS	369
FLAME-RETARDANT APPLICATIONS	370
INDUSTRIAL SEALS	370
MILITARY APPLICATIONS	370
PROSPECTIVE APPLICATIONS OF OTHER COMPOSITE FORMS OF CNTS	371
SPORTS EQUIPMENT APPLICATIONS	372
OTHER COMPETITIVE FACTORS AND DEVELOPMENTS	373
MARKET PROSPECTS FOR CNTS IN OTHER MATRIX COMPOSITES	374
MARKET PROSPECTS FOR CNTS IN ELECTRONIC APPLICATIONS	375
ELECTRONIC/NANOELECTRONIC COMPONENTS	375
FE DISPLAYS AND RELATED DEVICES	377

TOPIC	PAGE NO.
FE DISPLAYS	377
<i>TABLE 147 PROS AND CONS FOR CNT FE DISPLAY MARKET</i>	377
MARKET CHALLENGES: COMPETITION AND MANUFACTURING COST	377
COMMERCIAL CHAMPIONS-WHO'S LEADING THE CHASE AND WHEN?	378
LIGHT BULBS AND LIGHT SOURCES	380
FLEXIBLE DISPLAYS AND ELECTRONICS	381
MEMORY APPLICATIONS	383
SENSORS	385
Alpha Szenszor, Inc. (Worcester, Mass.)	385
Applied Nanotech Holdings, Inc. (Austin, Texas)	385
Nanomix, Inc. (Emeryville, CA)/Mystic MD, Inc. (Groton, Conn.)	385
Nanosense, Inc. (Redwood City, Calif.)/Evolved Machines, Inc. (Palo Alto, Calif.)	386
MARKET PROSPECTS FOR CNTS IN ENERGY APPLICATIONS	386
BATTERIES	386
Market Prognosis	386
CNT Commercial Battery Developments	386
Contour Energy Systems Inc., (Irwindale, Calif.)	387
Micro Bubble Technologies, Inc. (South Korea)/Next Alternative, Inc. (Canada)	387
Vendum Batteries, Inc. (El Segundo, Calif.)	387
Other Potential Battery Developments	388
CAPACITORS	388
Market Prognosis of Commercial Development in CNT-Based Supercapacitors	388
Recent Patent Activity and Commercial Development in CNT-Based EDLCs	389
Arrowhead Research Corp./Agonn Systems, Inc. (Pasadena, Calif.)	389
Kemet Corp. (Greenville, S.C.)	390
Nisshinbo Holdings, Inc. (Tokyo, Japan)	390
Honda Motor Co., Ltd. (Tokyo, Japan)	390
FUEL CELLS	390
Recent Patent Activity and Commercial Development in CNT-Based Fuel Cells	391
Bing Energy, Inc. (Tallahassee, Fla.)	391
Intematix Corp. (Fremont, Calif.)	392
Japan, Inc.	392
Neah Power Systems, Inc. (Bothel, Wash.)	392
Pacific Fuel Cell Corp. (Riverside, Calif.)	392
Show Denko KK (Japan)	392
UltraCell Corp. (Livermore, Calif.)	393
HYDROGEN STORAGE	393
SOLAR/PV CELLS	394
Ambit Corp. (Ashland, Mass.)	394
DuPont (Wilmington, Del.)	394
Eikos, Inc. (Franklin, Mass.)	395
Konarka Technologies (Lowell, Mass.)	395
Natcore Technogy (Red Bank, N.J.)	395
OTHER ENERGY CONVERSION SYSTEMS	395
MARKET PROSPECTS FOR CNTS IN OTHER APPLICATIONS	396
BIOMEDICAL DEVELOPMENTS	396
CATALYST SUPPORTS	396

TOPIC	PAGE NO.
INSTRUMENTS: ACTUATORS, MANIPULATORS AND PROBES	396
MEMBRANES AND SEPARATION TECHNOLOGY	397
OIL RECOVERY	398
SECURITY	398
Body Armor and Smart Textiles	399
RFID Tags	399
Alien Technology Corporation (Morgan Hills, Calif.)	399
Ambient Systems, B.V. (Enschede, Netherlands)	399
AMBIT Corp. (Ashland, Mass.)	400
Nantero Inc. (Woburn, Mass.)/HP Specialty Printing Systems (San Diego, Calif.)	400
Paru Co. Ltd. (Suncheon, Korea)/Suncheon National University/Rice University	400
X-ray Detection	400
XinRay Systems, LLC (Research Triangle Park, N.C.)	400
CHAPTER 12 APPENDIX	403
ACRONYMS AND ABBREVIATIONS	403
UNITS	408

LIST OF TABLES

TABLE HEADING	PAGE NO.
SUMMARY TABLE GLOBAL MARKET REVENUES FOR CNT GRADES BASED ON COMMITTED PRODUCTION ESTIMATES, THROUGH 2016 (\$ MILLIONS)	6
TABLE 1 CHRONOLOGY OF SOME CNT LANDMARK DEVELOPMENTS, 1953-2012	11
TABLE 2 SOME COMPARATIVE PROPERTIES OF CARBON ALLOTROPES	12
TABLE 3 SOME CHARACTERISTIC PROPERTIES OF CNTS	19
TABLE 4 COMPARATIVE PROPERTIES OF DIFFERENT CNTS AND CFS	20
TABLE 5 DIVERSE RANGE OF INDUSTRIAL APPLICATIONS FOR CNTS	20
TABLE 6 SOME EXAMPLES OF OPTIMUM FORMS OF CNTS REQUIRED FOR DIFFERENT APPLICATIONS	21
TABLE 7 PROPERTIES AND APPLICATIONS OF SOME INORGANIC NANOTUBES	23
TABLE 8 COMPARISON OF THE MOST COMMON TYPES OF CNT BATCH PRODUCTION TECHNOLOGIES	26
TABLE 9 SYNTHETIC PROCESS FACTORS AFFECTING CNT GROWTH	28
TABLE 10 COMPARATIVE ADVANTAGES AND DISADVANTAGES OF CNT PROCESSES	29
TABLE 11 COMPARISON OF SWNT CONTINUOUS PRODUCTION TECHNOLOGIES	29
TABLE 12 COMMON CNT CHEMICAL PURIFICATION PROCESSES, OUTCOMES AND DISADVANTAGES	39
TABLE 13 HISTORICAL DEVELOPMENT IN SEPARATION, PURIFICATION, CAPPING AND UNCAPPING OF CNTS BASED ON U.S. PATENTS	40
TABLE 14 LEADING U.S. RESEARCH ORGANIZATIONS SPEARHEADING CNT SYNTHESIS AND APPLICATIONS DEVELOPMENT	41
TABLE 15 RECENT DEVELOPMENTS IN CHEMICAL FUNCTIONALIZATION OF CNTS AND POSSIBLE APPLICATIONS	42
TABLE 16 EXEMPLARY U.S. PATENTS RELATING TO CNT CHEMICAL FUNCTIONALIZATION	43
TABLE 17 ORGANIZATIONS OFFERING SURFACE FUNCTIONALIZED CNT DISPERSIONS AND THEIR APPLICATIONS	43
TABLE 18 NOTABLE DEVELOPMENTS IN SORTING ELECTRONIC GRADE CNTS	44
TABLE 19 EXEMPLARY U.S. PATENTS RELATING TO SELF-ASSEMBLY AND ORGANIZATION OF CNTS	46
TABLE 20 SCALABLE DEVICE INTEGRATION OF CNTS	47
TABLE 21 EXEMPLARY U.S. PATENTS RELATING TO THE USE OF CNTS AS NANOTEMPLATES	48
TABLE 22 RECENT RESEARCH DEVELOPMENTS IN OTHER CNT VARIANTS	51
TABLE 23 INDUSTRIAL SECTORS AND EXEMPLARY APPLICATIONS EMERGING FROM ISSUED U.S. CNT PATENTS, 1994-2009	60
TABLE 24 LEADING SMALL U.S. BUSINESSES WITH CNT ISSUED AND PENDING PATENT APPLICATIONS, 2010-NOVEMBER 22, 2011 (NUMBER)*	72
TABLE 25 OTHER SMALL U.S. BUSINESSES WITH MULTIPLE CNT ISSUED AND PENDING PATENT APPLICATIONS, 2010-NOVEMBER 22, 2011 (NUMBER)*	73
TABLE 26 LEADING LARGE U.S. BUSINESSES WITH CNT ISSUED AND PENDING PATENT APPLICATIONS, 2010-NOVEMBER 22, 2011 (NUMBER)*	74
TABLE 27 OTHER LARGE U.S. BUSINESSES WITH MULTIPLE CNT ISSUED AND PENDING PATENT APPLICATIONS, 2010-NOVEMBER 22, 2011 (NUMBER)*	75
TABLE 28 CNT ISSUED AND PENDING PATENT APPLICATIONS AMONG LEADING U.S. ACADEMIC INSTITUTIONS, 2010-NOVEMBER 1, 2011 (NUMBER)*	76
TABLE 29 U.S. GOVERNMENT AND OTHER RESEARCH INSTITUTIONS WITH CNT ISSUED AND PENDING PATENT APPLICATIONS, 2010-NOVEMBER 24, 2011 (NUMBER)*	77
TABLE 30 CNT ISSUED AND PENDING PATENT APPLICATIONS FOR LEADING JAPANESE ORGANIZATIONS, 2010-NOVEMBER 24, 2011 (NUMBER)*	78
TABLE 31 U.S. CNT ISSUED AND PENDING PATENT APPLICATIONS FOR LEADING KOREAN, TAIWANESE AND CHINESE ORGANIZATIONS, 2010-NOVEMBER 24, 2011 (NUMBER)**	79

TABLE HEADING	PAGE NO.
TABLE 32 CNT ISSUED AND PENDING PATENTS FOR LEADING ORGANIZATIONS IN EUROPE AND OTHER COUNTRIES, 2010 TO NOVEMBER 24, 2011 (NUMBER)****	80
TABLE 33 INFLUENTIAL PLAYERS INVOLVED IN LARGE-SCALE CNT PRODUCTION AND MARKET EXPLOITATION	87
TABLE 34 INFLUENTIAL PLAYERS INVOLVED IN SMALL-SCALE CNT PRODUCTION AND/OR SPECIALIZED MARKET EXPLOITATION	88
TABLE 35 MARKET SEGMENTATION OF CNT INDUSTRY	89
TABLE 36 RECENT DEVELOPMENTS IN COMMERCIALIZING BAYER MATERIALSCIENCE MWNTS	92
TABLE 37 SWENT'S LATEST COMMERCIAL SWNT DEVELOPMENTS: OCTOBER 2009-OCTOBER 2011	111
TABLE 38 UNIDYM'S LATEST COMMERCIAL BUSINESS DEVELOPMENTS: 2010-2011	115
TABLE 39 ZYVEX TECHNOLOGIES COMMERCIAL DEVELOPMENTS IN CNT POLYMER COMPOSITES, 2007-2011	124
TABLE 40 LARGE U.S. CORPORATIONS LEADING IN U.S. CNT PATENT ACTIVITY* (TOTAL NUMBER OF PATENTS 579)	125
TABLE 41 EXEMPLARY COMPANIES LEADING THE CNT INDUSTRY EVOLUTION	129
TABLE 42 DIVERSITY IN CNT CONSUMER MARKET PRODUCTS	130
TABLE 43 COMPETITIVE MATERIAL ALTERNATIVES TO CNTS FOR CERTAIN APPLICATIONS	131
TABLE 44 PROGRESS IN IDENTIFYING AND RESOLVING CNT TOXICOLOGICAL BEHAVIOR, 2005-2007	132
TABLE 45 PROGRESS IN IDENTIFYING AND RESOLVING CNT TOXICOLOGICAL BEHAVIOR, 2008-2011	133
TABLE 46 MECHANICAL PROPERTIES OF CNTS COMPARED WITH OTHER FIBERS	143
TABLE 47 CNT COMPOSITES: RANGE OF POSSIBLE APPLICATIONS	144
TABLE 48 CNT COMPOSITES: PROPERTIES ENDOWED	144
TABLE 49 MECHANICAL PROPERTY ENHANCEMENTS IN VARIOUS CNT COMPOSITES	145
TABLE 50 ENHANCEMENTS CLAIMED IN VARIOUS CNT CERAMIC SYSTEMS	147
TABLE 51 SOME EXAMPLES OF CNT-METAL COMPOSITES	152
TABLE 52 EXAMPLES OF CNT-POLYMER COMPOSITE MATRIX SYSTEMS AMENABLE TO COMMERCIAL PROCESSING AND APPLICATION	154
TABLE 53 SOME EXAMPLES OF CNT-POLYMER COMPOSITES	155
TABLE 54 VARIOUS PROCESSING STRATEGIES USED TO MANUFACTURE POLYMER-CNT COMPOSITES	156
TABLE 55 ULTIMATE MECHANICAL PROPERTIES OF CNT FIBERS AND EXAMPLES OF THEIR ENHANCEMENT IN VARIOUS POLYMER COMPOSITE SYSTEMS	157
TABLE 56 KEY PROPERTIES CONTROLLING ULTIMATE REINFORCING AND CONDUCTIVITY POTENTIAL OF SWNTS IN A POLYMER MATRIX	158
TABLE 57 POLYMER COMPOSITE CNT PRODUCTS CURRENTLY MANUFACTURED OR UNDER COMMERCIAL DEVELOPMENT	159
TABLE 58 LEADING COMPANIES INVOLVED IN THE COMMERCIAL DEVELOPMENT OF CNT-POLYMER COMPOSITES	160
TABLE 59 MOST ACTIVE COMPANIES ACCORDING TO CNT-POLYMER COMPOSITE U.S. PATENTS, 2007-DECEMBER 29, 2011 (TOTAL NUMBER OF PATENTS 607)	161
TABLE 60 OTHER ACTIVE ORGANIZATIONS ACCORDING TO U.S. CNT-POLYMER COMPOSITE PATENTS, 2007-DECEMBER 29, 2011	162
TABLE 61 EXAMPLES OF READY-TO-MOLD HYPERION AUTOMOTIVE MWNT-RESIN COMPOUNDS	163
TABLE 62 COMPARATIVE PERFORMANCE FOR HYPERION CONDUCTIVE AUTOMOTIVE MWNT-RESIN COMPOUNDS	163

TABLE HEADING	PAGE NO.
TABLE 63 ADVANTAGES OF MWNTS COMPARED WITH CONVENTIONAL CONDUCTIVE FILLERS USED IN MOLDED AUTOMOTIVE PLASTICS	164
TABLE 64 CLASSIFICATION OF CONDUCTIVE MOLDED PLASTICS ACCORDING TO FILLER LOADING AND ELECTRICAL PROPERTIES	165
TABLE 65 VARIOUS APPLICATIONS OF MWNTS IN ELECTROSTATICALLY DISSIPATIVE PLASTIC AUTO COMPONENTS	165
TABLE 66 ADVANCES IN IMPROVING THE STRENGTH AND CONDUCTIVITY OF POLYMER-CNT COMPOSITES, 2007-2009	168
TABLE 67 RECENT DEVELOPMENTS IN AEROSPACE CF COMPOSITES INDUSTRY	171
TABLE 68 VARIOUS ELECTRONIC APPLICATIONS OF MWNTS IN MOLDED PLASTIC ELECTRONIC COMPONENTS	171
TABLE 69 CNT COMPOSITE COMPANIES ATTRACTING MILITARY AND OTHER CIVILIAN APPLICATIONS DEVELOPMENT	174
TABLE 70 FUTURE SPACE APPLICATIONS FOR CNTS	175
TABLE 71 SPORTING GOODS PROTOTYPES BASED ON MWNT-PLASTIC COMPOSITES	176
TABLE 72 RECENT PATENT ACTIVITY IN CNT DRY ADHESIVE SYSTEMS*	179
TABLE 73 ORGANIZATIONS EXPLORING CNT-BASED OR OTHER CARBON-BASED INKS AND SMART COATINGS	179
TABLE 74 COMPARATIVE PROPERTY PERFORMANCE OF CONDUCTIVE TRANSPARENT COMPOSITE COATINGS	181
TABLE 75 U.S. ORGANIZATIONS LEADING THE ELECTRONICS SECTOR WITH CNT PATENTS, 2010-DECEMBER 29, 2011 (NUMBER)*	186
TABLE 76 LEADING ASIAN AND EUROPEAN ORGANIZATIONS HOLDING ELECTRONICS CNT PATENTS, 2010-DECEMBER 29, 2011 (NUMBER)**	187
TABLE 77 KEY CNT PROPERTIES ATTRACTING FUTURE ELECTRONIC APPLICATIONS	190
TABLE 78 ORGANIZATIONS INVOLVED IN CNT ELECTRONIC THERMAL MANAGEMENT APPLICATIONS	200
TABLE 79 LEADING COMPANIES WITH CNTFET PATENT INTEREST	206
TABLE 80 ADVANTAGES OF CNTS AS A COLD FE CATHODE	209
TABLE 81 ADVANTAGES OF FE DISPLAYS OVER LCDS	212
TABLE 82 MAJOR FACTORS DICTATING EMERGENCE OF CNT-BASED TECHNOLOGY IN FPD MARKETPLACE	212
TABLE 83 LEADING U.S. ORGANIZATIONS INVOLVED IN U.S. CNT FED-DISPLAY PATENT ACTIVITY, 2000-DECEMBER 29, 2011 (NUMBER)	213
TABLE 84 LEADING FOREIGN COUNTRIES INVOLVED IN U.S. CNT-FED DISPLAY PATENT ACTIVITY, 2000-DECEMBER 29, 2011 (NUMBER)	213
TABLE 85 MAJOR PLAYERS AND ANCILLIARY GROUPS/COMPANIES INVOLVED IN CNT-FED HISTORY AND DEVELOPMENT	214
TABLE 86 ORGANIZATIONS ACTIVELY INVOLVED IN CNT-FED PROTOTYPES, 2000-2011	215
TABLE 87 ADVANTAGES AND CHALLENGES OF MOTOROLA'S CNT-BASED FED COMPARED WITH EXISTENT FPD TECHNOLOGIES	220
TABLE 88 EXAMPLES OF OTHER FED APPLICATIONS	226
TABLE 89 ADVANTAGES OF FE-CNT FLUORESCENT WHITE LIGHT SOURCE OVER CONVENTIONAL LAMPS	227
TABLE 90 RATIONALIZING CNT SYNTHESIS WITH END-USE FE PERFORMANCE REQUIREMENTS	228
TABLE 91 ORGANIZATIONS WITH U.S. PATENT ACTIVITY RELATING TO CNT-BASED FE LIGHT-SOURCES	228
TABLE 92 LEADING ORGANIZATIONS INVOLVED IN THE APPLICATION OF CNTS IN FLEXIBLE ELECTRONICS AND DISPLAYS	237
TABLE 93 ATTRACTIVE PROPERTIES OF CNTS FOR MEMORY APPLICATIONS	244

TABLE HEADING	PAGE NO.
TABLE 94 LEADING COMMERCIAL PLAYERS IN CNT-MEMORY INITIATIVES BASED ON U.S. PATENTS, 1997-DECEMBER 29, 2011	246
TABLE 95 RECENT DEVELOPMENTS IN OTHER APPLICATIONS OF CNTS USED IN ELECTRONIC DEVICES	248
TABLE 96 LEADING PLAYERS IN CNT-BASED BATTERY TECHNOLOGY ACCORDING TO U.S. PATENT ACTIVITY, 2004-DECEMBER 29, 2011	253
TABLE 97 CNTS ENDEARING PROPERTIES USED IN FUEL CELL APPLICATIONS	255
TABLE 98 KEY PROPERTIES AFFECTING FUEL CELL PERFORMANCE	256
TABLE 99 LEADING ORGANIZATIONS PATENTING U.S. CNT FUEL CELL ENHANCEMENTS, 2002-DECEMBER 30, 2006	260
TABLE 100 PATENT ACTIVITY IN CNT-BASED FUEL CELL APPLICATIONS AMONG U.S. ORGANIZATIONS, 2007-DECEMBER 29, 2011	261
TABLE 101 PATENT ACTIVITY IN U.S. CNT-BASED FUEL CELL APPLICATIONS AMONG FOREIGN ORGANIZATIONS, 2007-DECEMBER 29, 2011	262
TABLE 102 EARLY PATENT ACTIVITY IN U.S. CNT-BASED HYDROGEN STORAGE APPLICATIONS, 1997-APRIL 2006	270
TABLE 103 LEADING U.S. AND FOREIGN PATENT ACTIVITY IN U.S. CNT-BASED HYDROGEN STORAGE APPLICATIONS, 2007-DECEMBER 29, 2011	271
TABLE 104 PERFORMANCE COMPARISON OF ENERGY STORAGE DEVICES	273
TABLE 105 ADVANTAGES OF SUPERCAPACITOR ELECTRICAL STORAGE DEVICES COMPARED WITH BATTERIES	273
TABLE 106 COMPARATIVE PERFORMANCE OF BATTERIES VERSUS CAPACITORS	274
TABLE 107 U.S. PATENT ACTIVITY IN U.S. CNT-BASED EDL CAPACITORS AND APPLICATIONS, 1997-DECEMBER 30, 2006	281
TABLE 108 LEADING ORGANIZATIONS INVOLVED IN U.S. CNT-BASED EDL CAPACITOR PATENT ACTIVITY, 2007-DECEMBER 29, 2011	283
TABLE 109 ACADEMIC RESEARCH ACTIVITIES IN CNT-BASED SOLAR CELLS	286
TABLE 110 MORE RECENT DEVELOPMENTS IN CNT-BASED SOLAR CELLS, 2010 TO 2012	287
TABLE 111 CNT PATENT ACTIVITY IN SOLAR CELL APPLICATIONS, 1997-DECEMBER 30, 2006 (NUMBER)	288
TABLE 112 PATENT ACTIVITY LEADERS IN CNT-BASED SOLAR CELL APPLICATIONS, 2007-DECEMBER 29, 2011 (NUMBER)	289
TABLE 113 PATENT ACTIVITY IN U.S. CNT-BASED APPLICATIONS USED IN OTHER ENERGY CONVERSION SYSTEMS, 2007-DECEMBER 29, 2011 (NUMBER)	297
TABLE 114 ATTRACTIVE PROPERTIES OF CNTS AS SEPARATION MEMBRANES	301
TABLE 115 ORGANIZATIONS WITH U.S. PATENT ACTIVITY IN CNT MEMBRANES, FILTRATION AND SEPARATION MEDIA, 2007-DECEMBER 29, 2011	301
TABLE 116 RESEARCH AND COMMERCIAL PROTOTYPE DEVELOPMENTS OF VARIOUS CNT-BASED MEMBRANE SEPARATION TECHNOLOGIES	302
TABLE 117 TYPES OF CNT SENSORS	310
TABLE 118 RECENT TYPES OF CNT BIOSENSOR SYSTEMS	311
TABLE 119 KEY PROPERTIES OF CNTS EXPLOITED IN SENSOR APPLICATIONS	312
TABLE 120 LEADING ORGANIZATIONS INVOLVED IN U.S. CNT-SENSOR PATENT ACTIVITY, 2007-DECEMBER 29, 2011 (NUMBER)	315
TABLE 121 POTENTIAL USES OF CNTS IN THE BIOMEDICAL AREA	323
TABLE 122 RESEARCH DEVELOPMENTS IN CNT BIOMEDICAL APPLICATIONS, PRIOR TO 2007	323
TABLE 123 RESEARCH DEVELOPMENTS IN CNT BIOMEDICAL APPLICATIONS, 2007-2009	324
TABLE 124 RESEARCH DEVELOPMENTS IN CNT BIOMEDICAL APPLICATIONS, 2010-2011	326
TABLE 125 U.S. PATENT ACTIVITY LEADERS IN CNT CATALYST SUPPORTS, 2007-DECEMBER 29, 2011 (NUMBER)	329
TABLE 126 APPLICATIONS OF CNTS IN PHOTOCATALYTIC SYSTEMS	331

TABLE HEADING	PAGE NO.
TABLE 127 U.S. CNT PATENT ACTIVITY INVOLVING ACTUATORS, INSTRUMENTS AND MANIPULATORS, 2009-DECEMBER 29, 2011 (NUMBER)	332
TABLE 128 U.S. PATENT ACTIVITY IN CNT ENHANCEMENTS IN OIL RECOVERY, 2010-DECEMBER 29, 2011 (NUMBER)	335
TABLE 129 LEADING ORGANIZATIONS INVOLVED IN VARIOUS CNT-BASED SECURITY APPLICATIONS	336
TABLE 130 GLOBAL MARKET FORECAST FOR MWNT ANNUAL PRODUCTION AND REVENUES: TIER 1 COMPANIES, THROUGH 2016 (\$ MILLIONS)	345
TABLE 131 GLOBAL ANNUAL PRODUCTION COMMITMENT FOR COMMERCIAL SWNTS AND REVENUES: TIER 1 COMPANIES, THROUGH 2016 (KG/YEAR, \$ MILLIONS)	347
TABLE 132 FORECAST FOR SPECIALTY FWNTS PRODUCTION AND REVENUES, THROUGH 2016	347
TABLE 133 COMMERCIAL PROTOTYPE DEVELOPMENTS IN CNT POLYMER COMPOSITES	348
TABLE 134 COMMERCIAL PROTOTYPE DEVELOPMENTS IN OTHER MATRIX COMPOSITES	349
TABLE 135 COMMERCIAL PROTOTYPE DEVELOPMENTS IN ELECTRONICS	350
TABLE 136 COMMERCIAL PROTOTYPE DEVELOPMENTS IN ENERGY	350
TABLE 137 COMMERCIAL PROTOTYPE DEVELOPMENTS IN OTHER APPLICATIONS	351
TABLE 138 ANNUAL PRODUCTION COMMITMENT AND REVENUES FOR U.S. COMMERCIAL MWNT PRODUCERS: TIER 1 COMPANIES, THROUGH 2016 (METRIC TONS, \$ MILLIONS)	353
TABLE 139 ANNUAL PRODUCTION COMMITMENT AND REVENUES OF U.S. COMMERCIAL SWNT PRODUCERS: TIER 1 COMPANIES, THROUGH 2016 (KG/YEAR, \$ MILLIONS)	354
TABLE 140 FORECAST FOR NORTH AMERICAN SPECIALTY FWNTS PRODUCTION: REVENUES, THROUGH 2016	355
TABLE 141 OTHER COMPANIES AIDING GLOBAL CNT COMMERCIALIZATION	356
TABLE 142 EUROPEAN PRODUCTION COMMITMENT AND REVENUES OF COMMERCIAL MWNTS: TIER 1 COMPANIES, THROUGH 2016 (METRIC TONNES, \$ MILLIONS)	359
TABLE 143 EUROPEAN ANNUAL PRODUCTION COMMITMENT OF COMMERCIAL SWNTS AND REVENUES: TIER 1 THOMAS SWAN, THROUGH 2016 (KG/YEAR, \$ MILLIONS)	360
TABLE 144 JAPANESE ANNUAL COMMERCIAL PRODUCTION COMMITMENT AND REVENUES FOR MWNTS: TIER 1 SHOWA DENKO COMPANY, THROUGH 2016 (METRIC TONNES, \$ MILLIONS)	362
TABLE 145 UNCONFIRMED ANNUAL PRODUCTION COMMITMENT OF COMMERCIAL MWNTS: TIER 2 ASIAN COMPANIES, 2011-2016 (METRIC TONS)	363
TABLE 146 UNCONFIRMED ASIAN COMMERCIAL SWNT PRODUCTION COMMITMENT: TIER 2 COMPANIES, 2011-2016 (KG)	364
TABLE 147 PROS AND CONS FOR CNT FE DISPLAY MARKET	377

LIST OF FIGURES

FIGURE TITLE	PAGE NO.
SUMMARY FIGURE GLOBAL MARKET FOR CNT GRADES BASED ON COMMITTED PRODUCTION, 2011-2016 (\$ MILLIONS)	7
FIGURE 1 FORMATION OF A SWNT STRUCTURE	9
FIGURE 2 CNT STRUCTURES	10
FIGURE 3 CNT PATENTS ISSUED, 1994-2011 (CUMULATIVE TOTAL: 7,726)	58
FIGURE 4 BREAKDOWN OF THE MAIN INDUSTRY/APPLICATION SECTORS DERIVED FROM U.S. CNT ISSUED PATENTS, 1994-2004	59
FIGURE 5 BREAKDOWN OF THE MAIN INDUSTRY/APPLICATION SECTORS FROM U.S. CNT ISSUED PATENTS, 2007-JUNE 30, 2009 (%)	60
FIGURE 6 U.S. AND FOREIGN CNT PATENTS ISSUED, CLASSIFIED ACCORDING TO INDUSTRIAL/APPLICATIONS SECTORS, 1994-2002 (COMBINED TOTAL: 415)	62
FIGURE 7 U.S. AND FOREIGN CNT PATENTS ISSUED, CLASSIFIED ACCORDING TO INDUSTRY/APPLICATION SECTOR, 2003-2004 (COMBINED TOTAL 480)	63
FIGURE 8 U.S. AND FOREIGN CNT PATENTS ISSUED, CLASSIFIED ACCORDING TO INDUSTRIAL/APPLICATION SECTOR, 2007 TO JUNE 30, 2009 (COMBINED TOTAL 1,987)	64
FIGURE 9 U.S. VERSUS ASIAN CNT PATENTS ISSUED, 1994-2004 (COMBINED TOTAL 679)	65
FIGURE 10 EUROPEAN AND OTHER COUNTRIES WITH U.S. CNT ISSUED PATENTS, 1994-2004 (COMBINED TOTAL 51)	66
FIGURE 11 U.S. CNT PATENTS ISSUED: ASIA, 2007-JUNE 30, 2009	67
FIGURE 12 U.S. CNT PATENTS ISSUED: EUROPEAN AND OTHER COUNTRIES, 2007-JUNE 30, 2009 (NUMBER)	68
FIGURE 13 U.S. CNT PATENTS ISSUED: ASIA, 2011-2012 (NUMBER)*	69
FIGURE 14 U.S. CNT PATENTS ISSUED: EUROPEAN AND OTHER COUNTRIES, 2010-2011 (NUMBER)*	70
FIGURE 15 LEADING U.S. STATES WITH U.S. CNT ISSUED PATENTS, 2009-NOVEMBER 21, 2011 (NUMBER)*	71
FIGURE 16 GROWTH AND BACKLOG IN U.S. PATENTS FILED 2001-DECEMBER 29, 2011 (NUMBER)*	81