Table of contents

1 EXECUTIVE SUMMARY 28
1.1 Graphene properties 28
1.2 Commercialization 29
1.3 The graphene market to date 31
1.4 Market outlook for 2022 and beyond 32
1.5 The market in 2021 32
1.6 Graphene commercial market developments 2020-2022 34
1.7 Graphene funding and investments 2020-2022 38
1.8 Publicly listed graphene companies 41
1.9 Graphene global production capacities, in tons and by type 42
1.10 Global demand for graphene 44
1.10.1 Global graphene demand, to 2032, tons 44
1.10.2 Global graphene demand, by end user market to 2032 47
1.10.3 Graphene market, by region 50
1.10.3.1 Asia-Pacific 50
1.10.3.2 North America 53
1.10.3.3 Europe 55
1.11 Graphene products 56
1.12 Industrial collaborations and licence agreements 59
1.13 Graphene market challenges 67

2 TYPES OF GRAPHENE 69
2.1 Graphene materials 70
2.1.1 CVD Graphene 70
2.1.1.1 Applications 71
2.1.2 Graphene nanoplatelets 71
2.1.3 Graphene oxide and reduced Graphene Oxide 72
2.1.4 Graphene quantum dots (GQDs) 73
2.1.4.1 Applications 75
2.1.4.2 Markets 76
2.2 Intermediate products 83
2.2.1 Graphene masterbatches 83
2.2.2 Graphene dispersions 84

3 GRAPHENE PRODUCTION 85
3.1 Quality 86
3.2 Assessment of graphene production methods 87
3.3 Commercial production capacities 91
3.4 Graphene oxide and reduced Graphene Oxide production capacities 91
3.4.1 By producer 91
3.5 Graphene nanoplatelets production capacities 93

Copyright © Future Markets, Inc 2022. All rights reserved.

3.5.1 By producer....93
3.6 CVD graphene film....95
3.6.1 By producer....95
3.7 Graphene production issues and challenges....96
3.7.1 Oversupply....96
3.7.2 Quality....96
3.7.3 Large-volume markets....96
3.7.4 Commoditisation....97
3.7.5 Industrial end-user perspective....97

4 GRAPHENE PRICING....98
4.1 Pristine graphene flakes pricing/CVD graphene....100
4.2 Few-Layer graphene pricing....102
4.3 Graphene nanoplatelets pricing....103
4.4 Graphene oxide (GO) and reduced Graphene Oxide (rGO) pricing....104
4.5 Graphene quantum dots pricing....105
4.6 Multilayer graphene (MLG) pricing....106
4.7 Graphene ink....107

5 MARKETS FOR GRAPHENE....108
5.1 3D PRINTING....108
5.1.1 Market overview....109
5.1.2 Market drivers, trends and applications....109
5.1.3 Global market in tons, historical and forecast to 2032....113
5.1.4 Products and product developers....115
5.2 ADHESIVES....117
5.2.1 Market overview....117
5.2.2 Market drivers, trends and applications....118
5.2.3 Global market in tons, historical and forecast to 2032....121
5.2.4 Products and product developers....122
5.3 AEROSPACE....124
5.3.1 Market overview....124
5.3.2 Market drivers, trends and applications....124
5.3.3 Global market in tons, historical and forecast to 2032....127
5.3.4 Products and product developers....128
5.4 AUTOMOTIVE....131
5.4.1 Market overview....131
5.4.2 Market drivers, trends and applications....132
5.4.3 Global market in tons, historical and forecast to 2032....135
5.4.4 Product developers....136
5.5 BATTERIES....140
5.5.1 Market overview....140
5.5.2 Market drivers, trends and applications....140
5.5.3 Global market in tons, historical and forecast to 2032....145

Copyright © Future Markets, Inc 2022. All rights reserved.

5.5.4 Products and product developers 146
5.6 COMPOSITES 152
5.6.1 Market overview 152
5.6.1.1 Fiber-based composite parts 152
5.6.1.2 Metal-matrix composites 156
5.6.2 Global market in tons, historical and forecast to 2032 158
5.6.3 Products and product developers 159
5.7 CONDUCTIVE INKS 164
5.7.1 Market overview 164
5.7.2 Market drivers, trends and applications 165
5.7.3 Global market in tons, historical and forecast to 2032 169
5.7.4 Products and product developers 171
5.8 CONSTRUCTION AND BUILDINGS 174
5.8.1 Market overview 174
5.8.2 Market drivers, trends and applications 175
5.8.2.1 Cement 175
5.8.2.2 Asphalt bitumen 177
5.8.2.3 Aerogels 177
5.8.3 Global market in tons, historical and forecast to 2032 179
5.8.4 Products and product developers 180
5.9 ELECTRONICS 183
5.9.1 WEARABLE ELECTRONICS AND DISPLAYS 183
5.9.1.1 Market overview 183
5.9.1.2 Market drivers, trends and applications 184
5.9.1.3 Global market, historical and forecast to 2032 187
5.9.1.4 Products and product developers 188
5.9.2 TRANSISTORS AND INTEGRATED CIRCUITS 190
5.9.2.1 Market overview 190
5.9.2.2 Market drivers, trends and applications 191
5.9.2.3 Global market, historical and forecast to 2032 193
5.9.2.4 Products and product developer 194
5.9.3 MEMORY DEVICES 197
5.9.3.1 Market overview 197
5.9.3.2 Market drivers, trends and applications 198
5.9.3.3 Global market in tons, historical and forecast to 2031 199
5.9.3.4 Products and product developer 201
5.10 FILTER MEDIA 202
5.10.1 Market overview 202
5.10.2 Market drivers, trends and applications 203
5.10.3 Global market in tons, historical and forecast to 2032 207
5.10.4 Products and product developers 209
5.11 FUEL CELLS 212
5.11.1 Market overview 212

Copyright © Future Markets, Inc 2022. All rights reserved.

5.11.2 Market drivers, trends and applications 213
5.11.3 Global market in tons, historical and forecast to 2032 216
5.11.4 Products and product developers 217
5.12 LIFE SCIENCES AND MEDICINE 218
5.12.1 Market overview 219
5.12.1.1 Drug delivery 220
5.12.1.2 Imaging and diagnostics 221
5.12.1.3 Implants 221
5.12.1.4 Medical biosensors 222
5.12.1.5 Woundcare 222
5.12.1.6 Medical wearables 223
5.12.1.7 Gene delivery 224
5.12.2 Market drivers, trends and applications 224
5.12.3 Global market in tons, historical and forecast to 2032 229
5.12.4 Products and product developers 230
5.13 LIGHTING 234
5.13.1 Market overview 234
5.13.2 Market drivers, trends and applications 235
5.13.3 Global market in tons, historical and forecast to 2032 237
5.13.4 Products and product developers 238
5.14 LUBRICANTS 239
5.14.1 Market overview 239
5.14.2 Market drivers, trends and applications 240
5.14.3 Global market in tons, historical and forecast to 2032 243
5.14.4 Products and product developers 244
5.15 OIL AND GAS 247
5.15.1 Market overview 247
5.15.2 Market drivers, trends and applications 248
5.15.3 Global market in tons, historical and forecast to 2032 250
5.15.4 Products and product developers 251
5.16 PAINTS AND COATINGS 253
5.16.1 Market overview 253
5.16.2 Market drivers, trends and applications 254
5.16.3 Global market in tons, historical and forecast to 2031 257
5.16.4 Products and product developers 259
5.17 PHOTONICS 264
5.17.1 Market overview 264
5.17.2 Market drivers, trends and applications 265
5.17.3 Global market in tons, historical and forecast to 2031 268
5.17.4 Products and product developers 270
5.18 PHOTOVOLTAICS 271
5.18.1 Market overview 271
5.18.2 Market drivers, trends and applications 272

Copyright © Future Markets, Inc 2022. All rights reserved.

5.18.3 Global market in tons, historical and forecast to 2031 275
5.18.4 Products and product developers 276
5.19 RUBBER AND TIRES 278
5.19.1 Market overview 278
5.19.2 Market outlook 278
5.19.3 Market drivers, trends and applications 279
5.19.4 Global market in tons, historical and forecast to 2031 282
5.19.5 Products and product developers 284
5.20 SENSORS 287
5.20.1 Market overview 287
5.20.2 Market drivers, trends and applications 288
5.20.3 Global market in tons, historical and forecast to 2031 292
5.20.4 Products and product developers 294
5.21 TEXTILES AND APPAREL 298
5.21.1 Market overview 298
5.21.2 Market drivers, trends and applications 299
5.21.3 Global market in tons, historical and forecast to 2031 303
5.21.4 Product developers 305
5.22 SUPERCAPACITORS 310
5.22.1 Market overview 310
5.22.2 Market drivers, trends and applications 311
5.22.2.1 Flexible and stretchable supercapacitors 313
5.22.3 Global market in tons, historical and forecast to 2031 314
5.22.4 Products and product developers 315
5.23 OTHER MARKETS 318
5.23.1 Audio equipment 318
5.23.2 Sporting goods and apparel 318

6 GRAPHENE COMPANY PROFILES 320
6.1 [redacted] 320
6.2 [redacted] 321
6.3 [redacted] 322
6.4 [redacted] 323
6.5 [redacted] 324
6.6 [redacted] 324
6.7 [redacted] 325
6.8 [redacted] 326
6.9 [redacted] 328
6.10 [redacted] 328
6.11 [redacted] 329
6.12 [redacted] 330
6.13 [redacted] 331
6.14 [redacted] 332
6.15 [redacted] 332

Copyright © Future Markets, Inc 2022. All rights reserved.

6.16 333
6.17 333
6.18 335
6.19 336
6.20 336
6.21 337
6.22 338
6.23 338
6.24 339
6.25 341
6.26 341
6.27 342
6.28 343
6.29 344
6.30 344
6.31 345
6.32 345
6.33 346
6.34 347
6.35 347
6.36 348
6.37 349
6.38 350
6.39 351
6.40 351
6.41 352
6.42 352
6.43 353
6.44 353
6.45 354
6.46 355
6.47 355
6.48 356
6.49 356
6.50 357
6.51 358
6.52 359
6.53 359
6.54 360
6.55 361
6.56 362
6.57 362
6.58 363

Copyright © Future Markets, Inc 2022. All rights reserved.

6.59 364
6.60 364
6.61 365
6.62 366
6.63 366
6.64 367
6.65 368
6.66 368
6.67 369
6.68 370
6.69 371
6.70 372
6.71 373
6.72 374
6.73 374
6.74 375
6.75 376
6.76 376
6.77 377
6.78 377
6.79 378
6.80 379
6.81 379
6.82 380
6.83 381
6.84 381
6.85 382
6.86 383
6.87 384
6.88 385
6.89 386
6.90 387
6.91 387
6.92 388
6.93 388
6.94 389
6.95 390
6.96 391
6.97 392
6.98 393
6.99 395
6.100 396
6.101 397

Copyright © Future Markets, Inc 2022. All rights reserved.

6.102 398
6.103 398
6.104 399
6.105 400
6.106 401
6.107 402
6.108 402
6.109 403
6.110 404
6.111 405
6.112 405
6.113 406
6.114 406
6.115 407
6.116 407
6.117 408
6.118 408
6.119 409
6.120 410
6.121 410
6.122 411
6.123 412
6.124 414
6.125 415
6.126 416
6.127 417
6.128 418
6.129 418
6.130 419
6.131 419
6.132 420
6.133 421
6.134 421
6.135 422
6.136 423
6.137 425
6.138 426
6.139 426
6.140 427
6.141 427
6.142 428
6.143 429
6.144 430

Copyright © Future Markets, Inc 2022. All rights reserved.

6.145 430
6.146 431
6.147 432
6.148 433
6.149 434
6.150 434
6.151 435
6.152 435
6.153 436
6.154 437
6.155 438
6.156 439
6.157 440
6.158 441
6.159 441
6.160 442
6.161 442
6.162 443
6.163 443
6.164 444
6.165 444
6.166 446
6.167 446
6.168 447
6.169 447
6.170 448
6.171 449
6.172 449
6.173 450
6.174 450
6.175 451
6.176 451
6.177 452
6.178 452
6.179 453
6.180 454
6.181 455
6.182 455
6.183 456
6.184 457
6.185 458
6.186 459
6.187 459

Copyright © Future Markets, Inc 2022. All rights reserved.

6.188 460
6.189 460
6.190 461
6.191 462
6.192 463
6.193 463
6.194 464
6.195 464
6.196 465
6.197 466
6.198 467
6.199 467
6.200 468
6.201 469
6.202 469
6.203 470
6.204 471
6.205 472
6.206 472
6.207 473
6.208 474
6.209 474
6.210 475
6.211 476
6.212 476
6.213 477
6.214 477
6.215 478
6.216 478
6.217 479
6.218 479
6.219 480
6.220 480
6.221 481
6.222 481
6.223 482
6.224 483
6.225 483
6.226 484
6.227 485
6.228 486
6.229 487
6.230 487

Copyright © Future Markets, Inc 2022. All rights reserved.

6.231 488
6.232 488
6.233 489
6.234 489
6.235 491
6.236 492
6.237 494
6.238 496
6.239 497
6.240 497
6.241 498
6.242 498
6.243 499
6.244 500
6.245 501
6.246 501
6.247 502
6.248 502
6.249 503
6.250 503
6.251 505
6.252 506
6.253 507
6.254 507
6.255 508
6.256 509
6.257 510
6.258 511
6.259 512
6.260 512
6.261 513
6.262 513
6.263 514
6.264 515
6.265 515
6.266 516
6.267 516
6.268 517
6.269 518
6.270 518
6.271 519
6.272 519
6.273 520

Copyright © Future Markets, Inc 2022. All rights reserved.

6.274 521
6.275 522
6.276 523
6.277 525
6.278 528
6.279 528
6.280 529
6.281 530
6.282 530
6.283 531
6.284 532
6.285 532
6.286 533
6.287 534
6.288 534
6.289 535
6.290 537
6.291 538
6.292 538
6.293 539
6.294 540
6.295 540
6.296 542
6.297 542
6.298 543
6.299 543
6.300 544
6.301 545
6.302 546
6.303 547
6.304 548
6.305 548
6.306 549
6.307 550
6.308 551
6.309 554
6.310 554
6.311 555
6.312 556
6.313 557
6.314 557
6.315 558
6.316 559

Copyright © Future Markets, Inc 2022. All rights reserved.

6.317 [redacted] 559
6.318 [redacted] 560
6.319 [redacted] 561
6.320 [redacted] 562
6.321 [redacted] 563
6.322 [redacted] 564
6.323 [redacted] 565

7 RESEARCH METHODOLOGY 566
7.1 Technology Readiness Level (TRL) 567

8 REFERENCES 569

List of Tables

Table 1. Properties of graphene, properties of competing materials, applications thereof. 29
Table 2. Graphene commercial market developments 2020-2022. 34
Table 3. Graphene funding and investments 2020-2022. 38
Table 4. Publicly listed graphene companies. 41
Table 5. Main graphene producers by country, annual production capacities, types and main markets they sell to. 42
Table 6. Demand for graphene (tons), 2018-2032. 45
Table 7. Main graphene producers in North America. 53
Table 8. Main graphene producers in Europe. 55
Table 9. Commercial products incorporating graphene. 57
Table 10. Graphene industrial collaborations, licence agreements and target markets. 60
Table 11. Graphene market challenges. 67
Table 12. Applications of GO and rGO. 72
Table 13. Comparison of graphene QDs and semiconductor QDs. 75
Table 14. Applications of graphene quantum dots. 76
Table 15. Markets and applications for graphene quantum dots in electronics and photonics. 76
Table 16. Markets and applications for graphene quantum dots in energy storage and conversion. 77
Table 17. Markets and applications for graphene quantum dots in sensors. 78
Table 18. Markets and applications for graphene quantum dots in biomedicine and life sciences. 79

Copyright © Future Markets, Inc 2022. All rights reserved.

Table 19. Markets and applications for graphene quantum dots in electronics. 80
Table 20. Prices for graphene quantum dots. 83
Table 21. Assessment of graphene production methods. 89
Table 22. Graphene oxide production capacity by producer, 2014-2022. 91
Table 23. Graphene nanoplatelets capacity in tons by producer, 2010-2022. 93
Table 24. CVD graphene film capacity by producer, 2014-2022 in 000s m^2. 95
Table 25. Types of graphene and typical prices. 99
Table 26. Pristine graphene flakes pricing by producer. 101
Table 27. Few-layer graphene pricing by producer. 102
Table 28. Graphene nanoplatelets pricing by producer. 103
Table 29. Graphene oxide and reduced graphene oxide pricing, by producer. 104
Table 30. Graphene quantum dots pricing by producer. 106
Table 31. Multi-layer graphene pricing by producer. 106
Table 32. Graphene ink pricing by producer. 107
Table 33. Market outlook for graphene in 3D printing. 109
Table 34. Market and applications for graphene in 3D printing. 109
Table 35. Demand for graphene in 3-D printing (tons), 2018-2032. 113
Table 36. Product developers in graphene 3D printing. 115
Table 37. Market overview for graphene in adhesives. 117
Table 38. Market outlook for graphene in adhesives. 118
Table 39. Market and applications for graphene in adhesives. 118
Table 40. Demand for graphene in adhesives (tons), 2018-2032. 121
Table 41. Product developers in graphene adhesives. 122
Table 42. Graphene in aerospace. 124
Table 43. Market and applications for graphene in aerospace. 124
Table 44: Demand for graphene in aerospace (tons), 2018-2030. 127
Table 45: Product developers in graphene for aerospace. 128
Table 46. Market and applications for graphene in automotive. 132
Table 47. Demand for graphene in automotive (tons), 2018-2032. 135
Table 48. Product developers in the graphene automotive market. 136
Table 49. Market and applications for graphene in batteries. 140

Copyright © Future Markets, Inc 2022. All rights reserved.

Table 50. Estimated demand for graphene in batteries (tons), 2018-2032. 145
Table 51. Product developers in graphene batteries. 146
Table 52. Market outlook for graphene in fiber-based polymer composite parts. 152
Table 53. Market and applications for graphene in fiber-based composite parts. 152
Table 54. Market and applications for graphene in metal matrix composites. 156
Table 55. Global market for graphene in composites 2018-2032, tons. 158
Table 56. Product developers in graphene composites. 159
Table 57. Market overview for graphene in conductive inks. 164
Table 58. Market outlook for graphene in conductive inks. 164
Table 59. Market and applications for graphene in conductive inks. 165
Table 60. Comparative properties of conductive inks. 168
Table 61. Demand for graphene in conductive ink (tons), 2018-2032. 169
Table 62. Product developers in graphene conductive inks. 171
Table 63. Market overview for graphene in construction and buildings. 174
Table 64. Market outlook for graphene in construction. 174
Table 65. Graphene for cement. 175
Table 66. Graphene for asphalt bitumen. 177
Table 67. Demand for graphene in construction (tons), 2018-2032. 179
Table 68: Graphene product developers in construction. 180
Table 69. Market overview for graphene in wearable electronics and displays. 183
Table 70. Market outlook for graphene in wearable electronics and displays. 184
Table 71. Market and applications for graphene in electronics. 184
Table 72. Comparison of ITO replacements. 186
Table 73. Demand for graphene in wearable, flexible and stretchable electronics, 2018-2032. 187
Table 74. Product developers in graphene-based electronics. 188
Table 75. Market overview for graphene in transistors and integrated circuits. 190
Table 76. Comparative properties of silicon and graphene transistors. 190
Table 77. Market outlook for graphene in transistors and integrated circuits. 190
Table 78. Market and applications for graphene in transistors and integrated circuits. 191
Table 79. Demand for graphene in transistors and integrated circuits, 2018-2032. 193
Table 80. Product developers in graphene transistors and integrated circuits. 194

Copyright © Future Markets, Inc 2022. All rights reserved.

Table 81. Market overview for graphene in memory devices. 197
Table 82. Market outlook for graphene in memory devices. 197
Table 83. Market and applications for graphene in memory devices. 198
Table 84. Demand for graphene in memory devices, 2018-2032. 199
Table 85. Product developers in graphene memory devices. 201
Table 86. Market overview for graphene in filtration. 202
Table 87. Market outlook for graphene in filtration. 202
Table 88. Market and applications for graphene in filtration. 203
Table 89. Demand for graphene in filtration (tons), 2018-2032. 207
Table 90. Graphene product developers in filtration. 209
Table 91. Market overview for graphene in fuel cells. 212
Table 92. Market outlook for graphene in fuel cells. 212
Table 93. Market and applications for graphene in fuel cells. 213
Table 94. Demand for graphene in fuel cells (tons), 2018-2032. 216
Table 95. Product developers in graphene fuel cells. 218
Table 96. Market overview for graphene in life sciences and medicine. 220
Table 97. Market outlook for graphene in drug delivery. 220
Table 98. Scorecard for graphene in imaging and diagnostics. 221
Table 99. Scorecard for graphene in medical implants. 221
Table 100. Scorecard for graphene in medical biosensors. 222
Table 101. Scorecard for graphene in woundcare. 222
Table 102. Market and applications for graphene in life sciences and medicine. 224
Table 103. Demand for graphene in life sciences and medical (tons), 2018-2032. 229
Table 104. Product developers in graphene life sciences and biomedicine. 230
Table 105. Market overview for graphene in lighting. 234
Table 106. Market outlook for graphene in lighting. 234
Table 107. Market and applications for graphene in lighting. 235
Table 108. Demand for graphene in lighting, 2018-2032. 237
Table 109. Product developers in graphene lighting. 238
Table 110. Market overview for graphene in lubricants. 239
Table 111. Nanomaterial lubricant products 239

Copyright © Future Markets, Inc 2022. All rights reserved.

Table 112. Market outlook for graphene in lubricants. 240
Table 113. Market and applications for graphene in lubricants. 240
Table 114. Demand for graphene in lubricants (tons), 2018-2032. 243
Table 115. Product developers in graphene lubricants. 244
Table 116. Market overview for graphene in oil and gas. 247
Table 117. Market outlook for graphene in oil and gas. 247
Table 118. Market and applications for graphene in oil and gas. 248
Table 119. Demand for graphene in oil and gas (tons), 2018-2032. 250
Table 120. Product developers in graphene oil and gas. 251
Table 121. Market overview for graphene in paints and coatings. 253
Table 122. Market outlook for graphene in paints and coatings. 253
Table 123. Market and applications for graphene in paints and coatings. 254
Table 124. Demand for graphene in paints and coatings (tons), 2018-2032. 257
Table 125. Product developers in graphene paints and coatings. 259
Table 126. Market overview for graphene in paints and coatings. 264
Table 127. Market outlook for graphene in photonics. 264
Table 128. Market and applications for graphene in photonics. 265
Table 129. Demand for graphene in photonics, 2018-2032. 268
Table 130. Product developers in graphene photonics. 270
Table 131. Market overview for graphene in photovoltaics. 271
Table 132. Market outlook for graphene in photovoltaics. 272
Table 133. Market and applications for graphene in photovoltaics. 272
Table 134. Demand for graphene in photovoltaics (tons), 2018-2032. 275
Table 135. Product developers in graphene solar. 276
Table 136. Market overview for graphene in rubber and tires. 278
Table 137. Market outlook for graphene in rubber and tires. 278
Table 138. Market and applications for graphene in rubber and tires. 279
Table 139. Demand for graphene in rubber and tires (tons), 2018-2032. 282
Table 140. Product developers in rubber and tires. 284
Table 141. Market overview for graphene in sensors. 287
Table 142. Market outlook for graphene in sensors. 288

Copyright © Future Markets, Inc 2022. All rights reserved.

Table 143. Market and applications for graphene in sensors. 288
Table 144. Demand for graphene in sensors (tons), 2018-2032. 292
Table 145. Product developers in graphene sensors. 294
Table 146. Market overview for graphene in smart textiles and apparel. 298
Table 147. Market outlook for graphene in smart textiles and apparel. 298
Table 148. Market and applications for graphene in smart textiles and apparel. 299
Table 149. Demand for graphene in textiles (tons), 2018-2032. 303
Table 150. Graphene product developers in smart textiles and apparel. 305
Table 151. Market overview for graphene in supercapacitors. 310
Table 152. Market outlook for graphene in supercapacitors. 310
Table 153: Comparative properties of graphene supercapacitors and lithium-ion batteries. 311
Table 154. Market and applications for graphene in supercapacitors. 311
Table 155. Demand for graphene in supercapacitors (tons), 2018-2032. 314
Table 156. Product developers in graphene supercapacitors. 315
Table 157. Graphene audio equipment producers and products. 318
Table 158. Graphene sporting goods producers and products. 319
Table 159. Performance criteria of energy storage devices. 562
Table 160. Technology Readiness Level (TRL) Examples. 567

List of Figures

Figure 1. Demand for graphene, by market, 2021. 33
Figure 2. Demand for graphene, 2018-2032, tons. 46
Figure 3. Global graphene demand by market, 2018-2032 (tons), conservative estimate. 47
Figure 4. Global graphene demand by market, 2018-2032 (tons). Medium estimate. 48
Figure 5. Global graphene demand by market, 2018-2032 (tons). High estimate. 49
Figure 6. Demand for graphene in China, by market, 2021. 50
Figure 7. Demand for graphene in Asia-Pacific, by market, 2021. 51
Figure 8. Main graphene producers in Asia-Pacific. 52
Figure 9. Demand for graphene in North America, by market, 2021. 54
Figure 10. Demand for graphene in Europe, by market, 2021. 56

Copyright © Future Markets, Inc 2022. All rights reserved.

Figure 11. Graphene and its descendants: top right: graphene; top left: graphite = stacked graphene; bottom right: nanotube=rolled graphene; bottom left: fullerene=wrapped graphene. 69
Figure 12. Types of CVD methods. 70
Figure 13. Schematic of the manufacture of GnPs starting from natural graphite. 72
Figure 14. Green-fluorescing graphene quantum dots. 74
Figure 15. Schematic of (a) CQDs and (c) GQDs. HRTEM images of (b) C-dots and (d) GQDs showing combination of zigzag and armchair edges (positions marked as 1–4). 74
Figure 16. Revenues for graphene quantum dots 2019-2032, millions USD 82
Figure 17. Fabrication methods of graphene. 85
Figure 18. TEM micrographs of: A) HR-CNFs; B) GANF® HR-CNF, it can be observed its high graphitic structure; C) Unraveled ribbon from the HR-CNF; D) Detail of the ribbon; E) Scheme of the structure of the HR-CNFs; F) Large single graphene oxide sheets derived from GANF. 86
Figure 19. (a) Graphene powder production line The Sixth Element Materials Technology Co. Ltd. (b) Graphene film production line of Wuxi Graphene Films Co. Ltd. 87
Figure 20. Schematic illustration of the main graphene production methods. 88
Figure 21. CVD Graphene on Cu Foil. 101
Figure 22. Applications of graphene in 3D printing. 113
Figure 23. Demand for graphene in 3-D printing (tons), 2018-2032. 114
Figure 24. CNCTArch lightweight mounting for digital signalling. 115
Figure 25. Applications of graphene in adhesives. 121
Figure 26. Demand for graphene in adhesives (tons), 2018-2032. 122
Figure 27. Graphene Adhesives. 123
Figure 28. Applications of graphene in aerospace. 127
Figure 29: Demand for graphene in aerospace (tons), 2018-2032. 128
Figure 30. Orbex Prime rocket. 129
Figure 31: Graphene enhanced aircraft cargo container. 130
Figure 32: Graphene aircraft. 130
Figure 33. Summary of graphene in automobiles. 132
Figure 34. Applications of graphene in automotive. 134
Figure 35. Demand for graphene in automotive (tons), 2018-2032. 136
Figure 36. Supercar incorporating graphene. 136
Figure 37. Graphene anti-corrosion primer. 138

Copyright © Future Markets, Inc 2022. All rights reserved.

Figure 38. Graphene-R Brake pads. 138
Figure 39. Antistatic graphene tire. 138
Figure 40. Graphene engine oil additives 139
Figure 41. Applications of graphene in batteries. 144
Figure 42. Demand for graphene in batteries (tons), 2018-2032. 145
Figure 43. Apollo Traveler graphene-enhanced USB-C / A fast charging power bank. 147
Figure 44. Exide Graphene Lead Acid Battery. 147
Figure 45. 6000mAh Portable graphene batteries 148
Figure 46. Real Graphene Powerbank 150
Figure 47. Graphene Functional Films - UniTran EH/FH. 151
Figure 48. Applications of graphene in composites. 156
Figure 49. Demand for graphene in composites (tons), 2018-2032. 159
Figure 50. Graphene bike. 160
Figure 51. Graphene lacrosse equipment. 160
Figure 52. Graphene-based suitcase made from recycled plastic. 161
Figure 53. Aros Create. 162
Figure 54. Grays graphene hockey sticks. 163
Figure 55. Applications of graphene in conductive inks 169
Figure 56. Demand for graphene in conductive ink (tons), 2018-2032. 170
Figure 57. BGT Materials graphene ink product 171
Figure 58. Printed graphene conductive ink. 172
Figure 59. Textiles covered in conductive graphene ink 172
Figure 60. Comparison of nanofillers with supplementary cementitious materials and aggregates in concrete. 175
Figure 61. Demand for graphene in construction (tons), 2018-2032. 180
Figure 62. Graphene asphalt additives. 181
Figure 63. OG (Original Graphene) Concrete Admix Plus 181
Figure 64. Demand for graphene in wearable, flexible and stretchable electronics, 2018-2032. 187
Figure 65. Moxi flexible film developed for smartphone application 188
Figure 66. Applications of graphene in transistors and integrated circuits. 193
Figure 67. Demand for graphene in transistors and integrated circuits, 2018-2032 194

Copyright © Future Markets, Inc 2022. All rights reserved.

Figure 68. Graphene IC in wafer tester. 195
Figure 69. Schematic cross-section of a graphene based transistor (GBT, left) and a graphene field-effect transistor (GFET, right) 196
Figure 70. Demand for graphene in memory devices, 2018-2032. 200
Figure 71. Layered structure of tantalum oxide, multilayer graphene and platinum used for resistive random-access memory (RRAM). 201
Figure 72. Applications of graphene in filtration. 207
Figure 73. Demand for graphene in filtration (tons), 2018-2032. 208
Figure 74. Graphene anti-smog mask 209
Figure 75. Graphene filtration membrane. 210
Figure 76. Graphene water filer cartridge 210
Figure 77. Applications of graphene in fuel cells. 216
Figure 78. Demand for graphene in fuel cells (tons), 2018-2032 217
Figure 79. Graphene-based E-skin patch. 219
Figure 80. Applications of graphene in life sciences and medicine 228
Figure 81. Demand for graphene in life sciences and medical (tons), 2018-2032. 229
Figure 82. Graphene medical biosensors for wound healing. 231
Figure 83. Graphene Frontiers' Six™ chemical sensors consists of a field effect transistor (FET) with a graphene channel. Receptor molecules, such as DNA, are attached directly to the graphene channel. 231
Figure 84. BioStamp nPoint. 232
Figure 85. Applications of graphene in lighting. 237
Figure 86. Demand for graphene in lighting, 2018-2032. 238
Figure 87. Graphene LED bulbs. 238
Figure 88. Applications of graphene in lubricants 243
Figure 89. Demand for graphene in lubricants (tons), 2018-2032. 244
Figure 90. Tricolit spray coating. 245
Figure 91. Graphenoil products. 245
Figure 92. Applications of graphene in oil and gas 250
Figure 93. Demand for graphene in oil and gas (tons), 2018-2032. 251
Figure 94. Directa Plus Grafysorber 252
Figure 95. Applications of graphene in paints and coatings. 257

Copyright © Future Markets, Inc 2022. All rights reserved.

Figure 96. Demand for graphene in paints and coatings (tons), 2018-2032. 258
Figure 97. Cryorig CPU cooling system with graphene coating. 259
Figure 98. Four layers of graphene oxide coatings on polycarbonate. 260
Figure 99. 23303 ZINCTON GNC graphene paint. 261
Figure 100. Graphene-enhanced anti-corrosion aerosols under their Hycote brand. 261
Figure 101. Scania Truck head lamp brackets ACT chamber 6 weeks, equivalent to 3y field use. Piece treated with GO to the left together with different non-GO coatings. 262
Figure 102. Schematic of graphene heat film. 263
Figure 103. Applications of graphene in photonics. 268
Figure 104. Demand for graphene in photonics, 2018-2032. 269
Figure 105. All-graphene optical communication link demonstrator operating at a data rate of 25 Gb/s per channel. 270
Figure 106. Applications of graphene in photovoltaics. 275
Figure 107. Demand for graphene in photovoltaics (tons), 2018-2032. 276
Figure 108. Graphene coated glass. 277
Figure 109. Applications of graphene in rubber and tires. 282
Figure 110. Demand for graphene in rubber and tires (tons), 2018-2032. 283
Figure 111. Eagle F1 graphene tire. 284
Figure 112. Graphene floor mats. 285
Figure 113. Vittoria Corsa G+ tire. 285
Figure 114. Graphene-based sensors for health monitoring. 287
Figure 115. Applications of graphene in sensors. 292
Figure 116. Demand for graphene in sensors (tons), 2018-2032. 293
Figure 117. AGILE R100 system. 294
Figure 118. Graphene fully packaged linear array detector. 295
Figure 119. GFET sensors. 295
Figure 120. Graphene is used to increase sensitivity to middle-infrared light. 297
Figure 121. Applications of graphene in smart textiles and apparel. 303
Figure 122. Demand for graphene in textiles (tons), 2018-2032. 304
Figure 123. 878 Project One jacket display. 305
Figure 124. Colmar graphene ski jacket. 306

Copyright © Future Markets, Inc 2022. All rights reserved.

Figure 125. Graphene dress. The dress changes colour in sync with the wearer's breathing. 306
Figure 126. G+ Graphene Aero Jersey. 307
Figure 127. Inov-8 graphene shoes. 307
Figure 128. Graphene Functional Membranes - UniTran GM. 308
Figure 129. Graphene jacket. 309
Figure 130. Applications of graphene in supercapacitors. 314
Figure 131. Demand for graphene in supercapacitors (tons), 2018-2032. 315
Figure 132. KEPCO's graphene supercapacitors. 316
Figure 133. Skeleton Technologies supercapacitor. 317
Figure 134. Zapgo supercapacitor phone charger. 317
Figure 135. Callaway Chrome Soft golf and Chrome Soft X golf balls. 319
Figure 136. Graphene heating films. 320
Figure 137. Graphene flake products. 326
Figure 138. AIKA Black-T. 330
Figure 139. Printed graphene biosensors. 339
Figure 140. Brain Scientific electrode schematic. 358
Figure 141. Graphene battery schematic. 383
Figure 142. Dotz Nano GQD products. 384
Figure 143. Graphene-based membrane dehumidification test cell. 391
Figure 144. Proprietary atmospheric CVD production. 401
Figure 145. Wearable sweat sensor. 433
Figure 146. InP/ZnS, perovskite quantum dots and silicon resin composite under UV illumination. 439
Figure 147. Sensor surface. 454
Figure 148. BioStamp nPoint. 471
Figure 149. Nanotech Energy battery. 490
Figure 150. Hybrid battery powered electrical motorbike concept. 493
Figure 151. NAWAStitch integrated into carbon fiber composite. 494
Figure 152. Schematic illustration of three-chamber system for SWCNH production. 495
Figure 153. TEM images of carbon nanobrush. 496
Figure 154. Test performance after 6 weeks ACT II according to Scania STD4445. 508
Figure 155. Quantag GQDs and sensor. 510

Copyright © Future Markets, Inc 2022. All rights reserved.

Figure 156. The Sixth Element graphene products. 524
Figure 157. Thermal conductive graphene film. 525
Figure 158. Talcoat graphene mixed with paint. 536
Figure 159. T-FORCE CARDEA ZERO. 539

Copyright © Future Markets, Inc 2022. All rights reserved.