

| | |
|---|------------|
| FOREWORD..... | XVI |
| THE FRICTION PRODUCTS & MATERIALS MARKET | 1 |
| INTRODUCTION | 2 |
| STUDY GOALS AND OBJECTIVES..... | 2 |
| REASONS FOR DOING THE STUDY | 2 |
| INTENDED AUDIENCE..... | 2 |
| SCOPE OF REPORT | 3 |
| INFORMATION SOURCES | 4 |
| AUTHOR'S CREDENTIALS | 4 |
| RELATED BCC PUBLICATIONS | 5 |
| BCC ONLINE SERVICES..... | 5 |
| DISCLAIMER | 6 |
| SUMMARY..... | 7 |
| SUMMARY (CONTINUED) | 8 |
| SUMMARY (CONTINUED) | 9 |
| <i>TABLE 1 KEY END-USE MARKETS FOR GLOBAL FRICTION</i> | |
| <i>PRODUCTS (\$ MILLIONS).....</i> | <i>10</i> |
| <i>FIGURE 1 KEY END-USE MARKETS FOR GLOBAL FRICTION</i> | |
| <i>PRODUCTS (\$ MILLIONS).....</i> | <i>10</i> |
| TECHNOLOGICAL, ECONOMIC, AND REGULATORY ENVIRONMENT..... | 11 |
| OVERVIEW..... | 11 |
| HISTORY OF FRICTION PRODUCTS AND MATERIALS..... | 11 |
| <i>TABLE 2 REASONS WHY THE FRICTION MATERIALS INDUSTRY</i> | |
| <i>SHOWED LITTLE CHANGE BEFORE THE MID-1960S.....</i> | <i>12</i> |
| <i>TABLE 3 REASONS WHY THE FRICTION MATERIALS INDUSTRY</i> | |
| <i>CHANGED IN THE MID-1960S.....</i> | <i>13</i> |
| WHAT IS A FRICTION MATERIAL?..... | 14 |
| THE SCIENCE OF FRICTION..... | 14 |
| THE SCIENCE OF FRICTION (CONTINUED) | 15 |
| TEMPERATURE VARIATION OF THE FRICTIONAL | |
| COEFFICIENT | 16 |
| TESTING..... | 17 |
| PRODUCTION OF FRICTION MATERIALS | 17 |
| SOFT BATCH..... | 17 |
| MOLDING | 18 |
| TRUCK BLOCK | 18 |
| CURING | 18 |
| BONDING | 18 |
| INTEGRALLY MOLDED BRAKES | 19 |
| BRAKE INGREDIENTS..... | 19 |

| | |
|---|-----------|
| FIBERS IN COMPOSITES..... | 19 |
| THE EMPHASIS ON REDUCING COSTS | 20 |
| EMERGING TECHNOLOGIES..... | 21 |
| REGULATORY CONSIDERATIONS..... | 22 |
| HEALTH EFFECTS OF ASBESTOS..... | 22 |
| Health Effects of Asbestos (Continued)..... | 23 |
| HISTORY OF ASBESTOS LEGISLATION..... | 24 |
| TABLE 4 PRODUCTS THAT CANNOT CONTAIN ASBESTOS AFTER | |
| 1996 | 25 |
| TABLE 5 LIST OF PRODUCTS THAT CAN STILL CONTAIN | |
| ASBESTOS..... | 26 |
| THE USE OF ASBESTOS IN MATERIALS..... | 26 |
| The Use of Asbestos in Materials (Continued)..... | 27 |
| REGULATIONS DEALING WITH THE ENVIRONMENT | 28 |
| Regulations Dealing With the ... (Continued)..... | 29 |
| REGULATIONS CONCERNING THE TRANSPORTATION | |
| INDUSTRIES..... | 30 |
| Increased Calls for Regulation of the Automotive | |
| Aftermarket | 31 |
| The Threat of Litigation..... | 31 |
| ROLE OF ASSOCIATIONS..... | 32 |
| Friction Materials Standards Institute..... | 32 |
| Brake Manufacturers Council..... | 33 |
| ASBESTOS LITIGATION AND LIABILITY | 34 |
| FRICION MATERIALS | 35 |
| OVERVIEW..... | 35 |
| TABLE 6 GLOBAL FRICTION MATERIALS MARKET, THROUGH 2012 | |
| (SELECTED RAW MATERIALS) (\$ MILLIONS)..... | 35 |
| TABLE 7 GLOBAL FRICTION MATERIALS MARKET, THROUGH 2012 | |
| (SELECTED RAW MATERIALS) (MILLIONS OF POUNDS) | 36 |
| FRICION PRODUCTS CONSTRUCTION..... | 37 |
| DRY FRICTION PRODUCTS..... | 37 |
| ADVANCED MATERIALS AND DEVICES FOR RENEWABLE | |
| ENERGY SYSTEMS | 38 |
| INTRODUCTION | 39 |
| STUDY BACKGROUND | 39 |
| STUDY GOALS AND OBJECTIVES..... | 39 |
| INTENDED AUDIENCE..... | 39 |
| SCOPE AND FORMAT | 40 |
| INFORMATION SOURCES AND METHODOLOGY..... | 41 |
| ANALYST CREDENTIALS..... | 41 |
| RELATED BCC RESEARCH REPORTS..... | 41 |

| | |
|--|-----------|
| RELATED BCC RESEARCH REPORTS (CONTINUED) | 42 |
| EXECUTIVE SUMMARY | 43 |
| <i>TABLE 8 GLOBAL MARKET FOR ADVANCED MATERIALS AND DEVICES FOR RENEWABLE ENERGY SYSTEMS, THROUGH 2011 (\$ BILLION)</i> | 43 |
| <i>TABLE 9 RENEWABLE ENERGY CONSUMPTION OF ADVANCED MATERIALS AND DEVICES BY TYPE, 2005-2011 (\$ BILLIONS)</i> | 44 |
| <i>FIGURE 2 RENEWABLE ENERGY CONSUMPTION OF ADVANCED MATERIALS AND DEVICES BY TYPE, 2005-2011 (\$ BILLIONS)</i> | 44 |
| OVERVIEW | 45 |
| GENERAL DESCRIPTION | 45 |
| DEFINITIONS | 45 |
| Renewable Energy | 45 |
| Renewable Energy Systems | 45 |
| Advanced Materials and Devices | 45 |
| OVERALL MARKET SIZE AND SEGMENTATION..... | 46 |
| <i>TABLE 10 GLOBAL MARKET FOR ADVANCED MATERIALS AND DEVICES BY RENEWABLE ENERGY TECHNOLOGY, THROUGH 2011 (\$ BILLIONS)</i> | 46 |
| <i>FIGURE 3 RENEWABLE ENERGY TECHNOLOGIES' SHARE OF ADVANCED MATERIALS AND DEVICES MARKET, 2005 VS. 2011 (% OF TOTAL DEMAND)</i> | 47 |
| <i>FIGURE 3 (CONTINUED)</i> | 48 |
| PATENT ANALYSIS | 48 |
| <i>FIGURE 4 U.S. PATENTS AND PATENT APPLICATIONS RELATING TO RE ADVANCED MATERIALS AND DEVICES BY TYPE OF RE TECHNOLOGY (%)</i> | 49 |
| POWDER METALLURGY | 50 |
| INTRODUCTION | 51 |
| STUDY GOAL AND OBJECTIVES | 51 |
| REASONS FOR DOING THE STUDY | 51 |
| INTENDED AUDIENCE..... | 51 |
| SCOPE AND FORMAT | 52 |
| METHODOLOGY | 52 |
| INFORMATION SOURCES | 52 |
| ANALYST CREDENTIALS | 53 |
| RELATED BCC RESEARCH WORK CREDENTIALS | 53 |
| SUMMARY..... | 54 |

| | |
|---|-----------|
| <i>TABLE 11 GLOBAL POWDERS AND PARTS SHIPMENTS, THROUGH 2011 (MILLIONS)</i> | 55 |
| <i>FIGURE 5 GLOBAL POWDERS AND PARTS SHIPMENTS, 2006 AND 2011 (MILLION LBS.)</i> | 55 |
| <i>FIGURE 6 GLOBAL POWDERS AND PARTS SHIPMENTS, 2006 AND 2011 (\$ MILLIONS)</i> | 56 |
| PM MARKET OVERVIEW | 57 |
| MARKET PERSPECTIVE..... | 57 |
| POWDER MATERIALS..... | 57 |
| <i>TABLE 12 ESTIMATED GLOBAL POWDER METAL SHIPMENTS AND MARKET SHARE BY TYPE OF MATERIAL, 2006 (SHORT TONS AND % SHARE)</i> | 57 |
| <i>FIGURE 7 GLOBAL POWDER METAL SHIPMENTS, BY TYPE OF MATERIAL, 2006 (SHORT TONS)</i> | 58 |
| <i>FIGURE 8 GLOBAL POWDER METAL MARKET SHARE BY TYPE OF MATERIAL, 2006 (%)</i> | 58 |
| COMPONENT MARKETS | 59 |
| <i>TABLE 13 GLOBAL PM COMPONENT MARKETS, 2006 (% SHARE AND \$ MILLIONS)</i> | 59 |
| <i>FIGURE 9 GLOBAL PM COMPONENT MARKETS, 2006 (\$ MILLIONS)</i> | 60 |
| <i>FIGURE 10 GLOBAL PM COMPONENT MARKETS, 2006 (%)</i> | 61 |
| MEASUREMENT OBJECTIVES | 61 |
| Measurement Objectives (Continued) | 62 |
| ADVANCED PROTECTIVE GEAR AND ARMOR | 63 |
| INTRODUCTION | 64 |
| STUDY GOALS AND OBJECTIVES..... | 64 |
| REASONS FOR THIS STUDY | 64 |
| INTENDED AUDIENCE AND CONTRIBUTION OF STUDY..... | 65 |
| SCOPE OF REPORT | 66 |
| INFORMATION SOURCES | 67 |
| ANALYST'S CREDENTIALS..... | 67 |
| RELATED BCC RESEARCH PUBLICATIONS | 68 |
| SUMMARY..... | 69 |
| SUMMARY..... | 69 |
| SUMMARY (CONTINUED) | 70 |
| <i>TABLE 14 U.S. VALUE OF ADVANCED PROTECTIVE GEAR AND ARMOR, THROUGH 2012 (\$ MILLIONS)</i> | 71 |
| <i>FIGURE 11 U.S. VALUE OF ADVANCED PROTECTIVE GEAR AND ARMOR, 2001-2012 (\$ MILLIONS)</i> | 71 |
| SUMMARY (CONTINUED) | 72 |

| | |
|---|-----------|
| BALLISTIC BODY AND VEHICLE ARMOR | 73 |
| HISTORICAL EVOLUTION | 73 |
| BODY ARMOR..... | 74 |
| BODY ARMOR CONSTRUCTION..... | 74 |
| NON-MILITARY USE OF BODY ARMOR..... | 75 |
| BODY ARMOR AND POLICE DEATHS | 75 |
| <i>TABLE 15 LAW ENFORCEMENT OFFICERS FELONIOUSLY KILLED WITH FIREARMS, POINT OF ENTRY FOR TORSO WOUNDS AND WEARING BODY ARMOR, 1996-2005.....</i> | <i>76</i> |
| BODY ARMOR STANDARDS..... | 77 |
| AUTHORITY | 77 |
| DEVELOPMENT OF BODY ARMOR..... | 77 |
| MANUFACTURE OF BODY ARMOR..... | 78 |
| <i>TABLE 16 SUMMARY NATIONAL INSTITUTE OF JUSTICE BODY ARMOR STANDARDS</i> | <i>78</i> |
| 2007 REVISIONS TO NIJ STANDARDS | 79 |
| NIJ Requirements | 79 |
| BODY ARMOR ACQUISITION PROCESS | 79 |
| BODY ARMOR TESTING | 80 |
| CIVILIAN LAW ENFORCEMENT AGENCY ARMOR..... | 80 |
| CIVILIAN LAW ENFORCEMENT ARMORED VEHICLES..... | 81 |
| MILITARY PROTECTIVE BODY AND VEHICLE ARMOR | 81 |
| CONSIDERATIONS IN MILITARY BODY ARMOR DESIGN..... | 81 |
| <i>TABLE 17 KEY CONSIDERATIONS FOR MILITARY BODY ARMOR DESIGN.....</i> | <i>81</i> |
| PERSONAL ARMOR SYSTEM FOR GROUND TROOPS (PASGT)..... | 81 |
| RANGER BODY ARMOR (RBA) | 82 |
| DESIGN EFFECT OF INSURGENT CAMPAIGN | 83 |
| INTERCEPTOR BODY ARMOR SYSTEM..... | 84 |
| Description | 84 |
| IMPROVED INTERCEPTOR OTV (IOTV)..... | 85 |
| <i>FIGURE 12 IMPROVED OUTER TACTICAL VEST</i> | <i>86</i> |
| COMBAT HELMET | 86 |
| Personnel Armor System Ground Troops (PASGT) Helmet..... | 87 |
| Advanced Combat Helmet (ACH) | 88 |
| COMBAT EYE PROTECTION..... | 88 |
| NEW STANDARD DESIGN ANSI Z87.1-2003..... | 89 |
| COMBAT GLOVES..... | 90 |
| MILITARY BODY ARMOR INVENTORY | 91 |
| <i>TABLE 18 ARMY BODY ARMOR REQUIREMENTS AS OF FEBRUARY 2007</i> | <i>91</i> |
| REMAINING PROTECTIVE ISSUES..... | 91 |
| FUTURE BODY ARMOR | 92 |

| | |
|--|------------|
| VEHICLE ARMOR | 92 |
| EVOLUTION OF THE ARMORED HMMWV | 93 |
| TABLE 19 M1114 HMMWV SPECIFICATIONS | 94 |
| TABLE 19 (CONTINUED)..... | 95 |
| M1114 Variations | 95 |
| M1114 Armor Improvements: The Frag-5 Kit | 95 |
| FACTORS DRIVING ARMORED HUMVEE PROCUREMENT | 96 |
| THE STRYKER COMBAT VEHICLE..... | 97 |
| Specifications | 97 |
| Production History | 98 |
| Design | 98 |
| Power Pack and Mechanical Features | 98 |
| Command, Control, and Targeting | 99 |
| Protective Features..... | 99 |
| Slat Armor..... | 99 |
| Mobility Features..... | 100 |
| Variants..... | 100 |
| Combat Performance | 100 |
| Performance Criticism..... | 101 |
| THE MINE RESISTANT AMBUSH-PROTECTED (MRAP) | |
| VEHICLE | 102 |
| Effectiveness | 103 |
| LIMITS OF ARMOR | 103 |
| LIMITS OF ARMOR (CONTINUED)..... | 104 |
| LIGHTWEIGHT MATERIALS IN TRANSPORTATION | 105 |
| INTRODUCTION | 106 |
| BACKGROUND | 106 |
| STUDY GOALS AND OBJECTIVES..... | 106 |
| INTENDED AUDIENCE..... | 107 |
| SCOPE OF REPORT | 107 |
| INFORMATON SOURCES AND METHODOLOGY | 108 |
| ANALYST CREDENTIALS..... | 109 |
| RELATED BCC REPORTS | 109 |
| EXECUTIVE SUMMARY | 110 |
| TABLE 20 GLOBAL MARKET FOR LIGHTWEIGHT MATERIALS IN | |
| TRANSPORTATION, THROUGH 2011..... | 110 |
| FIGURE 13 TRENDS IN GLOBAL MARKET FOR LIGHTWEIGHT | |
| MATERIALS USED IN TRANSPORTATION EQUIPMENT, 2005- | |
| 2011 (MILLION TONS/\$ BILLIONS) | 110 |
| EXECUTIVE SUMMARY (CONTINUED) | 111 |
| OVERVIEW | 112 |

| | |
|---|-----|
| DEFINITIONS | 112 |
| LIGHTWEIGHT MATERIALS | 112 |
| TRANSPORTATION EQUIPMENT | 112 |
| IMPORTANCE OF LIGHTWEIGHT MATERIALS | 112 |
| FUEL CONSUMPTION IN THE TRANSPORT SECTOR | 112 |
| <i>FIGURE 14 TRANSPORTATION SECTOR SHARE OF GLOBAL OIL</i> | |
| <i>CONSUMPTION, 2003 AND 2010 (%)</i> | 113 |
| <i>FIGURE 15 GLOBAL FUEL CONSUMPTION BY TRANSPORT MODE,</i> | |
| <i>2005 (%)</i> | 114 |
| TRANSPORT SECTOR CONTRIBUTION TO GREENHOUSE | |
| GAS AND OTHER EMISSIONS | 115 |
| Greenhouse Gases | 115 |
| <i>FIGURE 16 GLOBAL TRANSPORT SECTOR CONTRIBUTION TO</i> | |
| <i>GREENHOUSE GAS EMISSIONS (%)</i> | 115 |
| <i>FIGURE 16 (CONTINUED)</i> | 116 |
| Other Pollutants | 116 |
| ROLE OF LIGHTWEIGHT MATERIALS IN REDUCING | |
| TRANSPORT ENERGY CONSUMPTION AND EMISSIONS ... | 117 |
| TRADEOFFS | 117 |
| Safety Aspects of Lightweight Materials | 117 |
| Cost | 118 |
| <i>FIGURE 17 COMPARATIVE COST/STRENGTH OF STEEL VS.</i> | |
| <i>LIGHTWEIGHT MATERIALS FOR VEHICLE PRIMARY</i> | |
| <i>STRUCTURES (\$/LB AND GPA)</i> | 119 |
| <i>FIGURE 18 CFRP FABRICATION COSTS USING DIFFERENT</i> | |
| <i>FABRICATION METHODS (\$/LB)</i> | 120 |
| Durability/Reliability | 121 |
| Recyclability | 122 |
| Conservatism | 123 |
| END-USER SEGMENTS | 124 |
| <i>TABLE 21 TRANSPORTATION EQUIPMENT MATERIALS</i> | |
| <i>CONSUMPTION, THROUGH 2011 (TONS)</i> | 124 |
| <i>FIGURE 19 TRENDS IN TRANSPORTATION EQUIPMENT</i> | |
| <i>MATERIALS CONSUMPTION, 2005-2011 (TONS)</i> | 125 |
| <i>FIGURE 20 MAJOR END-USER SHARES OF TRANSPORTATION</i> | |
| <i>EQUIPMENT MATERIALS CONSUMPTION, 2005 VS. 2011 (%)</i> | 126 |
| MOTOR VEHICLES | 126 |
| Historical Production | 126 |
| <i>FIGURE 21 GLOBAL PRODUCTION OF MOTOR VEHICLES BY TYPE,</i> | |
| <i>2005 (%)</i> | 127 |
| <i>TABLE 22 GLOBAL MOTOR VEHICLE PRODUCTION BY TYPE,</i> | |
| <i>THROUGH 2005 (MILLION UNITS)</i> | 128 |
| <i>FIGURE 22 TRENDS IN GLOBAL MOTOR VEHICLE PRODUCTION</i> | |
| <i>BY TYPE, 1998-2005 (MILLION UNITS)</i> | 128 |

| | |
|--|-----|
| Future Production | 129 |
| <i>FIGURE 23 FUTURE TRENDS IN PRODUCTION OF MOTOR VEHICLES BY TYPE, 2005-2011 (MILLION UNITS)</i> | 129 |
| <i>TABLE 23 PROJECTED MOTOR VEHICLE PRODUCTION BY TYPE, THROUGH 2011 (MILLION UNITS)</i> | 130 |
| Vehicle Weight and Materials Use | 130 |
| <i>FIGURE 24 AVERAGE VEHICLE WEIGHTS BY CLASS, 2005 (POUNDS)</i> | 130 |
| <i>FIGURE 24 (CONTINUED)</i> | 131 |
| <i>FIGURE 25 TOTAL MOTOR VEHICLE MATERIAL USAGE (MILLION TONS)</i> | 131 |
| <i>FIGURE 25 (CONTINUED)</i> | 132 |
| RAILWAY LOCOMOTIVES AND ROLLING STOCK..... | 132 |
| Historical Production..... | 132 |
| <i>TABLE 24 GLOBAL SHIPMENTS OF RAILWAY LOCOMOTIVES AND ROLLING STOCK, 2005 (UNITS)</i> | 132 |
| Future Shipments..... | 133 |
| <i>TABLE 25 PROJECTED SHIPMENTS OF RAILWAY LOCOMOTIVES AND ROLLING STOCK, THROUGH 2011 (UNITS)</i> | 133 |
| Weight and Materials Requirements..... | 133 |
| <i>TABLE 26 AVERAGE WEIGHT OF RAILWAY LOCOMOTIVES AND ROLLING STOCK (TONS PER UNIT)</i> | 133 |
| <i>TABLE 26 (CONTINUED)</i> | 134 |
| <i>FIGURE 26 TOTAL RAILWAY LOCOMOTIVE AND ROLLING STOCK MATERIAL USAGE (MILLION TONS)</i> | 134 |
| SHIPS | 135 |
| Historical Deliveries | 135 |
| <i>FIGURE 27 TRENDS IN WORLD SHIP DELIVERIES, 2001-2005 (MILLION GROSS TONS)</i> | 135 |
| <i>TABLE 27 WORLD SHIP DELIVERIES, THROUGH 2005 (MILLION TONS)</i> | 136 |
| Future Deliveries..... | 136 |
| <i>TABLE 28 WORLD SHIP DELIVERIES, THROUGH 2011 (MILLION GROSS TONS)</i> | 136 |
| <i>FIGURE 28 PROJECTED SHIP DELIVERIES, 2005-2011 (MILLION GROSS TONS)</i> | 136 |
| Weight and Materials Use | 137 |
| <i>FIGURE 29 STEELWEIGHT OF PROJECTED SHIP DELIVERIES, 2005-2011 (MILLION TONS)</i> | 137 |
| AIRCRAFT..... | 138 |
| Historical Aircraft Deliveries | 138 |
| <i>FIGURE 30 GLOBAL CIVIL AIRCRAFT DELIVERIES, 2005 (%)</i> | 138 |
| Future Deliveries | 139 |

| | |
|---|------------|
| <i>TABLE 29 GLOBAL DELIVERIES OF CIVILIAN AIRCRAFT, THROUGH 2011 (UNITS/\$ BILLIONS)</i> | 139 |
| <i>FIGURE 31 TRENDS IN GLOBAL DELIVERIES OF CIVILIAN AIRCRAFT, 2005-2011 (UNITS)</i> | 139 |
| Weight and Materials Requirements..... | 140 |
| <i>FIGURE 32 TOTAL CIVILIAN AIRCRAFT MATERIALS USAGE, 2005-2011 (MILLION TONS)</i> | 140 |
| <i>FIGURE 32 (CONTINUED)</i> | 141 |
| <i>TABLE 30 CIVILIAN AIRCRAFT AVERAGE UNLOADED WEIGHT, BY TYPE OF AIRCRAFT, 2005 (POUNDS)</i> | 141 |
| Weight and Materials ... (Continued)..... | 142 |
| EMI/RFI: MATERIALS AND TECHNOLOGIES | 143 |
| INTRODUCTION | 144 |
| STUDY OBJECTIVES | 144 |
| SCOPE AND FORMAT | 144 |
| METHODOLOGY | 145 |
| CONTRIBUTION OF THE STUDY..... | 145 |
| ABOUT THE AUTHOR..... | 146 |
| RELATED BCC REPORTS | 146 |
| SUMMARY..... | 147 |
| <i>TABLE 31 EMI/RFI SHIELDING OPTIONS BY TYPE, THROUGH 2012 (\$ MILLIONS)</i> | 147 |
| <i>FIGURE 33 EMI/RFI SHIELDING OPTIONS BY TYPE, 2006-2012 (\$ MILLIONS)</i> | 148 |
| SUMMARY (CONTINUED) | 149 |
| SHIELDING TECHNOLOGIES AND MATERIALS..... | 150 |
| COST AND PERFORMANCE CHARACTERISTICS OF THE SHIELDING OPTIONS..... | 150 |
| COST COMPARISONS..... | 150 |
| <i>TABLE 32 TOTAL RAW MATERIAL AND LABOR COSTS ASSOCIATED WITH THE MAJOR SHIELDING OPTIONS, 2007 (\$/SQ.FT)</i> | 151 |
| <i>TABLE 33 RELATIVE COST STRUCTURE OF VARIOUS SHIELDING OPTIONS, 2007 (\$/SQ.FT)</i> | 151 |
| PERFORMANCE COMPARISONS | 152 |
| <i>TABLE 34 SUMMARY OF STRENGTHS AND WEAKNESSES OF EMI SHIELDING OPTIONS</i> | 152 |
| <i>TABLE 35 QUALITATIVE RATINGS OF THE MAJOR SHIELDING OPTIONS</i> | 153 |
| METALLIZATION PROCESSES | 153 |
| Background..... | 153 |

| | |
|---|-----|
| Overview | 154 |
| Metallization Materials..... | 154 |
| <i>TABLE 36 METALLIZATION MATERIALS: FUNCTIONAL COATINGS</i> | 154 |
| <i>TABLE 37 PLATEABLE RESINS</i> | 155 |
| SHIELDING EFFECTIVENESS OVERVIEW BY TYPE OF COATING..... | 155 |
| <i>TABLE 38 SHIELDING EFFECTIVENESS OF KEY COATINGS (DB ATTENUATION)</i> | 155 |
| CONDUCTIVE PLASTICS..... | 155 |
| OVERVIEW | 155 |
| BACKGROUND | 156 |
| DIELECTRIC PROPERTIES OF PLASTICS | 156 |
| <i>TABLE 39 DIELECTRIC CONSTANTS FOR SELECTED MATERIALS</i> | 157 |
| TECHNIQUES FOR MAKING PLASTICS CONDUCTIVE..... | 157 |
| Overview | 157 |
| <i>TABLE 40 METHODS OF MAKING PLASTICS CONDUCTIVE</i> | 158 |
| Types of Conductive Materials..... | 158 |
| <i>TABLE 41 SURFACE RESISTIVITY FOR ELECTRONIC DEVICE SUBSTRATES</i> | 158 |
| <i>TABLE 42 RESISTANCE SPECTRUM FOR METHODS OF MAKING PLASTICS CONDUCTIVE (OHMS/SQ)</i> | 159 |
| FUNCTIONS | 160 |
| CONDUCTIVE ADDITIVE SELECTION..... | 160 |
| CONDUCTIVITY TESTS..... | 160 |
| ADVANTAGES AND DISADVANTAGES | 160 |
| COMPOUNDING CONDUCTIVE PLASTICS | 161 |
| CONDUCTIVE PLASTIC ADDITIVES | 162 |
| Overview | 162 |
| Background..... | 163 |
| Fibers and Powders | 163 |
| Silver-Coatings | 163 |
| Carbon Fibers and Powders | 164 |
| Overview..... | 164 |
| Carbon Fibers..... | 164 |
| Carbon Blacks | 164 |
| Metal Fibers..... | 165 |
| Overview..... | 165 |
| Advantages..... | 166 |
| Metal Fiber Conductivity | 166 |
| Metallized Glass Fibers | 167 |
| Nickel-Coated Graphite Fibers | 167 |
| Background..... | 167 |
| Advantages | 168 |
| Stainless Steel Fibers | 169 |

| | | |
|--|-----------------------------------|------------|
| | Overview | 169 |
| | Technology | 169 |
| | Effect on Processing | 170 |
| | Fiber Forms | 170 |
| | Advantages and Disadvantages..... | 171 |
| <i>TABLE 43 ADVANTAGES AND DISADVANTAGES OF STAINLESS</i> | | |
| <i>STEEL FIBERS</i> | | 171 |
| <i>TABLE 43 (CONTINUED)</i> | | 172 |
| SMART AND INTERACTIVE TEXTILES | | 173 |
| INTRODUCTION | | 174 |
| STUDY GOALS AND OBJECTIVES | | 174 |
| REASONS FOR DOING THE STUDY | | 174 |
| INTENDED AUDIENCE | | 174 |
| SCOPE OF REPORT | | 175 |
| METHODOLOGY AND INFORMATION SOURCES | | 175 |
| ESTIMATING THE MARKET FOR DEVELOPMENTAL | | |
| TECHNOLOGIES | | 175 |
| ESTIMATING THE MARKET FOR SMART TEXTILE | | |
| APPLICATIONS | | 176 |
| ANALYST CREDENTIALS | | 176 |
| RELATED MATERIALS FROM BCC RESEARCH | | 176 |
| RELATED MATERIALS FROM BCC ... (CONTINUED) | | 177 |
| SUMMARY | | 178 |
| <i>TABLE 44 U.S. SMART AND TEXTILE MARKETS, THROUGH 2012 (\$</i> | | |
| <i>MILLIONS)</i> | | 178 |
| <i>FIGURE 34 U.S. SMART AND TEXTILE MARKETS, 2006-2012 (\$</i> | | |
| <i>MILLIONS)</i> | | 179 |
| SMART TEXTILES OVERVIEW | | 180 |
| GENERAL DESCRIPTION | | 180 |
| DEFINITIONS | | 180 |
| What Is a Textile?..... | | 180 |
| Textiles and Polymers | | 180 |
| Smart Textiles | | 181 |
| Integrated vs. Embedded Sensors | | 181 |
| Basic Technologies, Intermediate Products and Final | | |
| Applications | | 181 |
| <i>FIGURE 35 PHASE CHANGE TEXTILES: BASIC TECHNOLOGIES,</i> | | |
| <i>INTERMEDIATE PRODUCTS, AND FINAL APPLICATIONS</i> | | 182 |
| Established, Emergent, and Developmental Applications | | 182 |
| HISTORY OF SMART TEXTILES | | 183 |
| TECHNOLOGIES | | 184 |

| | |
|--|-----|
| PHASE CHANGE MATERIALS | 184 |
| Applications | 184 |
| Technology | 185 |
| PCM Microcapsules | 185 |
| PCM Coatings..... | 186 |
| PCM Fibers..... | 186 |
| Patents Issued | 186 |
| <i>TABLE 45 U.S. PHASE CHANGE TEXTILE PATENTS ISSUED</i> | |
| <i>THROUGH JUNE 15, 2007</i> | 187 |
| <i>TABLE 45 (CONTINUED)</i> | 188 |
| <i>FIGURE 36 U.S. PHASE-CHANGE TEXTILE PATENT HOLDERS (%</i> | |
| <i>OF TOTAL U.S. PATENTS ISSUED THROUGH JUNE 15, 2007)</i> | 189 |
| Manufacturers | 189 |
| <i>TABLE 46 PHASE CHANGE MATERIALS MANUFACTURERS</i> | 190 |
| SHAPE MEMORY MATERIALS..... | 190 |
| Applications | 190 |
| Clothing Applications | 190 |
| Medical Applications..... | 191 |
| Technology | 192 |
| Shape Memory Alloys | 192 |
| <i>TABLE 47 SHAPE MEMORY ALLOYS</i> | 193 |
| Nitinol | 193 |
| Cuprous-zinc SMAs..... | 194 |
| Shape Memory Polymers | 195 |
| Diaplex | 196 |
| Polyurethane Films..... | 196 |
| Bi-material Film Laminates | 196 |
| Encapsulated Bi-gels | 196 |
| Other SMPs | 197 |
| Patents Issued | 197 |
| <i>FIGURE 37 SHAPE MEMORY TEXTILE PATENTS AS A</i> | |
| <i>PERCENTAGE OF ALL U.S. SHAPE MEMORY MATERIAL</i> | |
| <i>PATENTS ISSUED THROUGH JUNE 15, 2007 (%)</i> | 197 |
| <i>FIGURE 37 (CONTINUED)</i> | 198 |
| <i>TABLE 48 SHAPE MEMORY FABRIC PATENTS</i> | 198 |
| <i>TABLE 48 (CONTINUED)</i> | 199 |
| Manufacturers | 199 |
| <i>TABLE 49 SHAPE MEMORY FABRIC MANUFACTURERS</i> | 200 |
| CHROMIC MATERIALS | 200 |
| Applications | 200 |
| Technology | 200 |
| Photochromic Textiles..... | 201 |
| Thermochromic Textiles | 201 |
| Liquid Crystal Dyes | 202 |

| | |
|---|-----|
| Molecular Rearrangement Dyes | 202 |
| Electrochromic Textiles | 202 |
| Solvatechromic Textiles | 203 |
| Patents Issued | 203 |
| <i>FIGURE 38 U.S. CHROMIC TEXTILE FABRIC PATENTS ISSUED</i> | |
| <i>THROUGH JUNE 15, 2007 (%)</i> | 204 |
| <i>TABLE 50 CHROMIC FABRIC PATENTS AND PATENT</i> | |
| <i>APPLICATIONS</i> | 204 |
| <i>TABLE 50 (CONTINUED)</i> | 205 |
| Manufacturers | 205 |
| <i>TABLE 51 CHROMIC FABRIC PRODUCT MANUFACTURERS</i> | 205 |
| CONDUCTIVE MATERIALS | 206 |
| Description | 206 |
| Applications | 206 |
| Technology | 207 |
| Conductive Coated Yarns | 207 |
| Carbon Nanotube-based Fibers and Yarns | 208 |
| Dry Spinning | 208 |
| Aqueous Spinning | 208 |
| Direct Spinning | 209 |
| Patents Issued | 209 |