Table of contents

1 INTRODUCTION 12
1.1 Electric Vehicle Definitions 12
1.2 EV Specifications 13
1.3 Evolution of the Powertrain in EVs 14
1.3.1 Resurgence and Hybrid Technology 14
1.3.2 Modern Electric Vehicles (2000s to Present) 15
1.3.3 Next-Generation Developments 15
1.4 Role of Power Electronics in EVs 16
1.5 Types of Power Electronic Components in EVs 18
1.5.1 Inverters 19
1.5.1.1 Function and Working Principle 19
1.5.1.2 Key Specifications and Requirements 19
1.5.1.3 Discretes & Modules 20
1.5.1.4 Inverter Printed Circuit Boards 20
1.5.2 DC-DC Converters 20
1.5.2.1 Function and Working Principle 20
1.5.2.2 Key Specifications and Requirements 21
1.5.3 Onboard Chargers (OBC) 21
1.5.3.1 Function and Working Principle 21
1.5.3.2 Key Specifications and Requirements 21
1.5.4 Other Components 22
1.5.4.1 Battery Management Systems (BMS) 22
1.5.4.2 High-Voltage Distributors 22
1.5.4.3 Auxiliary Power Modules (APMs) 22
1.5.4.4 Charging Control Units (CCUs) 22
1.5.4.5 DC Charging Inlet and Connector 23
1.6 Key Market Drivers and Trends 23
1.7 Power Electronics Value Chain 24

2 GLOBAL ELECTRIC VEHICLE MARKET TRENDS 25
2.1 Growth in Regional EV Markets 25
2.2 Regional Trends in Electric Vehicles (EVs) 26
2.2.1 China 26
2.2.2 Europe 26
2.2.3 USA 27
2.3 Hybrid Car Sales 28
2.4 Emissions Reduction with Powertrain 29
2.5 Costs of EVs 31
2.6 Issues with Chip Supply for EV Power Electronics 32
2.7 Global power electronics market size 35

3 EV POWER ELECTRONICS AND WBG SEMICONDUCTORS 37
3.1 Power Semiconductor Devices in Electric Vehicles 37
3.1.1 Integration of Power Electronics 37

© Future Markets, Inc 2024. All rights reserved.

3.2 Insulated Gate Bipolar Transistors (IGBTs) 39
3.2.1 Structure and Working Principle 39
3.2.2 Key Properties and Applications 40
3.3 Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) 40
3.3.1 Structure and Working Principle 40
3.3.2 Key Properties and Applications 41
3.4 Wide Bandgap (WBG) Semiconductors 42
3.4.1 Silicon Carbide (SiC) 43
3.4.1.1 Advantages 43
3.4.1.2 SiC MOSFET 43
3.4.1.3 SiC Schottky Diode 44
3.4.1.4 Silicon Insulated Gate Bipolar Transistors (Si IGBTs) 44
3.4.1.5 SiC in the automotive industry 46
3.4.1.6 Costs 46
3.4.1.7 High voltage charging platforms 47
3.4.1.8 SiC Substrate Manufacturing Chain 50
3.4.1.9 SiC Power Roadmap 57
3.4.2 Gallium Nitride (GaN) 58
3.4.2.1 Material Properties and Advantages 58
3.4.2.2 GaN HEMT and GaN FET 60
3.4.2.3 GaN for onboard chargers (OBCs) in EVs 61
3.4.2.4 Challenges for GaN Devices 63
3.4.2.5 Enhancement Mode vs Depletion Mode 64
3.4.2.6 Power electronics inverters 64
3.4.2.7 GaN Companies and Automotive Industry Suppliers 65
3.4.3 Comparative Analysis of Si, SiC, and GaN Devices 67
3.5 Inverters 71
3.5.1 Overview 71
3.5.2 Pulse Width Modulation 71
3.5.3 Traditional EV Inverter 72
3.5.4 Discretes & Modules 72
3.5.5 Inverter Printed Circuit Boards 72
3.5.6 Inverter Components and Cost 73
3.5.7 Global market 74
3.5.7.1 Inverters per Car 74
3.5.7.2 Global Inverter Market 2022-2035 (GW) 75
3.5.7.3 Global DC-DC Converter Market 2022-2035 (GW) 76
3.5.7.4 Global Inverter Cooling Unit Sales 2022-2035 77
3.5.7.5 Global Market for Discretes vs Power Modules for Inverters 79
3.6 Onboard Chargers (OBC) 80
3.6.1 Components 80
3.6.2 DC-DC Converters 81
3.6.3 Tesla Onboard Charger/DC-DC Converter 82
3.6.4 OBC by Level: 4kW, 6-11.5kW, 16-22kW 2023-2035 83
3.6.5 Global market 83
3.6.5.1 Global OBC Market for Si, SiC, GaN 2022-2035 83

© Future Markets, Inc 2024. All rights reserved.

3.6.5.2 Global OBC Market by Level 2023-2035. 84
3.6.5.3 Global Inverter, OBC, DC-DC Converter Revenues 2022-2035 85
3.6.5.4 Global Inverter, OBC, DC-DC Converter Unit Sales 2022-2035 86
3.6.5.5 Global DC-DC Converter Market for Si, SiC, GaN 2022-2035 (GW) 87
3.6.5.6 Global Inverter, OBC, DC-DC Converter Market 2022-2035 (GW) 88

4 TRENDS IN POWER ELECTRONICS FOR EVS 90
4.1 Improving efficiency 90
4.1.1 Transition from traditional 400V systems to higher-voltage 800V 90
4.1.1.1 SiC and 800V 90
4.1.1.2 800V charging speeds 91
4.1.1.3 Split battery pack configurations 91
4.1.1.4 Charging technology for 800V EVs 93
4.1.1.5 400V SiC Platforms 94
4.1.1.6 800V SiC and Si insulated-gate bipolar transistor (IGBT) inverters 95
4.1.1.7 800V Adoption 95
4.1.1.8 800V Pros and Cons 97
4.1.2 DC fast charging (DCFC) for Li-ion cells 99
4.2 Integration of Power Electronics 100
4.2.1 Integrated OBC with DC-DC converter 100
4.2.2 Traction Integrated Onboard charger (iOBC) 101
4.2.3 Hyundai Electric Global Modular Platform (E-GMP) 102
4.2.4 Combined Inverter and DC-DC Converter 103
4.2.5 SiC Diodes 104
4.2.5.1 Onboard Chargers 104
4.2.5.2 Inverters 104
4.2.5.3 Hybrid approach 104

5 SUPPLY CHAIN 107
5.1 SiC MOSFET and Si IGBT Suppliers 107
5.2 Automotive Power SC Suppliers 107
5.3 SiC MOSFET 109
5.3.1 Automotive OEMs and Suppliers 109
5.4 Si IGBT 110
5.4.1 Automotive OEMs and Suppliers 110
5.5 SiC Fabrication Centres 111
5.6 Device Suppliers 112
5.7 Tier-1 Suppliers 113
5.8 Automotive OEMs 114
5.9 Power Electronics Packages by Automotive OEM 115

6 THERMAL MANAGEMENT FOR EV POWER ELECTRONICS 118
6.1 Overview 118
6.1.1 Cooling approaches 118
6.1.2 Key thermal management strategies used in power electronics 119
6.2 Thermal Interface Materials (TIMs) 121
6.2.1 TIM1 and TIM2 in power electrics 122
6.2.2 Application of TIMs in EV Power Electronics 122

© Future Markets, Inc 2024. All rights reserved.

6.2.3 Flip Chip Packaging 124
6.2.4 Solders 124
6.2.5 Die-Attach Solution 125
6.2.5.1 Sintering 125
6.2.6 Companies 126
6.3 Liquid cooling - single and double sided 130
6.3.1 Single-Sided Cooling 131
6.3.1.1 Direct Single-Sided Cooling 131
6.3.1.2 Indirect Single-Sided Cooling 132
6.3.1.3 TIM2 133
6.3.2 Double-Sided Cooling (DSC) 134
6.3.2.1 Direct Double-Sided Cooling 134
6.3.2.2 Indirect Double-Sided Cooling 136
6.3.2.3 Advantages 137
6.3.2.4 Transition from single-sided to double-sided liquid cooling in power electronics 137
6.3.2.5 OEMs and suppliers implementing double-sided cooling 139

7 EMERGING TECHNOLOGIES 140
7.1 Advanced WBG Materials 140
7.2 Intelligent Power Modules with Embedded Sensing and Control 142
7.3 High-Frequency Switching Technologies 142

8 COMPANY PROFILES 144
8.1 Advanced Electric Machines Ltd 144
8.2 Arteco 145
8.3 BMW 147
8.4 BYD Auto 148
8.5 Diamond Foundry 149
8.6 Dynex Semiconductor (CRRC) 150
8.7 Efficient Power Conversion Corporation (EPC) 150
8.8 Elaphe 151
8.9 Equipmake 152
8.10 Fengzhi Ruilian 154
8.11 GaN Systems 155
8.12 General Motors 156
8.13 Heraeus 158
8.14 Hyundai 159
8.15 Infineon 161
8.16 Integral e-Drive 162
8.17 Lotus 164
8.18 Lucid Motors 165
8.19 Magna International 166
8.20 McLaren Automotive 168
8.21 Nexperia 169
8.22 NXP Semiconductors 171
8.23 Qorvo (QPT) 173
8.24 Renesas Electronics Corporation 174

© Future Markets, Inc 2024. All rights reserved.

8.25 Rivian 175
8.26 ROHM Semiconductor 176
8.27 STMicroelectronics 178
8.28 Transphorm 179
8.29 Valeo 180
8.30 Wolfspeed 182
8.31 ZF Friedrichshafen AG 183

9 RESEARCH METHODOLOGY 185

10 REFERENCES 186

List of Tables

Table 1. Electric Vehicle Definitions. 12
Table 2. Typical EV Specifications. 13
Table 3. Key Components of Modern EV Powertrains. 16
Table 4. Types of Power Electronic Components in EVs. 18
Table 5. Key Market Drivers and Trends in Power Electronics for EVs. 23
Table 6. Key Trends in China in EVs. 26
Table 7. Regional Trends in Europe for Electric Vehicles. 26
Table 8. EU Emissions and Targets. 27
Table 9. Regional Trends in the USA for Electric Vehicles. 27
Table 10. Powertrain Tailpipe Emissions Comparison 30
Table 11. Tailpipe emissions of different vehicle powertrains. 30
Table 12. Global power electronics market 2022-2035 (Billions USD). 35
Table 13. Power electronics in EVs. 38
Table 14. Applications for WBG Devices. 38
Table 15. Wide Bandgap (WBG) Semiconductor Advantages & Disadvantages, by type. 42
Table 16. Advantages of SiC Material. 43
Table 17. Comparison of Si IGBTs and SiC MOSFETs: 45
Table 18. Examples of SiC in the automotive industry. 46
Table 19. Si IGBT and SiC MOSFET Cost Comparison. 46
Table 20. SiC and GaN Device Cost Comparison. 46
Table 21. Si IGBT and SiC MOSFET Price Comparison. 47
Table 22. OEMs Adopting 800V Platforms. 48
Table 23. Automotive OEMs Using Si IGBTs. 50

© Future Markets, Inc 2024. All rights reserved.

Table 24. Suppliers of Si IGBTs. 51
Table 25. Automotive OEMs Using SiC MOSFETs. 52
Table 26. Suppliers of SiC MOSFETs. 52
Table 27. SiC-Specific Equipment. 52
Table 28. Players in 200mm SiC Wafer Production. 53
Table 29. Global 200mm SiC Wafer Production. 54
Table 30. Limitations of SiC Power Devices. 57
Table 31. Benefits of GaN in Automotive Applications. 58
Table 32. Challenges for GaN Devices. 63
Table 33. GaN vs. SiC in power electronics inverters. 64
Table 34. GaN companies. 65
Table 35. Major Players in GaN devices for the automotive sector. 67
Table 36. Benchmarking Silicon, Silicon Carbide & Gallium Nitride Semiconductors 67
Table 37. Performance Metrics of Si, SiC, and GaN Devices. 69
Table 38. Cost Comparison of Si, SiC, and GaN Devices. 69
Table 39. Suitability for Different EV Applications. 69
Table 40. Electric Vehicle Inverter Benchmarking. 71
Table 41. Inverter Components and Cost. 73
Table 42. Inverter, OBC & Converter, Si, SiC, GaN Cost Assumptions (US$ per kW). 74
Table 43. Inverters per Car 2022-2035. 74
Table 44. Global Inverter Market 2022-2035 (GW): GaN 600V, Si IGBT 600V, SiC MOSFET 600V, 1200V. 75
Table 45. Global DC-DC Converter Market: Si, SiC, GaN 2022-2035 (GW). 76
Table 46. Global Inverter Cooling Strategy Market 2022-2035 (Units). 77
Table 47. Global Market for Discretes vs Power Modules for Inverters 2022-2035 (Units). 79
Table 48. Expected onboard charger (OBC) circuit levels and their corresponding power ranges from 2023 to 2035. 83
Table 49. Global OBC Market: Si, SiC, GaN, 2022-2035 (GW). 83
Table 50. Global OBC Market by Level: 4kW, 6-11.5kW, 16-22kW 2023-2035. 84
Table 51. Global Inverter, OBC, DC-DC Converter Revenues 2022-2035 (US$ billion). 85
Table 52.Global Inverter, OBC, DC-DC Converter Sales 2022-2035 (Units). 86
Table 53. Global DC-DC Converter Market: Si, SiC, GaN 2022-2035 (GW). 87
Table 54. Global DC-DC Converter Market: Si, SiC, GaN 2022-2035 (GW). 88
Table 55. Global Inverter, OBC, DC-DC Converter Market 2022-2035 (GW). 88

© Future Markets, Inc 2024. All rights reserved.

Table 56. 400V SiC Platforms, by company. 94
Table 57. 800V Models in China. 96
Table 58. 800V Pros and Cons. 97
Table 59. DC Fast Charging Levels. 100
Table 60. Traction iOBC suppliers. 101
Table 61. Hybrid SiC Suppliers. 105
Table 62. SiC MOSFET vs Si IGBT: Overall Vehicle Cost. 106
Table 63. SiC MOSFET and Si IGBT Suppliers. 107
Table 64. Automotive Power SC Supplier Market Shares 2023. 107
Table 65. Automotive Power SC Supplier activities. 108
Table 66. Automotive OEMs and Their SiC MOSFET Suppliers. 109
Table 67. Automotive OEMs and Their Si IGBT Suppliers 110
Table 68. Recently established and planned SiC Fabrication Centres. 111
Table 69. Tier-1 Suppliers 113
Table 70. Power Electronics Packages by Automotive OEM. 115
Table 71. Summary of Cooling Approaches. 118
Table 72. Application of TIMs in EV Power Electronics. 123
Table 73. Comparison of Single-Sided Cooling and Double-Sided Cooling. 130
Table 74. Summary of Single-Sided Cooling. 131
Table 75. Benefits and Drawbacks of Single-Sided Cooling. 132
Table 76. Summary of Double-Sided Cooling (DSC). 134
Table 77. Double-Sided cooling examples 137
Table 78. Comparison of Advanced WBG Materials for Power Electronics. 140
Table 79. Technical Specifications of Arteco EV-Specific Water-Glycol Coolants 146

List of Figures

Figure 1. Scheme of a battery electric vehicle. 14
Figure 2. Power Electronics Value Chain. 24
Figure 3. Global power electronics market 2022-2035 (Billions USD). 36
Figure 4. IGBT: Insulated Gate Bipolar Transistor. 40

© Future Markets, Inc 2024. All rights reserved.

Figure 5. onsemi SiC MOSFETs. 41
Figure 6. SOITEC's SmartSiC technology. 56
Figure 7. structure of QST engineered substrate. 60
Figure 8. Inverters per Car Forecast 2022-2035. 75
Figure 9. Global Inverter Forecast 2022-2035 (GW): GaN 600V, Si IGBT 600V, SiC MOSFET 600V, 1200V. 76
Figure 10. Global DC-DC Converter Forecast: Si, SiC, GaN 2022-2035 (GW). 77
Figure 11. Global Inverter Cooling Strategy Market 2022-2035 (Units). 78
Figure 12. Global Market for Discretes vs Power Modules for Inverters 2022-2035 (Units). 79
Figure 13. Global OBC Market: Si, SiC, GaN, 2022-2035 (GW). 84
Figure 14. Global OBC Market by Level: 4kW, 6-11.5kW, 16-22kW 2023-2035. 85
Figure 15. Inverter, OBC, DC-DC Converter Forecast 2022-2035 (US$ billion). 86
Figure 16. Global Inverter, OBC, DC-DC Converter Sales 2022-2035 (Units). 87
Figure 17. Tesla Cybertruck split battery pack. 92
Figure 18. Porsche Taycan battery pack. 93
Figure 19. Preh's 800V onboard charger. 94
Figure 20. Hyundai 800V E-GMP platform. 96
Figure 21. Hyundai Electric Global Modular Platform (E-GMP). 103
Figure 22. Hybrid inverter proposed by STMicroelectronics. 105
Figure 23. Application of thermal interface materials in EVs. 122
Figure 24. Thermal Interface Materials companies. 126
Figure 25. Market Share of Single and Double-Sided Cooling: 2024-2035. 131
Figure 26. EliteSiC series of power modules. 133
Figure 27. AEM's SSRD rare earth free electric motor. 144
Figure 28. GD316x from NXP. 172
Figure 29. ZF Inverter with silicon carbide technology. 184

© Future Markets, Inc 2024. All rights reserved.