

POWER ELECTRONICS FOR E-MOBILITY 2021

Market & Technology Report - February 2021

Strict CO₂ targets will push EV/HEV share to 38% of all passenger vehicles in 2026, representing a \$5.6B market opportunity for various semiconductor technologies and power devices.

WHAT'S NEW

- OEMs' electrification plans, investments, and business diversification
- Focus on Korea and China
- Battery trends for EV/HEV (48, 400 and 800V)
- Insight into power electronics in different converters by vehicle electrification type (Traction inverter, DC/DC, OBC)
- COVID impact on automotive
- E-bus and E-truck market trends
- Automotive fuel cell drivers and trends

KEY FEATURES

- 2020 - 2026 market metrics and forecasts for each EV/HEV type, from vehicle sales and power converter market to power devices
- Market trends overview for EV/HEV, electric buses and trucks
- Supply chain overview, including "who supplies to whom", and business diversification for OEMs, Tier 1s and power semiconductor manufacturers
- Significant mergers and acquisitions, collaborations, and investments
- Main technology trends, including system integration and the use of vehicle platforms by major OEMs
- Power devices overview, with a focus on Wide Band Gap components (SiC and GaN) and packaging

GLOBAL ELECTRIFICATION PUSHES THE ACCELERATION OF BEV TECHNOLOGY

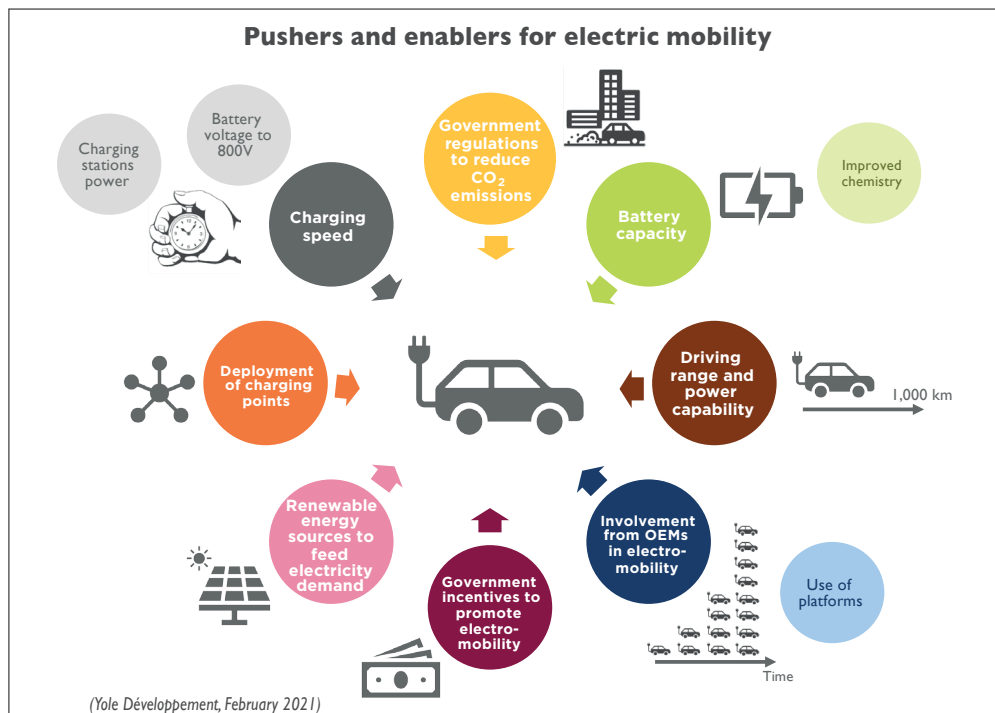
With the stringent CO₂ reduction targets followed by carbon neutrality targets announced by several countries, the automotive industry has taken a big step forward toward vehicle electrification. The electrification strategy differs for each OEM, particularly within different regions, but there is a common goal to increase the share of Battery Electric Vehicles (BEV) in their fleet. Hybrid electrification remains an option for the coming 10-15 years, although it does not meet the long-term carbon neutrality goals.

The electrification choice is directly linked to the technology architecture choice regarding converter power or battery capacity, which will lead to completely different performance characteristics from vehicle to vehicle. In the coming five years, Yole Développement (Yole) still expects a growing market for power semiconductor linked to Mild-Hybrid Electric Vehicles (MHEV), with the addition of 48V battery in the car. Moreover, the semiconductor content per vehicle increases with the electrification level, from hybrid to full electric vehicles.

Indeed, BEV is driving the acceleration of the technology, where customers are clearly demanding a long driving range with a short

recharging time while pushing to keep costs down. As detailed in the report, there are several ways to increase the driving range, such as optimizing the battery design to increase its energy capacity or increasing the efficiency of the inverter. On the other hand, the drive to decrease battery charging times is leading to the deployment of high-power chargers (up to 350kW) worldwide. To avoid the challenges associated with high current levels, the trend is to increase the battery voltage. The increase of battery voltage from today's 400V to 800V also enables faster charging, providing a high added value for car users. Indeed, 800V batteries have been adopted by Porsche and Hyundai, and others will follow. As the main inverter is then operating at higher voltage, its power semiconductor components have also to be rated at higher voltage levels, typically at 1,200V. This transition from 600V-750V components to 1,200V components represents a new business opportunity for some suppliers and reduced business for others.

An overview of the vehicle electrification choices, together with the different technology options and the strategy of the leading OEMs, is presented in the report.



THE TRACTION INVERTER IS THE MAIN MARKET CONTRIBUTOR FOR POWER ELECTRONICS IN EV/HEV

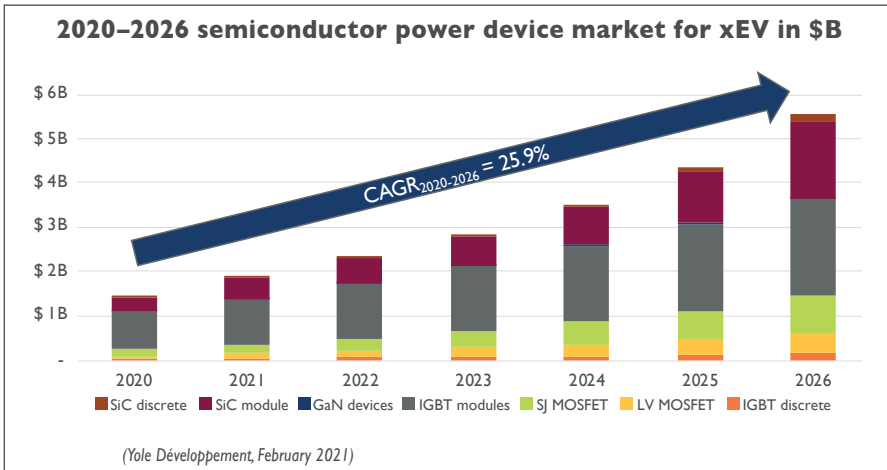
There are basically three converter types in an electric car: the main inverter, DC/DC and onboard charger (OBC). The main inverter is the largest market among the different converters due to the higher power levels, leading also to the highest content of power semiconductors. Thus, the main inverter market is expected to reach \$19.5B by 2026, representing 67% of the total EV/HEV converter market, with a CAGR of 26.9%.

Regarding the power semiconductor market, its value is expected to triple from 2020 to 2026, driven by a major technology battle between IGBT and SiC modules. Indeed, SiC modules are presently still about x3 the cost of a 650V IGBT module, but this difference will shrink when larger volumes are produced, with the transition to 8-inch wafers, and

with the penetration of 1,200V devices for higher battery voltages.

The EV/HEV supply chain continues to be impacted by the increased demand and technology trends. Although the leading semiconductor manufacturers for EV/HEV remain the same as for other power applications (such as Infineon, STMicroelectronics, Hitachi, Mitsubishi Electric, ON Semiconductor), other companies are now offering power modules for EV/HEV (Tier 1s, OEMs, power semiconductor manufacturers, and pure module newcomers). A similar situation occurs with the battery design and manufacturing, where OEMs such as Tesla and GM are further trying to control their supply chains. Competition at OEM level has also opened two main fronts: on the one hand, there are the traditional OEMs with established markets and known brands that are transforming their business towards electric vehicles. On the other hand, pure EV OEMs are popping up in the different regions of the world (such as NIO, Rivian, Rimac, Xpeng, and Hozon), some of which are rapidly increasing their volumes year after year (lead by Tesla). The new car models being launched often offer better performance/cost ratio, and this has led to a continuous reshaping of the top 10 vehicle sales.

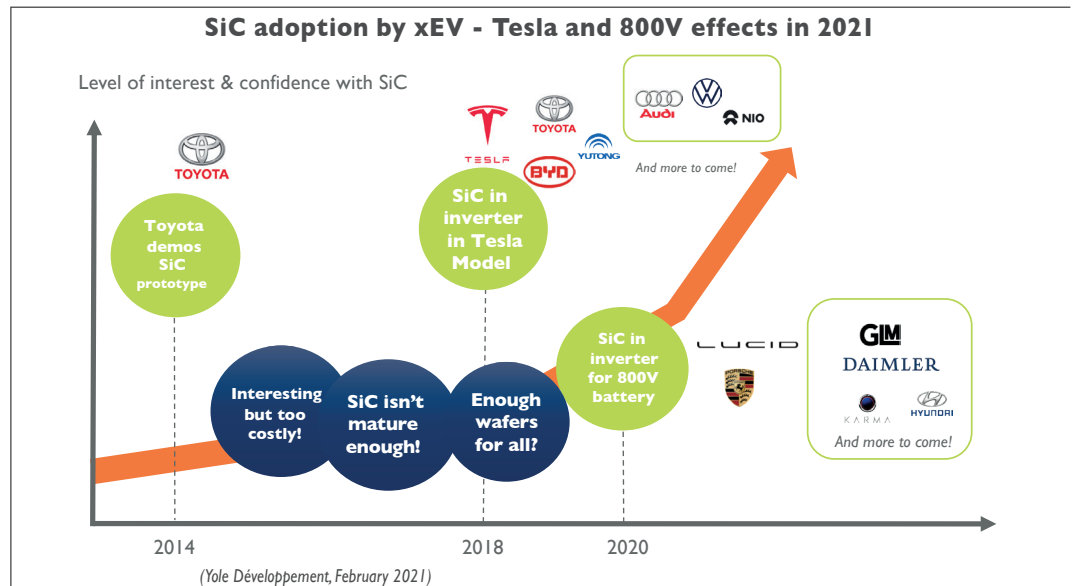
In the report, Yole discusses the forecasts for the major markets and provide a detailed overview of the supply chain from different viewpoints.



SiC IS NOW WALKING THE EV/HEV RED CARPET

Over the last couple of years (and especially since Tesla introduced SiC in their Model 3 main inverter), there has been much noise around SiC adoption in EV/HEV. But not all converters or all types of electrification are suitable for this expensive material. Without a doubt, BEV is the winner due to the requirements of a long driving range and fast charging time (km driven

by charge time). Therefore, the increased cost of the converter is repaid, as the efficiency of the converter will improve, allowing battery savings. It is no surprise then that the use of SiC in the main inverter has become a common goal for the leading OEMs, with players such as Daimler and Hyundai soon including it in their main inverters. Who will be next?



Today, there is already a good portfolio of SiC devices with SiC dies coming from Infineon, Cree (Wolfspeed), and STMicroelectronics. Many semiconductor players are targeting SiC modules for EV applications, and the SiC module market is expected to reach 32% of the total EV/HEV semiconductor market by 2026.

There is a focus on WBG materials in the report. We include SiC adoption roadmaps for different OEMs together with a focus on WBG adoption for different converters and different car electrification types for the next five years.

REPORT OBJECTIVES

- Provide an overview of the main global drivers for vehicle electrification as well as drivers for each vehicle electrification approach
- Analyze the impact of the COVID-19 crisis in EV/HEV segment
- Furnish an analysis of each vehicle electrification approach, along with forecasts for vehicles, converters and power devices
- Enlarge the overview of the EV/HEV supply chain with focus on power module suppliers, system makers (Tier1s) and vehicle manufacturers (OEMs), with also a focus in China and Korea
- Analyze the changes in business models, synergies with other EV/HEV business segments and other applications outside of EV/HEV
- Review the latest announcements of M&A, partnerships or investments for EV/HEV main actors
- Identify the key technology trends that will influence the power electronic system and component choice in the future

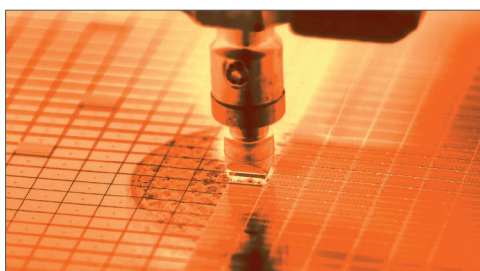
COMPANIES CITED IN THE REPORT (non exhaustive list)

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- Status of the Power Module Packaging Industry 2020
- Li-ion Battery Packs for Automotive and Stationary Storage Applications 2020
- Power SiC: Materials, Devices and Applications 2020
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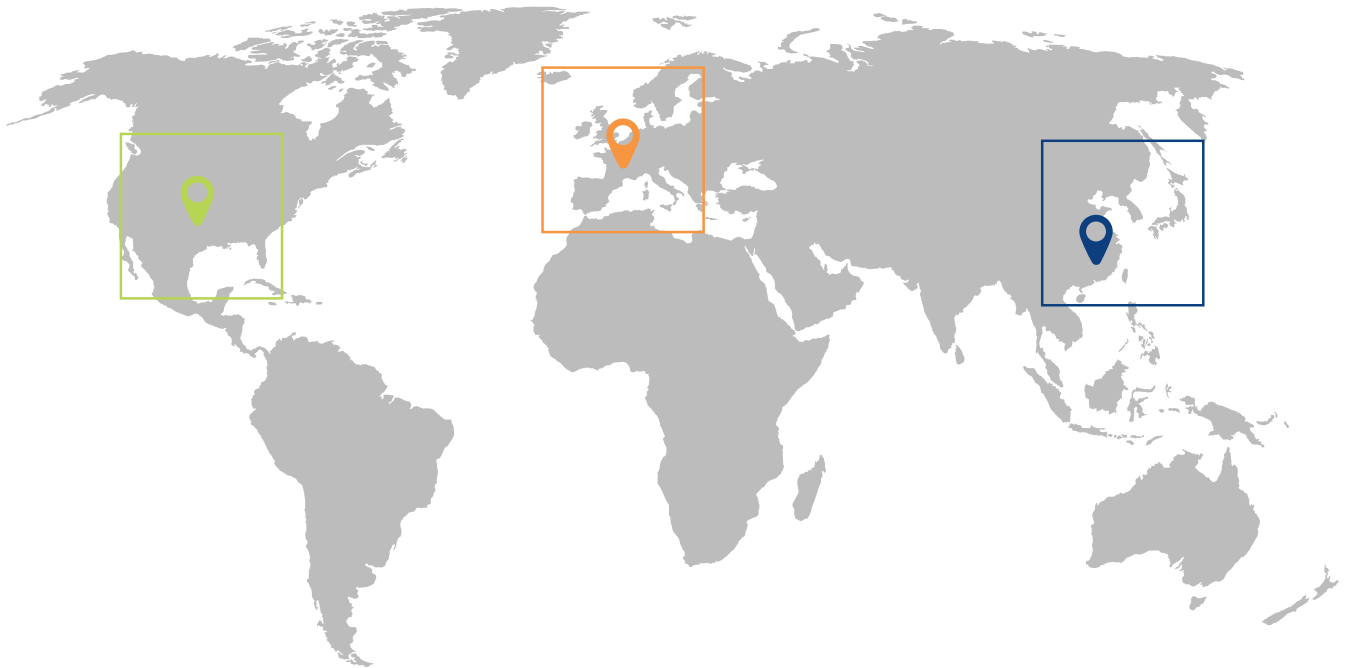
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ABOUT YOLE DEVELOPPEMENT

Founded in 1998, Yole Développement (Yole) has grown to become a group of companies providing marketing, technology and strategy consulting, media and corporate finance services, reverse engineering and reverse costing services. With a strong focus on emerging applications using silicon and/or micro manufacturing, the Yole group of companies has expanded to include more than 120 collaborators worldwide covering MEMS and Image Sensors, Compound Semiconductors, RF Electronics, Solid-state Lighting, Displays, Software, Optoelectronics, Microfluidics & Medical, Advanced Packaging, Manufacturing, Power Electronics, Batteries & Energy Management and Memory.

The “More than Moore” market research, technology and strategy consulting company Yole Développement, along with its partners System Plus Consulting, PISEO and Blumorpho, supports industrial companies, investors and R&D organizations worldwide to help them understand markets and follow technology trends to grow their business.

CONSULTING AND ANALYSIS

- Market data & research, marketing analysis
- Technology analysis
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“Buyer”: Any business user (i.e. any person acting in the course of its business activities for its business needs) placing an order pursuant to these General Terms and Conditions of Sale, with the exclusion of any individual consumer acting for his/her sole personal interest.

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1. SCOPE

1.1 Both Contracting Parties undertake to comply with these General Terms and Conditions of Sale.
ANY ADDITIONAL, DIFFERENT, OR CONFLICTING TERMS AND CONDITIONS IN ANY OTHER DOCUMENTS ISSUED BY THE BUYER AT ANY TIME ARE HEREBY OBJECTED TO BY THE SELLER, ARE DEEMED WHOLLY INAPPLICABLE TO ANY SALE MADE HEREUNDER, AND SHALL NOT BE BINDING IN ANY WAY ON THE SELLER.

1.2 These General Terms and Conditions of Sale shall be deemed valid and enforceable between the Contracting Parties after acceptance of an order from the Buyer by the Seller pursuant to Article 1.3 below. For such purpose, the Buyer, when signing the purchase order which mentions “I hereby accept Yole Développement’s Terms and Conditions of Sale” is deemed to have fully and unequivocally accepted these Terms and Conditions of Sale.

1.3 Orders are deemed to be accepted only upon written acceptance and confirmation by the Seller, within [7 days] from the date of order, to be sent either by email. In the absence of any confirmation in writing, no order shall be deemed to have been accepted.

2. MAILING OF THE PRODUCTS

- 2.1 Products are sent by email to the Buyer after Seller’s confirmation:
 - Within a few days from the Seller’s confirmation of the order for Products already released and paid; or
 - Within a reasonable time for Products ordered prior to their effective release. In this case, the Seller shall use its best endeavours to inform the Buyer of an indicative release date and the evolution of the work in progress.
- 2.2 The Seller shall by no means be responsible for any delay pursuant to Article 2.1 above, in particular in cases where a new event or access to new contradictory information would require the Seller analyst to dedicate extra time to compute or compare the data in order to enable the Seller to deliver a high quality Product.
- 2.3 The mailing of the Product will occur only upon payment by the Buyer, in accordance with the conditions contained in Article 3 above.

2.4. The mailing is operated through electronic means either by email via the sales department or automatically online via an email/password. The Buyer is responsible for ensuring that the Buyers platform has the required capacities and authorisations to receive the Product(s) emailed by the Seller. If the Product’s electronic delivery format is defective, the Seller undertakes to replace it at no charge to the Buyer provided that the Seller is informed of the defective formatting within 90 days from the date of the original download or receipt of the Product.

2.5 The person receiving the Products on behalf of the Buyer shall immediately verify the quality of the Products and their conformity with the order. Any claim for apparent defects or for non-conformity shall be sent in writing to the Seller within 8 days of receipt of the Products. For this purpose, the Buyer agrees to produce sufficient evidence of such defects.

2.6 No return of Products shall be accepted without prior written notification from the Buyer to the Seller, even in case of delayed delivery. Any Product returned to the Seller without the Buyer providing prior notification to the Seller as required under Article 2.5 above shall remain at the Buyer’s risk. In no event shall the Seller incur any liability for Products erroneously ordered by the Buyer, or for any request from the Buyer to replace a Product previously ordered by a different Product.

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3.1 Prices are given in the orders corresponding to each Product sold on a unit basis or corresponding to annual subscriptions. They are deemed to be inclusive of all taxes applicable in the country where the Seller is based (except for France where VAT will be added). The prices are re-evaluated from time to time by the Seller. The effective price is deemed to be the one applicable at the time of the order.

3.2 Payments due by the Buyer shall be sent by cheque payable to Yole Développement, or made by credit card or by electronic transfer to the following account:
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Bank code: 30056
Branch code: 00170
Account n°: 0170 200 1565 87
BIC or SWIFT code: CCFRFRPP
IBAN: FR76 3005 6001 7001 7020 0156 587

To secure the payments due to the Seller, the Seller reserves the right to request down payments from the Buyer. In such case, the need for a down payment will be mentioned on the corresponding order.

3.3 Payment is due by the Buyer to the Seller within 30 days from invoice date, except as otherwise specifically agreed in writing by the Buyer and the Seller. If the Buyer fails to pay at the due date and fails to request and obtain from the Seller a payment extension, the latter shall be entitled to invoice interest in arrears based on the annual rate Refi of the “BCE” + 7 points, in accordance with article L.441-6 of the French Commercial Code.

3.4 The Seller publications (reports, monitors, tracks...) are due for delivery only after receipt by the Seller of any payment due by the Buyer prior to delivery.

3.5 In the event of termination of the contract by the Seller attributable to Buyer misconduct during the contract, the Seller will have the right to invoice all work performed at the time of termination, and to take legal action for damages.

4. LIABILITIES

4.1 The Buyer or any other individual or legal person acting on its behalf, being a business user buying the Products for its business activities, shall be solely responsible for the choice of the Products purchased as well as for the use and interpretations the Buyer makes of the documents it purchases, of the results the Buyer obtains, and of the advice and acts the Buyer bases thereon .

4.2 In no event shall the Seller be liable for:
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- Posting any Product to any other online service (including bulletin boards or the Internet);
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6.5 The Buyer shall define within its Company an identified user who shall serve as a contact person for the License purchased by the Buyer. This person will be the recipient of each new report. This person shall also be responsible on behalf of the Buyer, for compliance with all copyrights and other obligations relating to the protection of the Seller’s IP rights and general compliance with the terms of the License purchased by the Company. In the context of Bundle and Annual Subscriptions, the contact person shall decide within the Buyer which person(s) shall be entitled to receive the protected link that will allow the Buyer to access the Products.

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6.7 It is further acknowledged and agreed by the Buyer that any investor in the Buyer Company, any external consultant of the Buyer Company or any joint venture done with a third party in which the Buyer Company is involved , is not entitled to use a Product, without paying to the Seller the full price for a license to the required Product..

7. TERMINATION

If the Buyer cancels the order in whole or in part or postpones the date of mailing, the Buyer shall indemnify the Seller for the entire costs that have been incurred as at the date of notification by the Buyer of such delay or cancellation. This may also apply for any other direct or indirect consequential loss that may be incurred by the Seller, pursuant to such cancellation or postponement.

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8.1 All the provisions of these General Terms and Conditions of Sale are for the benefit of the Seller, but also for that of its licensors, resellers and agents. Each of them is entitled to assert and enforce these provisions against the Buyer.

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8.2 The Seller may, from time to time, update these General Terms and Conditions of Sale, and the Buyer, shall be deemed to have accepted the latest version of such General Terms and Conditions of Sale, once they have been duly communicated to the Buyer by the Seller.

9. GOVERNING LAW AND JURISDICTION

9.1 Any dispute arising out or linked to these General Terms and Conditions of Sale or to any Licenses or Products purchased in application thereof shall be submitted to the French Commercial Court of Lyon, which shall have exclusive jurisdiction upon such issues.

9.2 French law (without reference to any applicable conflict of law provisions) shall apply to these General Terms and Conditions of sale and any agreement between the Buyer and the Seller made pursuant thereto.