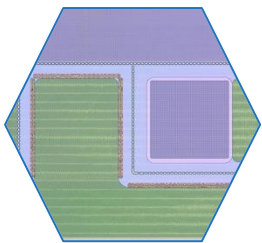
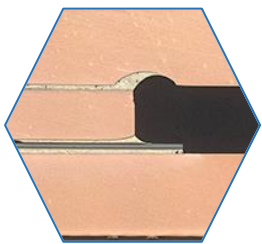
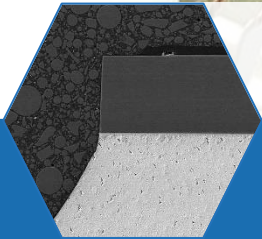


## DENSO SiC Power Module in the Toyota Mirai II

*Discover the technology, design, and cost analysis of DENSO's SiC module, the first to be used in fuel cell electric vehicles.*



**Title:** DENSO SiC Power Module in the Toyota Mirai II

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SPR21627

The new environmental regulations to reduce average CO<sub>2</sub> emissions, along with automotive trends, play in favor of greater vehicle electrification and faster deployment of electric vehicles/hybrid electric vehicles (EV/HEVs). Yole Développement expects the EV/HEV market to reach 41 million vehicles by 2026 according to the [Power Electronics for E-Mobility 2021](#) report.

Numerous carmakers continue qualifying SiC devices in main inverters, OBC, and DC/DC converters for their next-generation models. Toyota is one of the pioneers in integrating SiC dies in their vehicles and, now it is the first car maker using a SiC MOSFETs in fuel cell electric vehicle (FCEV). In fact, the Toyota Mirai II integrates a SiC based power module in the boost converter.

In this context, System Plus Consulting provides a full reverse costing study of the DENSO SiC Power Module in the Toyota Mirai II.

Supported by a full teardown of the module, this report reveals DENSO's technology choices in its SiC MOSFET, as well as the design of the module's packaging and diode chip. The module is assembled with the standard molding

technology of Denso and uses spacer for better thermal dissipation. The two dies are assembled with clips and wire bonding.

Detailed optical and SEM images with precise measurements show the structure of the transistor and the diode. Then a complete analysis of the supply chain is performed, and the dies process flow is described step-by-step.

This report provides insights into technology data, manufacturing cost, and selling price of the module. Also furnished is an estimated manufacturing cost of all the module's components, as well as a selling price analysis.

### COMPLETE TEARDOWN WITH:

- Detailed optical and SEM photos
- Precise measurements
- Manufacturing process flow
- Supply chain evaluation
- Manufacturing cost analysis
- Estimated selling price

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## RELATED ANALYSES



### SiC Transistor Comparison 2021

Comparing the technology and cost of 37 SiC transistors from Wolfspeed, Rohm, STMicroelectronics and more.  
December 2021



### GeneSiC 1200V Gen3 and 3300V Gen2 SiC MOSFETs

Discover the cost and technology choices of the first commercially available discrete 3300V SiC MOSFET from GeneSiC.  
August 2021

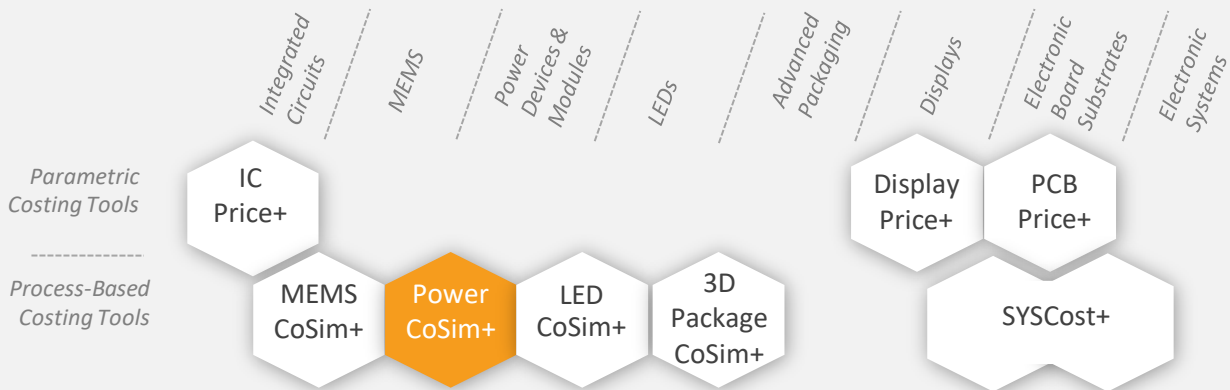


### Power SiC: Materials, Devices and Applications 2020

Despite the COVID outbreak, SiC-based design wins have multiplied for electric vehicle applications and will drive the SiC market beyond \$2.5B by 2025.

November 2020

## COSTING TOOLS



Our analysis is performed with our costing tool Power CoSim+.

System Plus Consulting offers powerful costing tools to evaluate the production cost and selling price from single chip to complex structures.

### Power CoSim+

Cost simulation tool to evaluate the cost of any Power Electronics process or device from single chip to complex structures.

## ABOUT SYSTEM PLUS CONSULTING

### WHAT IS A REVERSE COSTING®?

Reverse Costing® is the process of disassembling a device (or a system) in order to identify its technology and calculate its manufacturing cost, using in-house models and tools.



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System Plus Consulting is specialized in the cost analysis of electronics from semiconductor devices to electronic systems. A complete range of services and costing tools to provide in-depth production cost studies and to estimate the objective selling price of a product is available.

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# TERMS AND CONDITIONS OF SALES



**Definitions:** "Acceptance": Action by which the Buyer accepts the terms and conditions of sale in their entirety. It is done by signing the purchase order which mentions "I hereby accept Yole Développement's Terms and Conditions of Sale".

"Buyer": Any business user (i.e. any person acting in the course of its business activities, for its business needs) entering into the following general conditions to the exclusion of consumers acting in their personal interests.

"Contracting Parties" or "Parties": The Seller on one hand and the Buyer on the other hand. "Intellectual Property Rights" ("IPR") means any rights held by the Seller in its Products, including any patents, trademarks, registered models, designs, copyrights, inventions, commercial secrets and know-how, technical information, company or trading names and any other intellectual property rights or similar in any part of the world, notwithstanding the fact that they have been registered or not and including any pending registration of one of the above mentioned rights.

"Products": Depending on the purchase order, reports or monitors on MEMS, Imaging, SSL, Advanced Packaging, MedTech, Power Electronics and more, can be bought either on a unit basis or as a bundled offer (i.e. subscription for a period of 12 calendar months).

"Report"

Reports are established in PowerPoint and delivered in a PDF format with an additional Excel file. 30 min of Q&A session with an analyst/author can be included for all purchased reports (except the ones bought in one user license). More time can be allocated on a fee basis.

"License": For the reports 3 different licenses are proposed. The buyer has to choose one license type:

- One user license: The report is intended for only one identified user at the Company purchasing the report - Sharing is strictly forbidden
  - Multi-user license: The report can be shared by the identified user of the Company purchasing the report with an unlimited number of employees of said Company. However these rights are limited to the country of the identified user. Subsidiaries and joint-ventures are excluded.
  - Corporate license: The report can be shared by the identified user of the Company purchasing the report with an unlimited number of employees of said Company on a global basis. Subsidiaries are included, while joint-ventures are excluded. Nothing herein is intended to prevent the Yole Group of Companies from offering to sell a report to an employee who shall place an order with Yole Group of Companies for such purpose.
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"Monitor"

Monitors are established and delivered in Excel. An additional PDF can also join it. Q&A with an Analyst is possible for each monitor with a maximum limit of 100h/year. Frequency of the release varies according to the monitor or service.

"Seller": Based in Villeurbanne (France, headquarters) Yole Développement provides marketing, technology and strategy consulting, media and corporate finance services, reverse engineering/costing services as well as IP and patent analysis. With more than 70 market analysts, Yole Développement works worldwide with the key industrial companies, R&D institutes and investors to help them understand the market and technology trends.

## 1. SCOPE

**1.1** The Contracting Parties undertake to observe the following general conditions when agreed by the Buyer and the Seller.

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, SHALL BE WHOLLY INAPPLICABLE TO ANY SALE MADE HEREUNDER AND SHALL NOT BE BINDING IN ANY WAY ON THE SELLER.

**1.2** This agreement becomes valid and enforceable between the Contracting Parties after clear and non-equivocal consent by any duly authorized person representing the Buyer. For these purposes, the Buyer accepts these conditions of sales when signing the purchase order which mentions "I hereby accept Yole Développement's Terms and Conditions of Sale". This results in acceptance by the Buyer.

**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 or to the Buyer's address. In the absence of any confirmation in writing, orders shall be deemed to have been accepted.

## 2. MAILING OF THE PRODUCTS

**2.1** Products are sent by email to the Buyer:

- Within a few days from 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 in respect of article 2.1 above, and including in cases where a new event or access to new contradictory information would require for the analyst extra time to compute or compare the data in order to enable the Seller to deliver a high quality Products.

**2.3** The mailing of the Product will occur only upon payment by the Buyer, in accordance with the conditions contained in article 3.

**2.4** The mailing is operated through electronic means either by email via the sales department or automatically online via an email/password. If the Product's electronic delivery format is defective, the Seller undertakes to replace it at no charge to the Buyer provided that it 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 to 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 information to the Seller, even in case of delayed delivery. Any Product returned to the Seller without providing prior information to the Seller as required under article 2.5 shall remain at the Buyer's risk.

## 3. PRICE, INVOICING AND PAYMENT

**3.1** Prices are given in the orders corresponding to each Product sold on a unit basis or corresponding to annual subscriptions. They are expressed to be inclusive of all taxes (except for France where VAT will be added). The prices are re-evaluated from time to time. 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, credit card or by electronic transfer to the following account:

HSBC, 1 place de la Bourse 69002 Lyon France

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 ensure the payments, the Seller reserves the right to request down payments from the Buyer. In this case, the need of down payments will be mentioned on the order.

**3.4** Payment is due by the Buyer to the Seller within 30 days from invoice date, except in the case of a particular written agreement. If the Buyer fails to pay within this time and fails to contact the Seller, 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. Our publications (report, database, tool...) are delivered only after reception of the payment.

**3.5** In the event of termination of the contract, or of misconduct, during the contract, the Seller will have the right to invoice at the stage in progress, 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 choosing the Products and for the use and interpretations he makes of the documents it purchases, of the results he obtains, and of the advice and acts it deduces therefrom.

**4.2** The Seller shall only be liable for (i) direct and (ii) foreseeable pecuniary loss, caused by the Products or arising from a material breach of this agreement

**4.3** In no event shall the Seller be liable for:

- a) Damages of any kind, including without limitation, incidental or consequential damages (including, but not limited to, damages for loss of profits, business interruption and loss of programs or information) arising out of the use of or inability to use the Seller's website or the Products, or any information provided on the website, or in the Products;
- b) Any claim attributable to errors, omissions or other inaccuracies in the Product or interpretations thereof.

**4.4** All the information contained in the Products has been obtained from sources believed to be reliable. The Seller does not warrant the accuracy, completeness adequacy or reliability of such information, which cannot be guaranteed to be free from errors.

**4.5** All the Products that the Seller sells may, upon prior notice to the Buyer from time to time be modified by or substituted with similar Products meeting the needs of the Buyer. This modification shall not lead to the liability of the Seller, provided that the Seller ensures the substituted Product is similar to the Product initially ordered.

**4.6** In the case where, after inspection, it is acknowledged that the Products contain defects, the Seller undertakes to replace the defective products as far as the supplies allow and without indemnities or compensation of any kind for labour costs, delays, loss caused or any other reason. The replacement is guaranteed for a maximum of two months starting from the delivery date. Any replacement is excluded for any event as set out in article 5 below.

**4.7** The deadlines that the Seller is asked to state for the mailing of the Products are given for information only and are not guaranteed. If such deadlines are not met, it shall not lead to any damages or cancellation of the orders, except for non-acceptable delays exceeding [3] months from the stated deadline, without information from the Seller. In such case only, the Buyer shall be entitled to ask for a reimbursement of its first down payment to the exclusion of any further damages.

**4.8** The Seller does not make any warranties, express or implied, including, without limitation, those of sale ability and fitness for a particular purpose, with respect to the Products. Although the Seller shall take reasonable steps to screen Products for infection by viruses, worms, Trojan horses or other codes containing contaminating or destructive properties before making the Products available, the Seller cannot guarantee that any Product will be free from infection.

## 5. FORCE MAJEURE

The Seller shall not be liable for any delay in performance directly or indirectly caused by or resulting from acts of nature, fire, flood, accident, riot, war, government intervention, embargoes, strikes, labour difficulties, equipment failure, late deliveries by suppliers or other difficulties which are beyond the control, and not the fault of the Seller.

## 6. PROTECTION OF THE SELLER'S IPR

**6.1** All the IPR attached to the Products are and remain the property of the Seller and are protected under French and international copyright law and conventions.

**6.2** The Buyer agreed not to disclose, copy, reproduce, redistribute, resell or publish the Product, or any part of it to any other party other than employees of its company (only in the country of the primary user). The Buyer shall have the right to use the Products solely for its own internal information purposes. In particular, the Buyer shall therefore not use the Product for purposes such as:

- Information storage and retrieval systems;
- Recordings and re-transmittals over any network (including any local area network);
- Use in any timesharing, service bureau, bulletin board or similar arrangement or public display;
- Posting any Product to any other online service (including bulletin boards or the Internet);
- Licensing, leasing, selling, offering for sale or assigning the Product.

**6.3** If the Buyer would like to use data coming from the Products for presentations, press announcements and any other projects, the Buyer needs to contact Yole Développement's Public Relations Director ([info@yole.fr](mailto:info@yole.fr)) to get an official authorization and verify data are up to date. In return the Seller will make sure to provide up-to-date data under a suitable public format.

**6.4** The Buyer shall be solely responsible towards the Seller of all infringements of this obligation, whether this infringement comes from its employees or any person to whom the Buyer has sent the Products and shall personally take care of any related proceedings, and the Buyer shall bear related financial consequences in their entirety.

**6.5** The Buyer shall define within its company a contact point for the needs of the contract. This person will be the recipient of each new report. This person shall also be responsible for respect of the copyrights and will guaranty that the Products are not disseminated out of the company. In the context of Bundle and Annual Subscriptions, the contact person shall decide who within the Buyer, shall be entitled to receive the protected link that will allow the Buyer to access the Products.

**6.6** Please note that whether in Bundles or Annual Subscription, all unselected reports will be cancelled and lost after the 12 month validity period of the contract.

**6.7** As a matter of fact the investor of a company, external consultants, the joint venture done with a third party, and so on cannot access the report and should pay a full license price.

## 7. TERMINATION

**7.1** 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 borne by the Seller, following this decision.

**7.2** In the event of breach by one Party under these conditions or the order, the non-breaching Party may send a notification to the other by recorded delivery letter upon which, after a period of thirty (30) days without solving the problem, the non-breaching Party shall be entitled to terminate all the pending orders, without being liable for any compensation.

## 8. MISCELLANEOUS

All the provisions of these Terms and Conditions are for the benefit of the Seller itself, but also for its licensors, employees and agents. Each of them is entitled to assert and enforce those provisions against the Buyer.

Any notices under these Terms and Conditions shall be given in writing. They shall be effective upon receipt by the other Party.

The Seller may, from time to time, update these Terms and Conditions and the Buyer, is deemed to have accepted the latest version of these terms and conditions, provided they have been communicated to him in due time.

## 9. GOVERNING LAW AND JURISDICTION

**9.1** Any dispute arising out or linked to these Terms and Conditions or to any contract/orders entered into in application of these Terms and Conditions shall be settled by the French Commercial Courts of Lyon, which shall have exclusive jurisdiction upon such issues.

**9.2** French law shall govern the relation between the Buyer and the Seller, in accordance with these Terms and Conditions.