TEKTRONIX INNOVATION FORUM 2021

Engineering the Future

From Technologies to Markets

Market & Technology trends in Power Electronics

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Custom projects business developer

Yole Développement

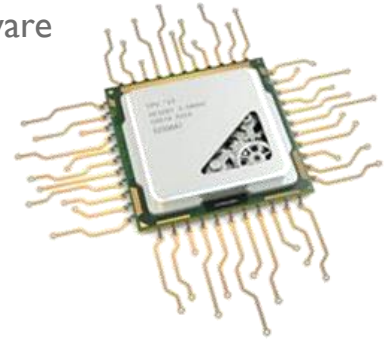
FIELDS OF EXPERTISE COVERING THE SEMICONDUCTOR INDUSTRY

Photonics & Sensing

- Photonics
- Lighting
- Imaging
- Sensing & Actuating
- Display

Semiconductor, Memory & Computing

- Semiconductor Packaging and Substrates
- Semiconductor Manufacturing
- Memory
- Computing and Software

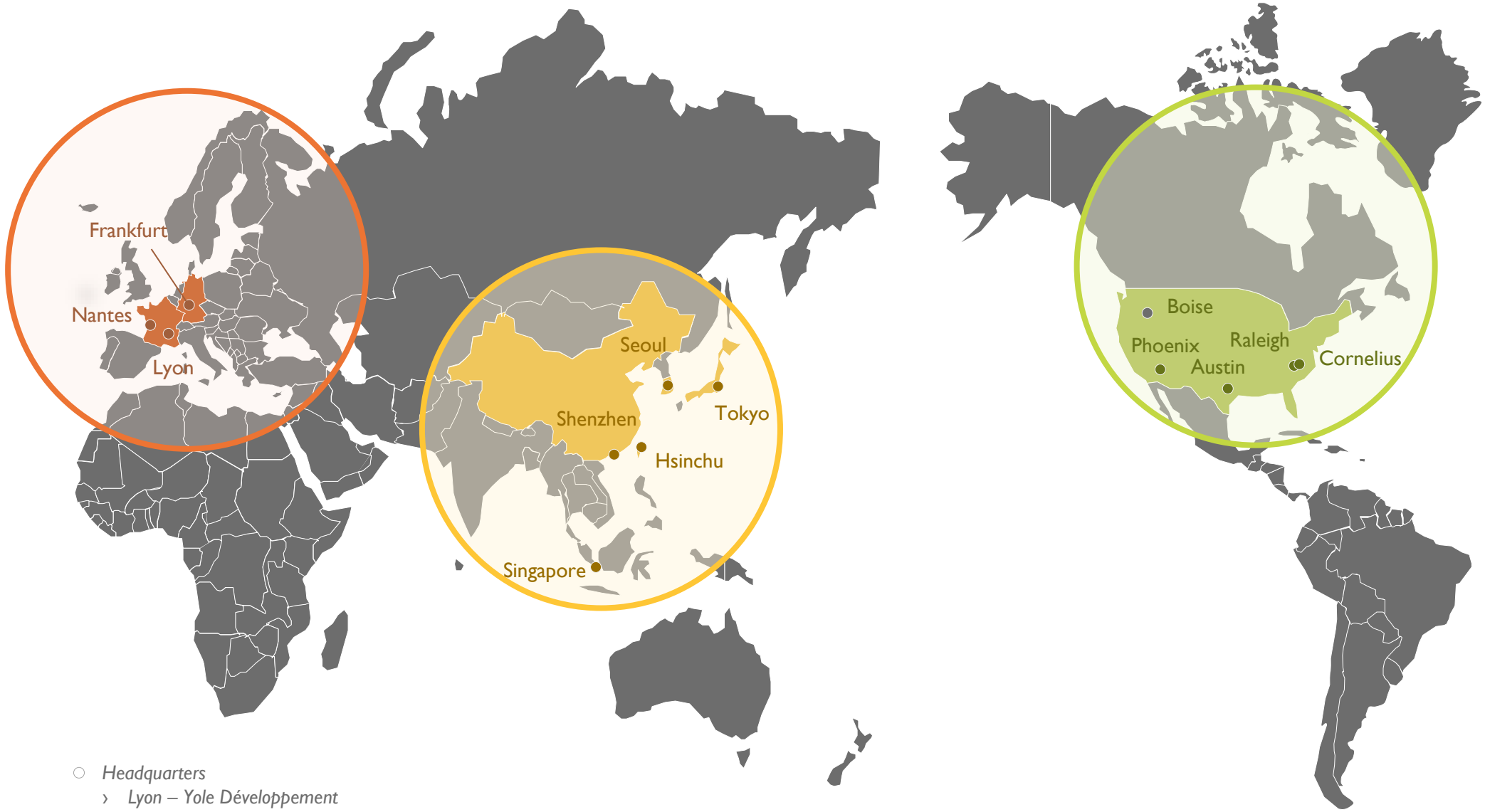


Power & Wireless

- RF Devices & Technologies
- Compound Semiconductors & Substrates Materials
- Power Electronics
- Batteries & Energy Management

A WORLDWIDE PRESENCE

100+ collaborators in 8 different countries



- *Headquarters*
  - *Lyon – Yole Développement*
  - *Nantes – System Plus Consulting*

A COMPLETE SET OF PRODUCTS & SERVICES TO ANSWER YOUR NEEDS

YEARLY REPORTS

Insight
- Yearly reports
- Market, technology and strategy analysis
- Supply chain changes analysis
- Reverse costing and reverse engineering

Format
- PDF files with analyses
- Excel files with graphics and data

Topics
- Photonics, Imaging & Sensing
- Lighting & Displays
- Power Electronics & Battery
- Compound Semiconductors
- Semiconductor Manufacturing and Packaging
- Computing & Memory

115+ reports per year

QUARTERLY MONITORS

Insight
- Quarterly updated market data and technology trends in units, value and wafer
- Direct access to the analyst

Format
- Excel files with data
- PDF files with analyses graphs and key facts
- Web access (to be available soon)

Topics
- Advanced Packaging
- Application Processor
- DRAM
- NAND
- Compound Semiconductor
- CMOS Image Sensors
- Smartphones

7 different monitors quarterly updated

WEEKLY TRACKS

Insight
- Teardowns of phones, smart home, wearables and automotive modules and systems
- Bill-of-Materials
- Block diagrams

Format
- Web access
- PDF and Excel files
- High-resolution photos

Topics
- Consumer: Smartphones, smart home, wearables
- Automotive: Infotainment, ADAS, Telematics

175+ teardowns per year

CUSTOM SERVICE

Insight
- Specific and dedicated projects
- Strategic, financial, technical, supply chain, market and other semiconductor-related fields
- Reverse costing and reverse engineering

Format
- PDF files with analyses
- Excel files with graphics and data

Topics
- Photonics, Imaging & Sensing
- Lighting & Displays
- Power Electronics & Battery
- Compound Semiconductors
- Semiconductor Manufacturing and Packaging
- Computing & Memory

190 custom projects per year

Global market drivers

POWER ELECTRONIC APPLICATIONS – MAIN DRIVERS

Changing world…

Population growth

Megacities

CO_2 emissions

Limited resources

…adapting products

- Energy generation ↑
- Energy consumption ↓
- Air Pollution ↓
- CO_2 ↓

DRIVING APPLICATIONS - HISTORICAL PERSPECTIVE

1970 … 2000 2010 2020 2030

Time

Today, the automotive segment, especially EVs/HEVs, drives both technological development and market demand.

Industrial applications

Renewables

Photovoltaic inverters, wind converters

We should not forget about **other applications** which represent **significant demand and have some specific requirements**

Strong synergies with other segments

Automotive incl. EVs/HEVs

EV/HEV inverter, boost converter, DC-DC converter, 48V converter, on-board charger, etc.

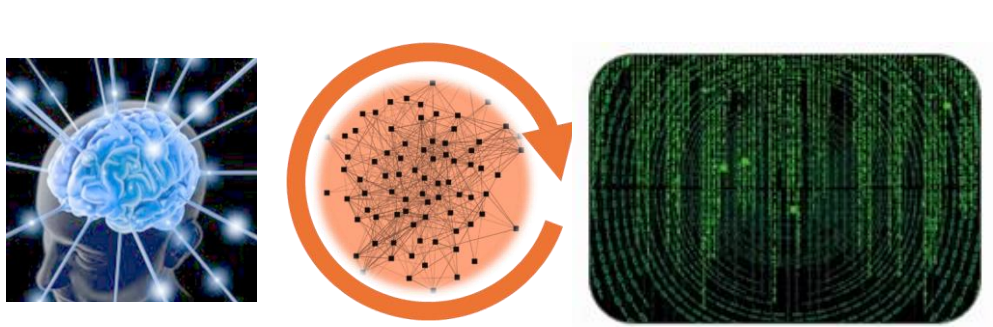
Renewable energy, stationary battery energy storage, charging infrastructure etc.

MEGATRENDS IN POWER ELECTRONICS

Power electronics devices, systems and applications are getting stronger, greener, smarter and more connected and integrated.

Efficiency

Green - clean, renewable and high power conversion efficiency

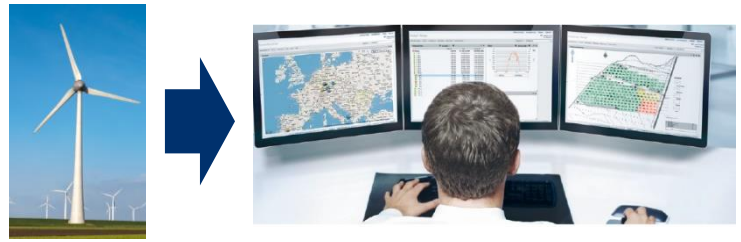


Smart and interconnected

Power generation → Energy solutions for smart buildings and cities

Battery-powered cordless end-system 'batteryfication'

Increasing system power and power semiconductor content per system

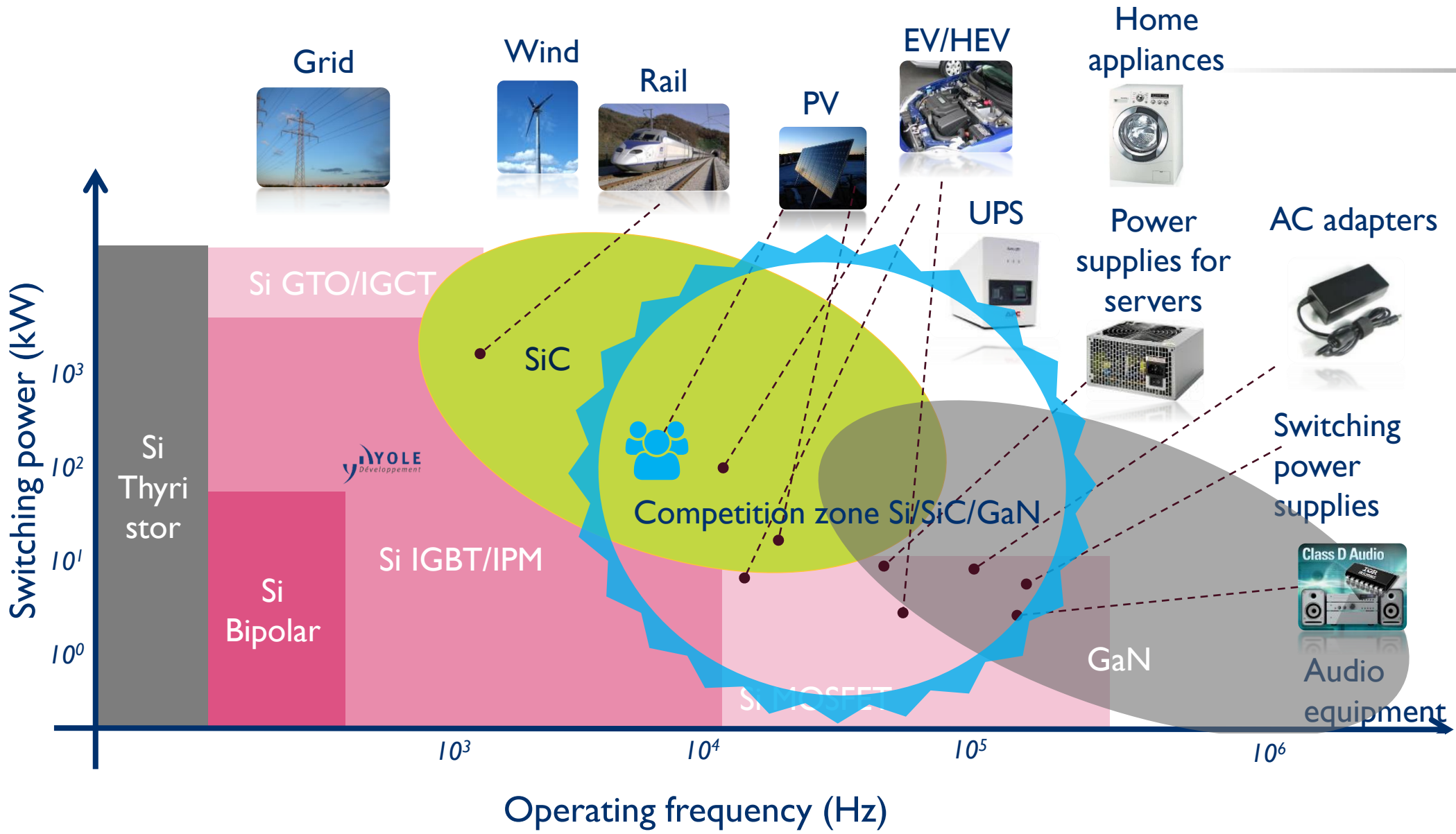


Product → Service

Market Forecast

The power electronics market: main trends and dynamics in an increasingly

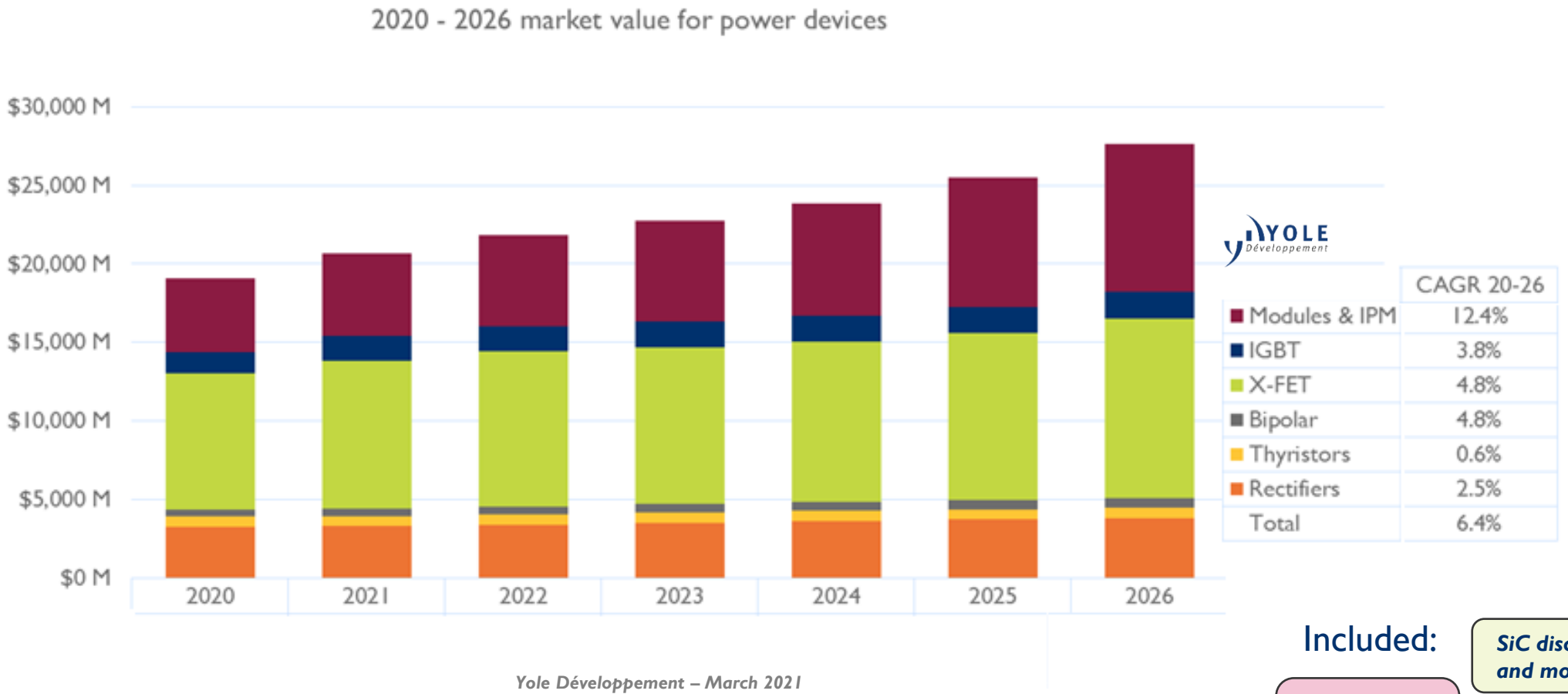
POWER DEVICE POSITIONING AS FUNCTION OF POWER & FREQUENCY



POWER DEVICE MARKET

2020-2026, split by device type

The whole power device market reached $19.2B in 2020 and is expected to be around $27.6B in 2026.



Yole Développement – March 2021

Included:

- ***SiC discretes and modules***
- ***Silicon discretes and modules***
- ***GaN***

*Module: IGBT, MOSFET, and bipolar devices that are sold as modules. Not including rectifiers in the specific category.

POWER MODULE MARKET TRENDS

- EV/HEV is the main driving application for power modules.
- The power module market for other applications is still the largest portion of power module

$4.9B

Power module market

$9.1B

EV/HEV

$CAGR_{20-26}$: 20.8%

Industrial
Renewable
Consumer

$CAGR_{20-26}$: 6.7%

2020 2026 Time

DEVICE REVENUE MARKET SHARE IN $M: SIC VS. GAN VS. SILICON

Silicon is and will remain the mainstream semiconductor technology in power electronics

As of 2021, Si still dominates the Power Electronic market. By 2026, we expect SiC device revenue to represent more than 16% of the market, with GaN device revenue comprising more than 4.2% of the market.

- *Silicon devices include: Rectifiers, thyristors, bipolar, X-FETs such as MOSFETs and JFETs, IGBTs, and modules and IPMs.*

SUMMARY OF DEVICES BY APPLICATION

Voltage summary, split by device and application

Trend

SiC today

GaN today, only a few $M

	Voltage required	Wind	PV	Rail	Motor drive	UPS	BESS	EV/HEV and automotive auxiliaries	Networking and telecom	Consumer	White goods	Medical	Computing and storage
IGBT	250V-900V												
	1.2kV-1.7kV												
	>3.3kV												
MOSFET	<40V												
	60V-100V												
	150V-400V												
	>500V												

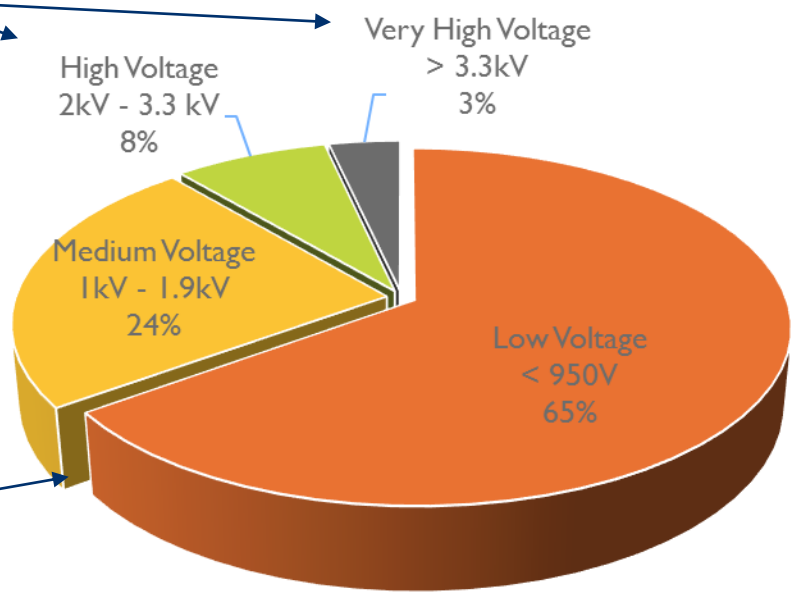
- *For the time being, GaN has only entered in high-end applications, except for in consumer applications*
- *SiC 3.3kV is still in development*

POWER DEVICES

Split by voltage level in 2020

The fact that consumer increased (low voltage) but also computing & servers (mid-voltage) and renewables (mid-high voltage) makes the chart look the same as in 2019

2020 market for power devices in power electronics; split by voltage range



Includes amongst others:
- Rail
- Renewables
- HVDC

Includes amongst others:
- EV/HEVs
- EV chargers
- PV inverters

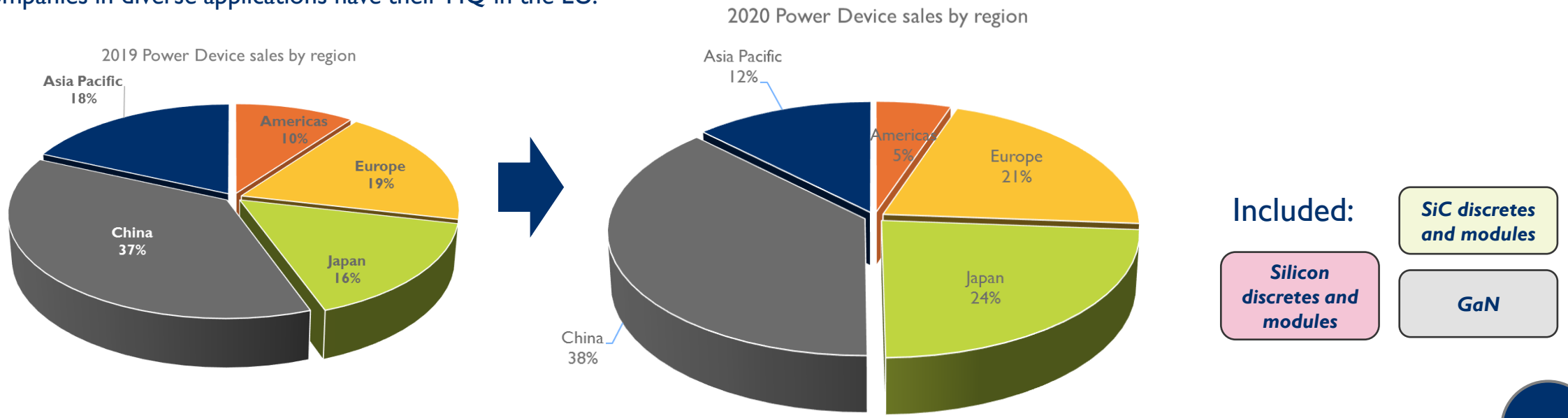
Includes 650V – 750V devices used i:
- EV/HEV (with 200V-400V batteries in electrified vehicles)
- Automotive
- Consumer electronics

Total power device market was $19 billion in 2020

POWER DEVICE MARKET

Sales - geographic split

- In 2020, the sales worldwide have been heavily affected by COVID. Some regions have been in lockdown longer times and the divers end markets are affected in a different way. China, Japan and Europe had an increase in system manufacturing, Asia Pacific and Americas decreased their volumes.
- Asia, comprised of China, Asia-Pacific, and Japan, accounts for 74% of the worldwide power device market.
  - China plays a very important role in power device integration, with about 38% of power device sales, with a big portion of IGBT and bipolar devices. Even if China is still by far the main integrator of power electronic assemblies, Japan has increased their sales from 16% to 24% as from 2019.
  - Asia-Pacific accounts for 12% of the market, and we believe in the potential of this Asian market to increase in the coming years, due to the increase in foundries implementing power devices in the region, as well as companies like Hyundai or Honda that push for EVs.
- Europe maintains a strong power electronics production industry, with about 21% of worldwide power electronics sales, as many leading companies in diverse applications have their HQ in the EU.



Included:

- ***SiC discretes and modules***
- ***Silicon discretes and modules***
- ***GaN***

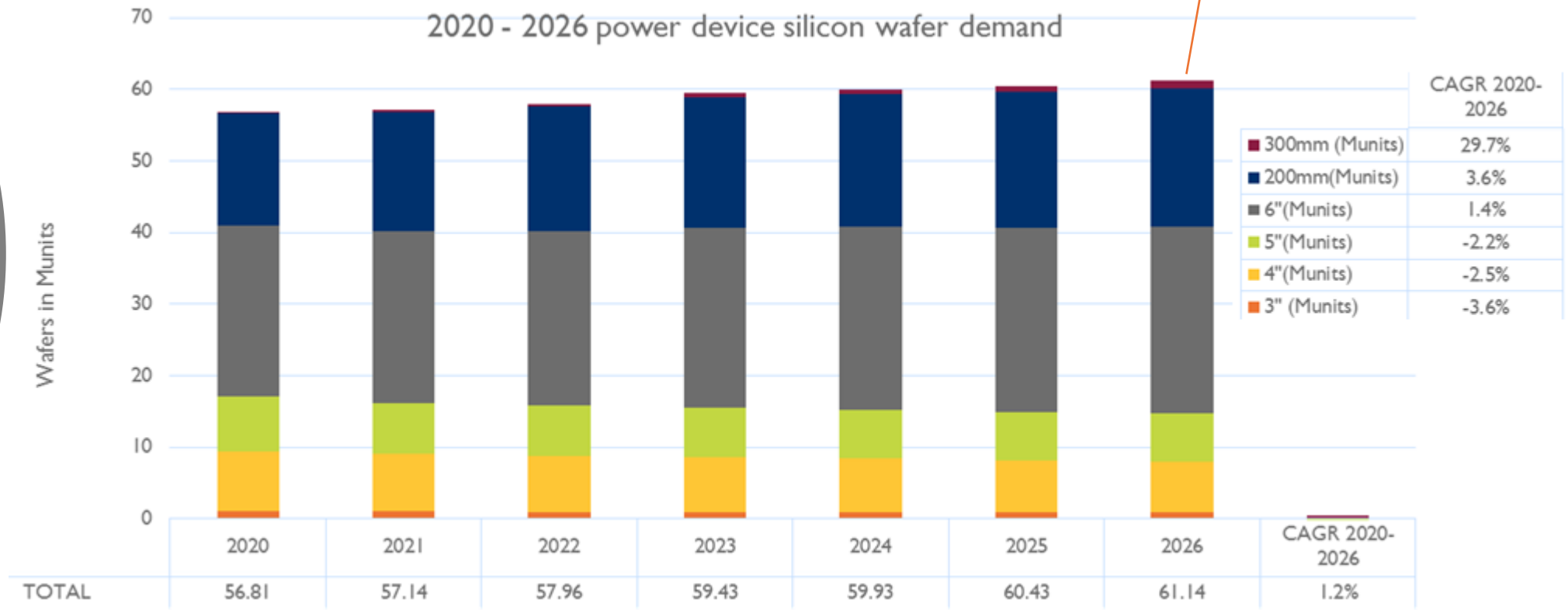
2020 – 2026 OVERALL POWER ELECTRONICS SILICON WAFER DEMAND

In wafer million units; split by wafer diameter

High and growing demand on power electronic devices drives the transition towards larger wafer diameters (200mm and 300 mm).

However, there are companies such as Hitachi, ABB, Toshiba or Fuji that continue their MOSFET and/or IGBT production at 6inch.

300mm wafers will represent 2% of the market in Munits (6% MS in revenue) by 2026

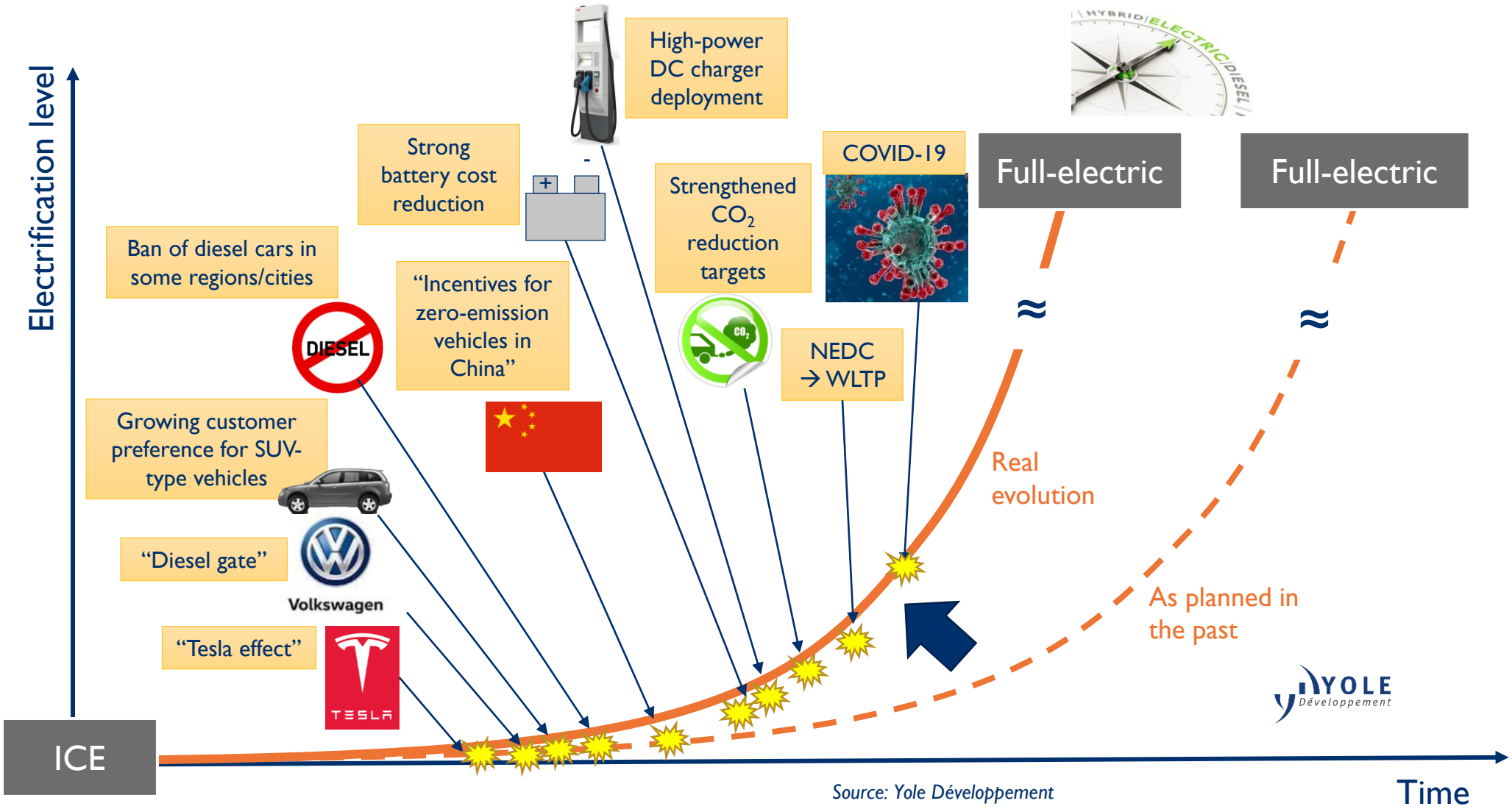


	2020	2021	2022	2023	2024	2025	2026	CAGR 2020-2026
TOTAL	56.81	57.14	57.96	59.43	59.93	60.43	61.14	1.2%

Focus on EV/HEV

FOCUS ON EV/HEV

Where does the acceleration of vehicle electrification come from?



NEDC: New European Driving Cycle
WLTP: Worldwide Harmonized Light Duty Vehicles Test Procedure

EV/HEV POWER ELECTRONICS CONTENT

What power devices do each xEV type use?

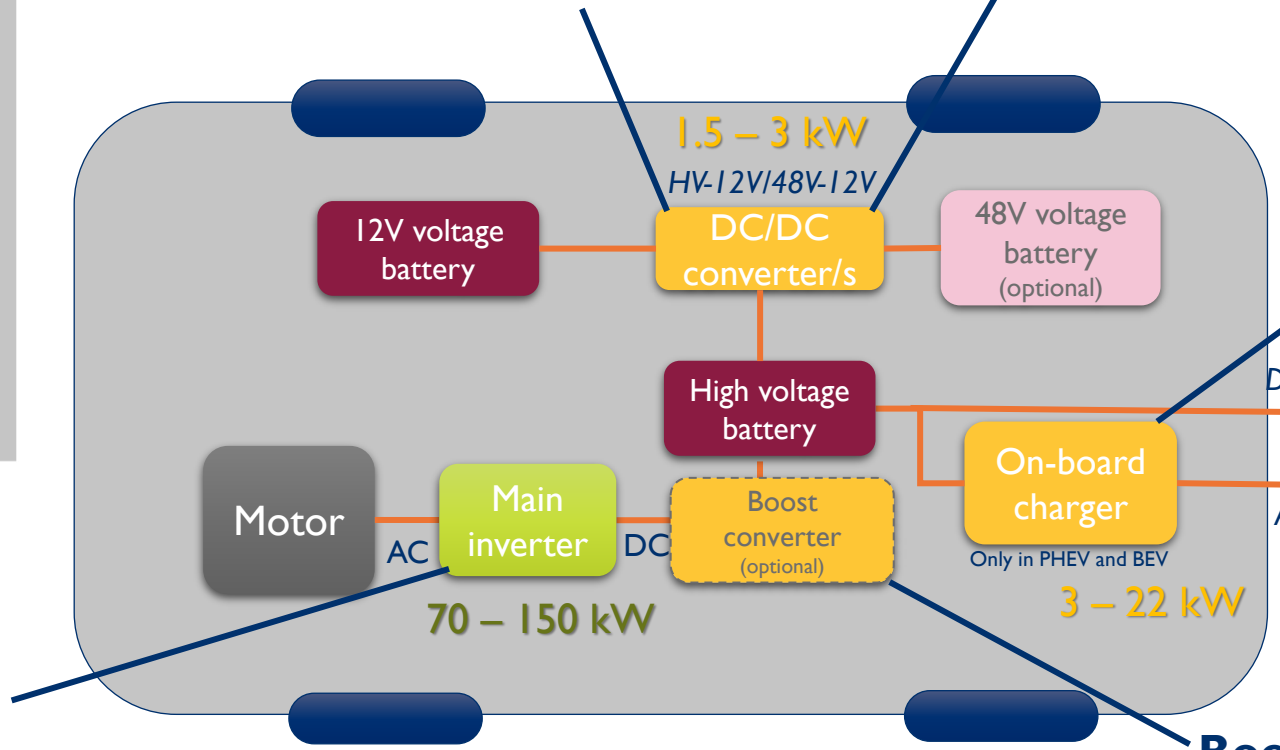
Vehicle type	On-board charger	Main inverter	Boost converter	DC-DC converter
ICE	-	-	-	-
MHEV	-	LV MOSFET or GaN HEMT 5 - 20 kW Av: 15 kW	-	LV MOSFET or GaN HEMT 1.5 - 4 kW Av: 2 kW ---- HV MOSFET or GaN HEMT or SiC MOSFET 1.5 - 5 kW Av: 3 kW
HEV	-	IGBT module or SiC MOSFET 40 - 120 kW Av: 70 kW	IGBT 30 - 100 kW Av: 50 kW	
PHEV	IGBT or SiC MOSFET or HV MOSFET or GaN HEMT 3.3, 7, 22,43 kW possible Av: 10 kW		IGBT 30 - 100 kW Av: 50 kW	
BEV		IGBT module or SiC MOSFET 60 - 600 kW Av: 70-150 kW		
FCEV		IGBT module or SiC MOSFET 40 - 120 kW Av: 70 kW	IGBT 30 - 100 kW Av: 50 kW	

48-12V DC/DC

We can find basically 80-100V discrete devices

HV-12V DC/DC

We can find basically 500-650V and 80-100V discrete devices



OBC

We can find basically 600-650V discrete devices

Main inverter

The power level will be different depending on electrification type and manufacturer choice. We can find both discrete or modules, 600 or 1200V.

Boost converter

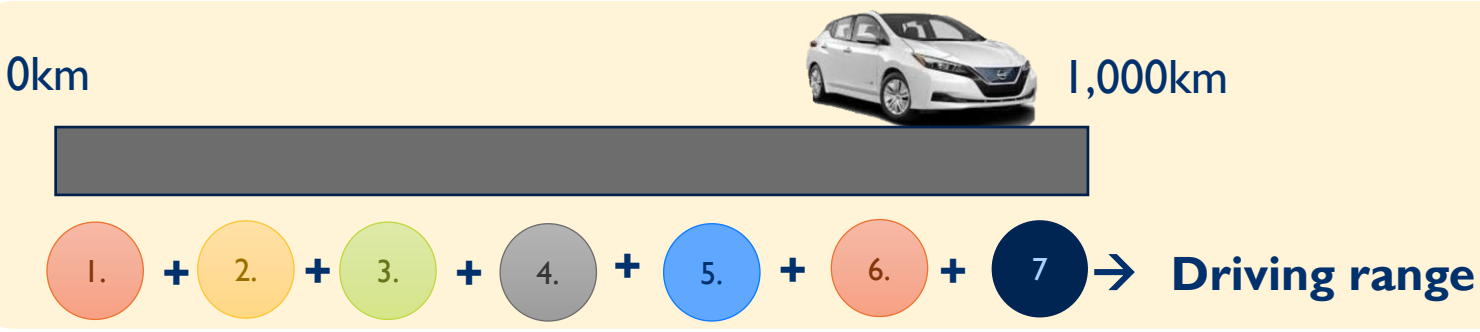
We can find basically 600V IGBT discrete or modules

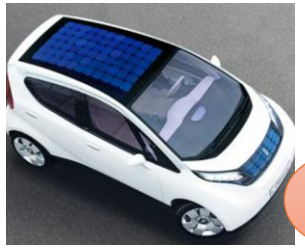
**Simplified view*

DRIVING RANGE EXTENSION

Following the comparison from the previous page…

The real picture is much more complex…





1d.

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3b. Other converters

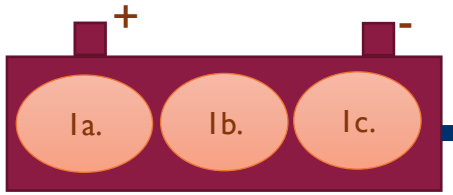
5. Loads

Auxiliary loads (HVAC, ADAS, lighting, entertainment…)

7 Autonomous driving

6a.

Tire rolling resistance



2.

3a. DC / AC

Traction inverter

4. AC motor +gearbox

6b.

More cells → larger battery capacity (kWh)

Enhanced cell technology / design

Enhanced cell-to-pack assembly

Additional electricity source: PV roof, TEG…

Higher circuitry voltage (such as with 800 V battery)

Enhanced inverter topology

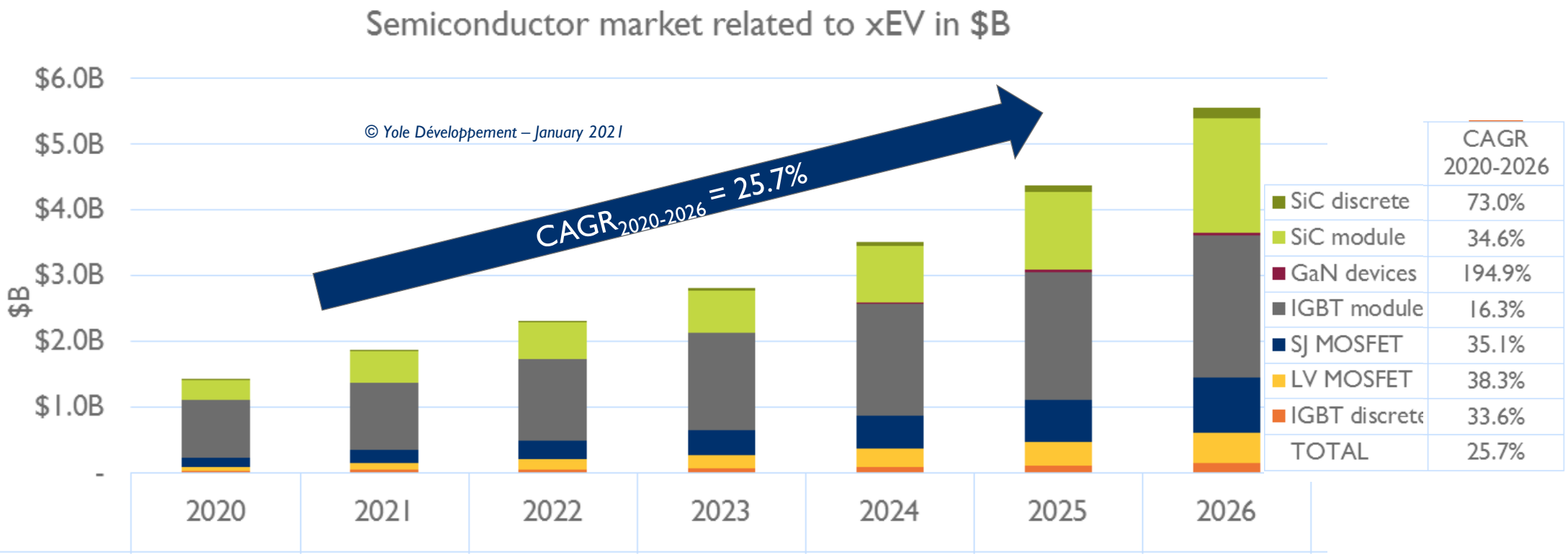
Use of SiC / GaN instead or silicon

High-efficiency and lightweight AC motor

Car rolling resistance aerodynamic drag

2020 – 2026 SEMICONDUCTOR POWER DEVICE MARKET FOR xEV

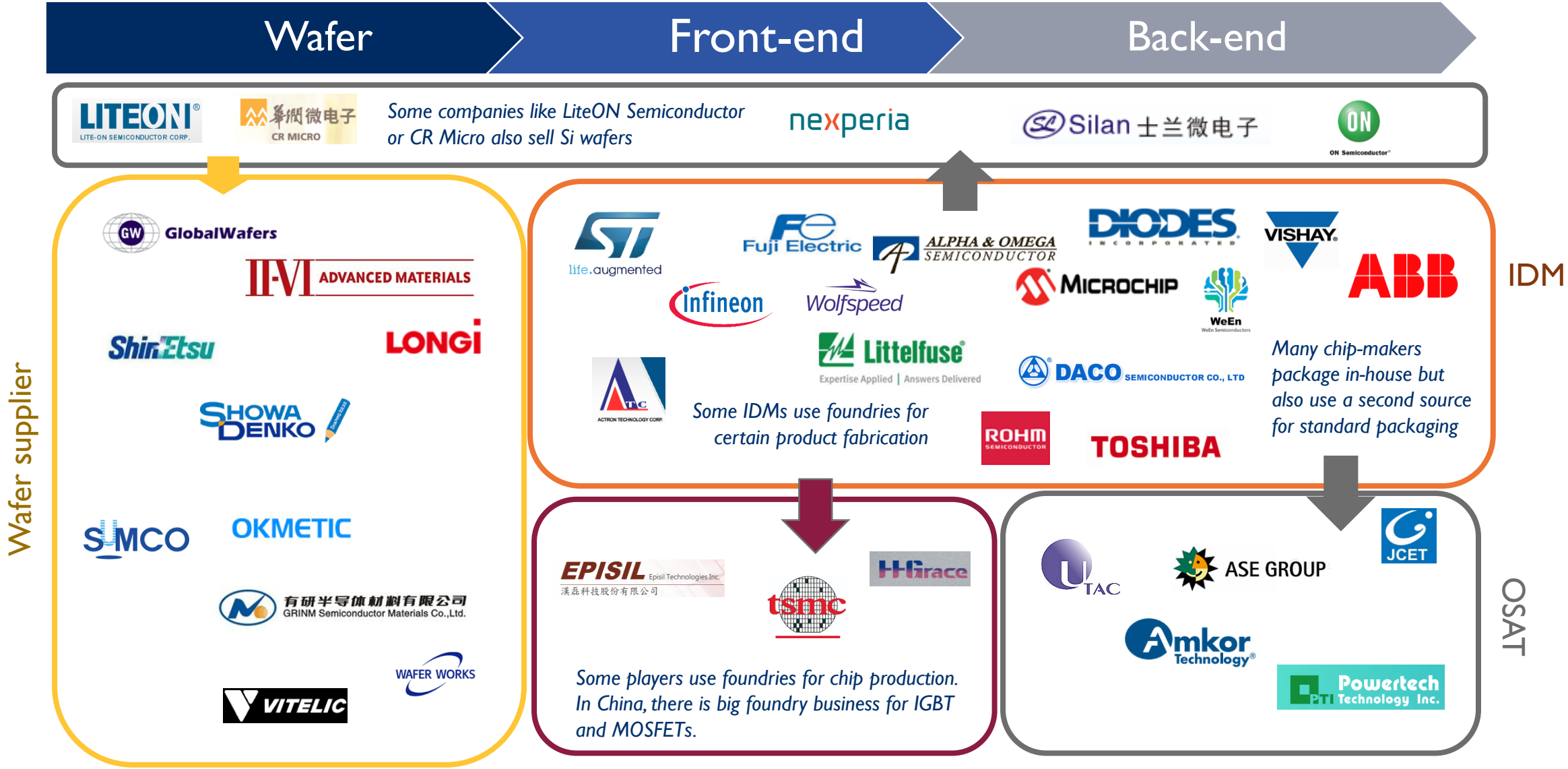
The market for power semiconductor devices in xEV will be around $5.6B in 2026.



Supply chain

COMPONENT SUPPLY CHAIN

Varied offers exist in the supply chain for larger market capture



POWER ELECTRONICS SUPPLY CHAIN DEVELOPMENT

maxim integrated
ANALOG DEVICES
infineon
HITACHI
DIODES INCORPORATED
LITEON LITE-ON SEMICONDUCTOR CORP.
Danfoss

By acquisitions

Conventional power electronics players

Small but strong portfolio
Limited customers
On-demand products

Sometimes the investment in money and in time is lower through inorganic growth than organic growth.

Big power electronics players

- *Big portfolio*
- *Diversification*
- *Consolidated customers*
- *Many markets*
- *Enlarges supply value-chain*

Mergers and acquisitions are ongoing and more are expected to come!

Investments are vital to keep a leading position.

By diversification

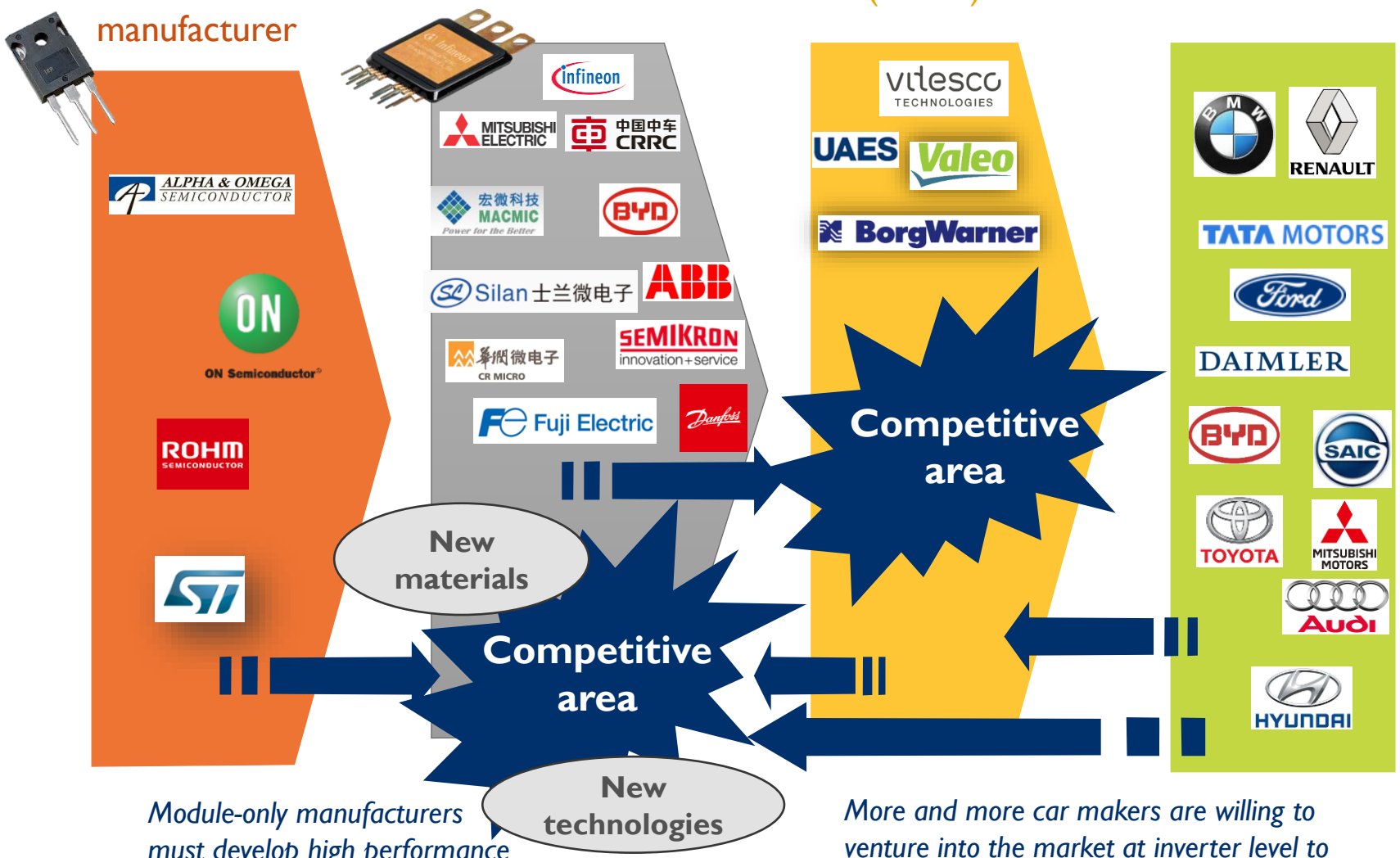
Internal development of new technology and/or penetration in new applications.

GaN
EV/HEV
Wind
PV
SiC
Higher power

EV/HEV SUPPLY CHAIN RESHAPING

Focus on EV

The rapidly growing power electronics device market is attracting the interest of different players in the power electronics supply chain, especially within the EV/HEV supply chain.



Module-only manufacturers must develop high performance products to stay competitive.

More and more car makers are willing to venture into the market at inverter level to differentiate themselves from competitors.

Takeaway and Outlook

TAKE AWAY

- The power electronics market is in good health, increasing y-o-y, driven by industrialization, increase of efficiency and clean environmental goals from worldwide governments. Moreover, there are new applications that are pushed from the need of other applications, like Charging infrastructure or Energy storage systems that reinforce the power electronics market.
- Discrete:
  - We still see developments in Silicon SJ MOSFET and IGBTs…silicon is not dead!
  - GaN is gaining momentum, driven by fast chargers for smartphones
- Module:
  - The IGBT power module market will continue to increase pushed by CO2 targets and efficiency increase, with a big market growth for EV/HEV power modules.
    - Main players are developing power module packaging for EV
  - SiC market keeps growing thanks to its penetration to EV power modules.
    - Main OEMs looking actively for SiC modules
- The transition toward 300mm remains a major trend in power electronics wafers as some of the major players invest in 300mm manufacturing facilities for power devices. There is still 200mm development (Ex. Fuji, BYD…)
- In 2020, there has been an impact on device production and sales due to COVID-19 lockdowns. However, the different applications were impacted in a different way and the overall device power market had only a small impact.

YOLE GROUP OF COMPANIES RELATED ANALYSES

Yole Développement

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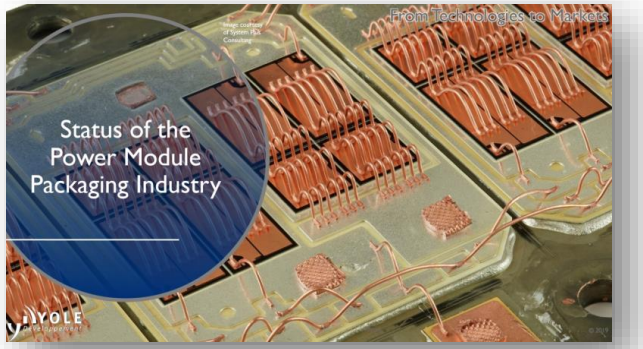

CONTACT INFORMATION

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