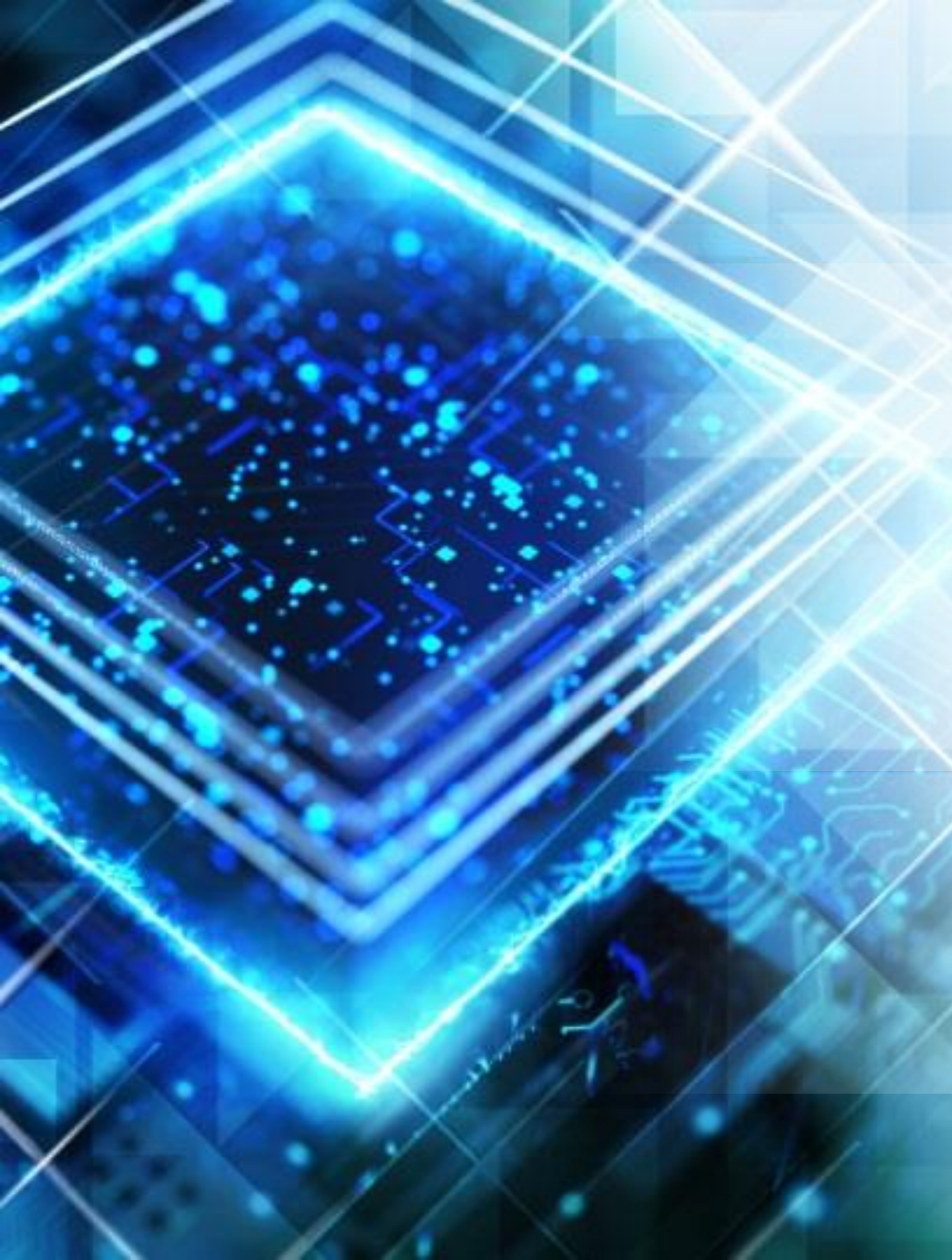


Emerging Power Electronics Packaging and System Integration for Automotive Applications

Mahadevan (Devan) Iyer l VP, Power Products

3D PEIM February 1-3, 2023

Amkor by the Numbers

Founded in **1968**

$6.1B Net Sales*

30,000 Employees

$780M CapEx*

11,000,000 Square Feet of Manufacturing Space

Footprint in **11** countries

End Markets

Automotive

Communications

Industrial

Computing

Consumer

*2021 results

Amkor Automotive by the Numbers

#1 **OSAT** for Automotive

0 **defect** quality focus

40 **different** package families

11 Automotive **production locations**

40+ **years engaged** in Automotive

~$1B net **sales**

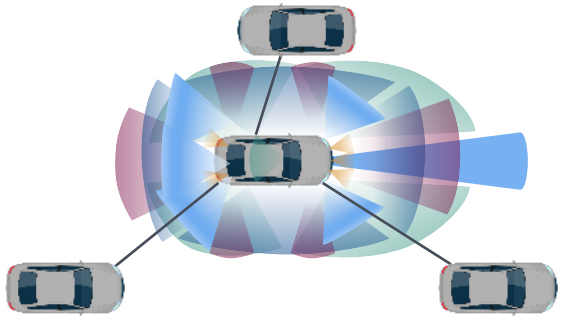
Agenda

1. Introduction – System Integration Applications & Market Trends
2. Automotive Power Electronic System Integration
3. Power Discrete Packages Trends and Needs
4. Power Modules for EV Systems
5. Summary

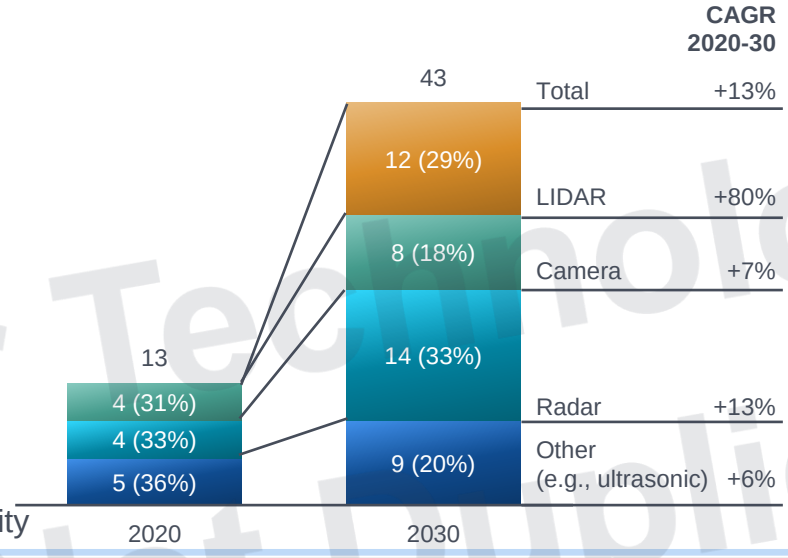
Introduction – System Integration Applications & Market Trends

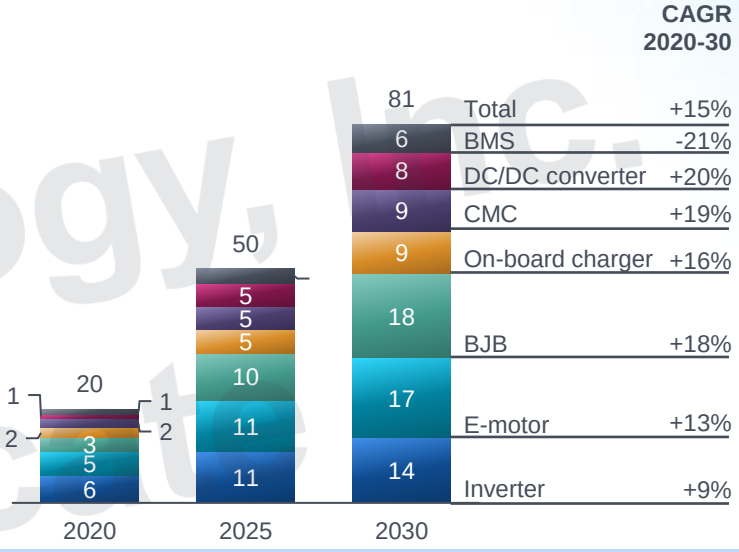
System Integration Applications & Market Trends

Applications in Automotive

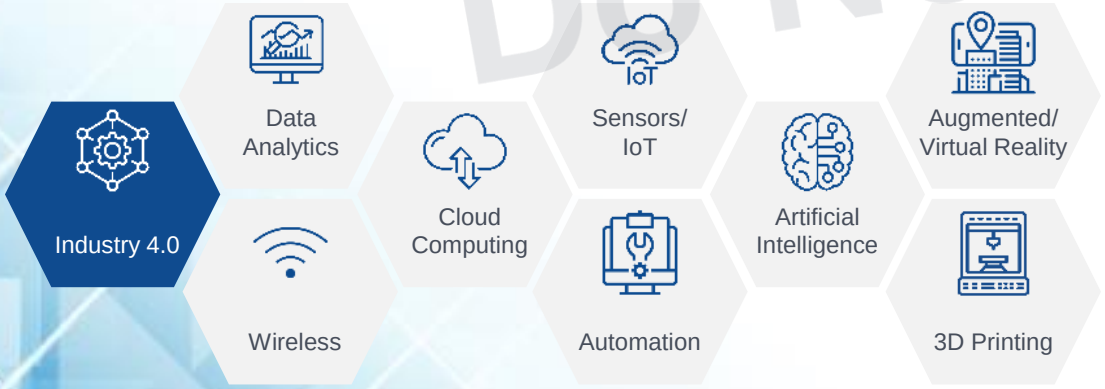


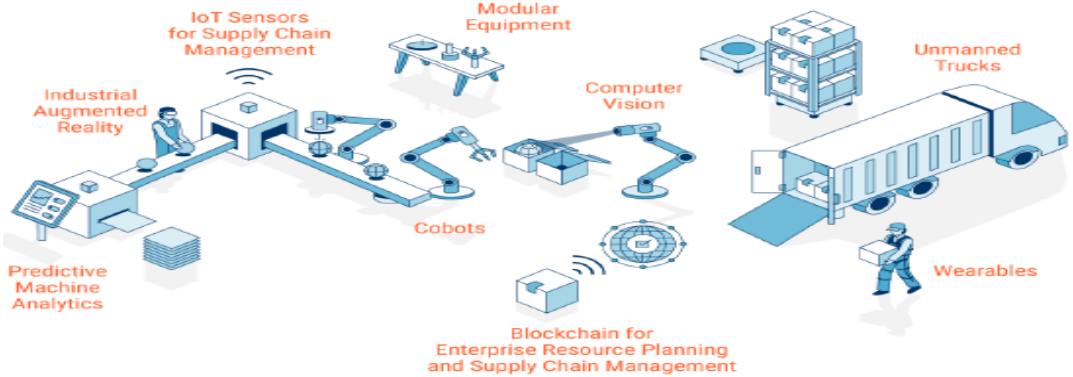
- Connectivity & communications – ECO mobility
- Processors, ADAS, Autonomous driving sensors
- Electric drive train – power electronics
- Integration, electrical & thermal management and reliability





Applications in industrial automation





Source : McKinsey Analysis Reports

System Integration Applications & Market Trends

Applications in biomedical devices & instrumentation

3.7M Medical devices in use today connecting to & monitoring various parts of the body

Active implantable medical devices control stimulation and/or precision medicine therapy to treat disease and prove patient quality of life

Monitors medical conditions specific to patient's disease & other systemic conditions such as heart rate, blood sugar, exercise, etc.

One IOMT system solution collecting data from medical devices, medications & biometrics to modify therapeutic window towards best care option

Closed-loop System

"Smart" software supports device iteration based on data inputs to deliver best patient therapy

97% Wi-Fi adoption rates in hospitals

10% Medical devices enabled with Wi-Fi

Hospitals and home care

- Intelligent analysis of symptoms
- Personalized care
- Virtual hospitals and health centers

Digitization

- Health solutions, wireless, IoT, 5G technology, virtualization, sensors, data analysis, wearable technology, data-based decision making, robotics

Prevention of disease

- Identification of risks
- Genomic information
- Early diagnosis of disease

Individual responsibility

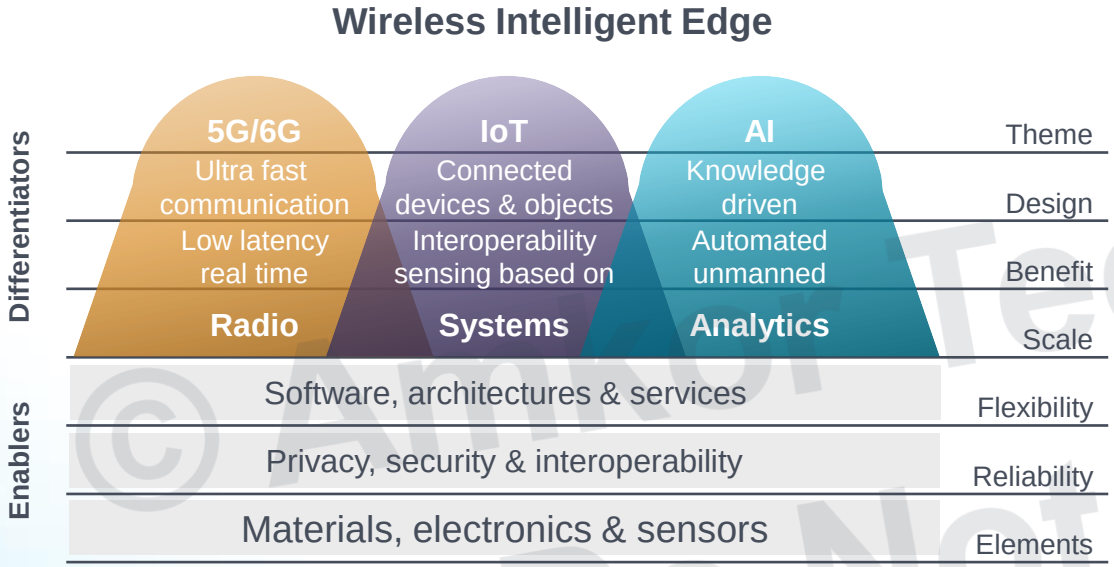
- My data
- Self measurements
- Self diagnosis
- Monitoring
- Remote communication

Source: McKinsey Analysis March 2020

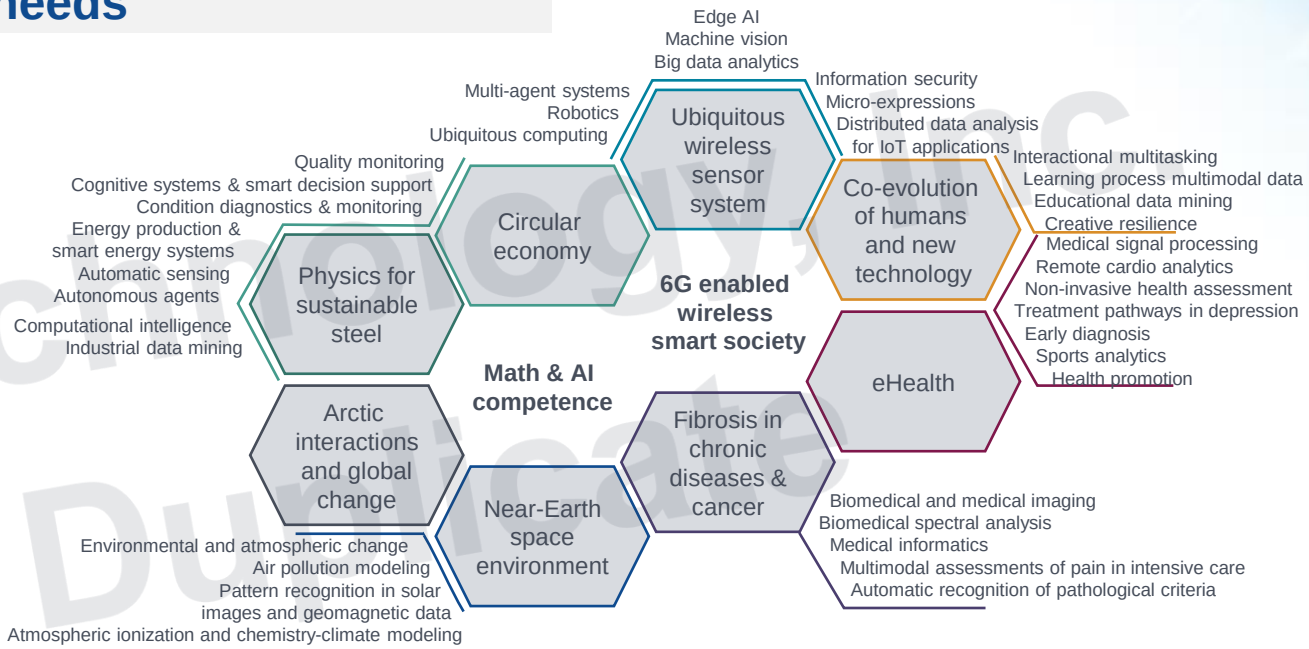
Source: IEEE 6G Summit 2019

System Integration Applications

R&D needs



Source: Juha Ala-Mursula, IEEE 6G Summit 2019



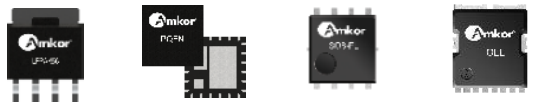
Source: IEEE 6G Summit 2019

Research driven by system advancements & integration needs

Smart health: Wireless sensing, THz radios, edge analytics, machine learning
Personal experiences: Sensing system, renewable energy, machine vision, cybersecurity
Automated vehicles: Multi-sensing, advanced power system integration, AI, THz radio
Automated factories: Sensors, design automation, AI hardware/process automation
Computing systems: Digital AI cores, analog AI cores with optimized materials, algorithms dev + hardware, heterogenous integration

Automotive Power Electronic System Integration

Power Electronics Integration in Automotive: EV Adding New Power Packaging & Modules Technologies



DC-DC Converter

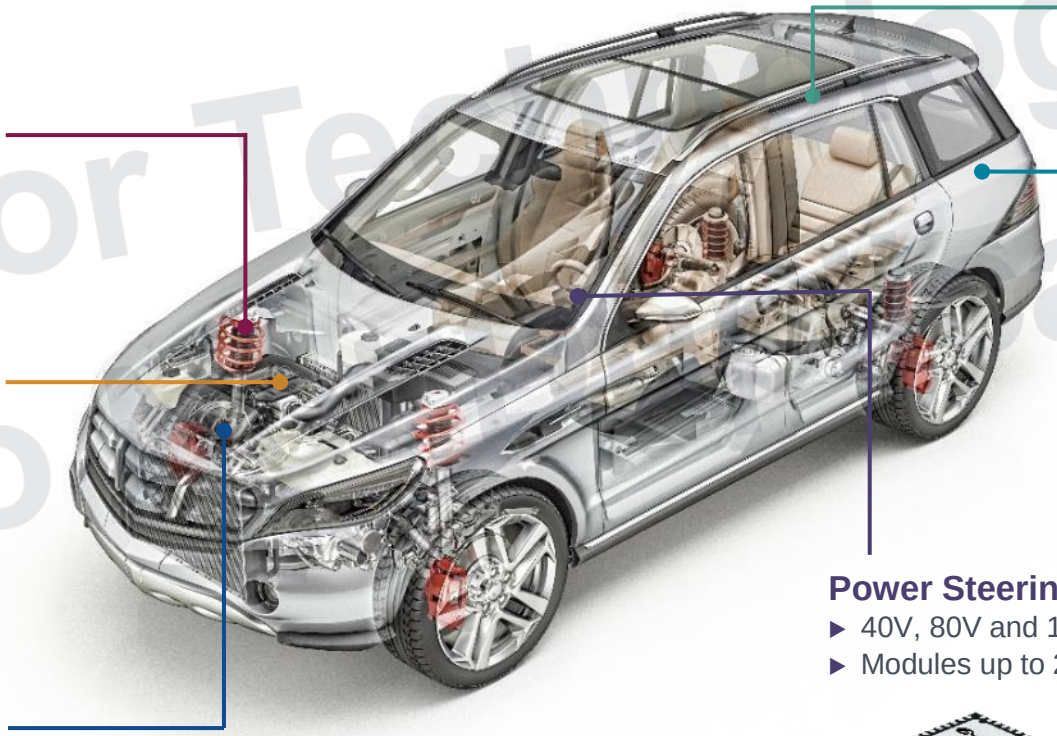
- 650V/1200V Si/SiC MOSFETs
- 80V/100V Si MOSFETs in ½ bridge
- 40V Si MOSFETs

Auxiliary Inverter

- 650V SJ MOSFETs
- 650V Si/SiC rectifiers/MOSFETs
- 650V Si IGBTs
- 650V GaN HEMTs

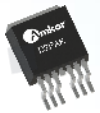
Main Inverter

- 650V/1200V Si rectifiers
- 1200V SiC rectifiers/FETs
- 650V/1200V Si IGBTs



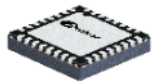
On-board Charger

- 650V SJ MOSFETs
- 650V Si/SiC rectifiers/MOSFETs
- 650V Si IGBTs
- 650V GaN HEMTs



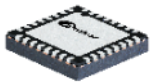
Battery Management

- 40V low R_{DS}(on) Si MOSFETs



Power Steering

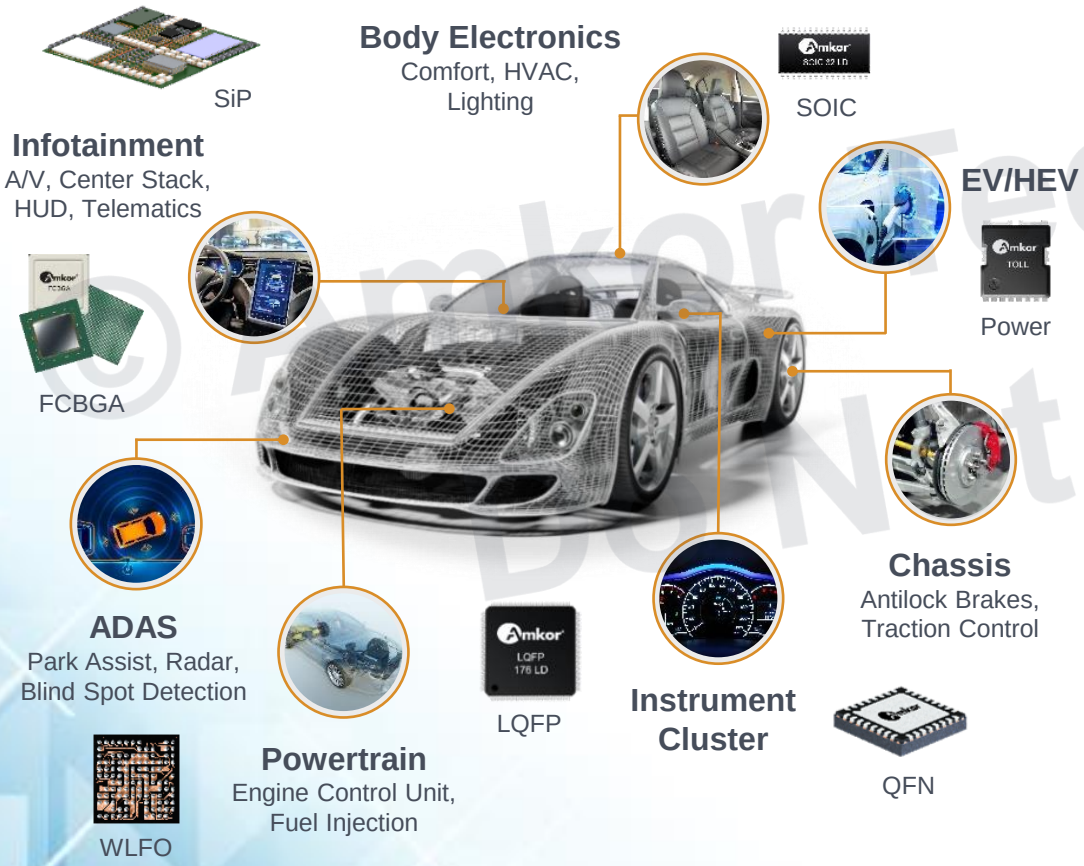
- 40V, 80V and 100V discrete Si MOSFETs
- Modules up to 200-250A current rating



Automotive Packaging

Advanced Packages

Wirebond Packages



Accelerated Adoption of Advanced Packaging

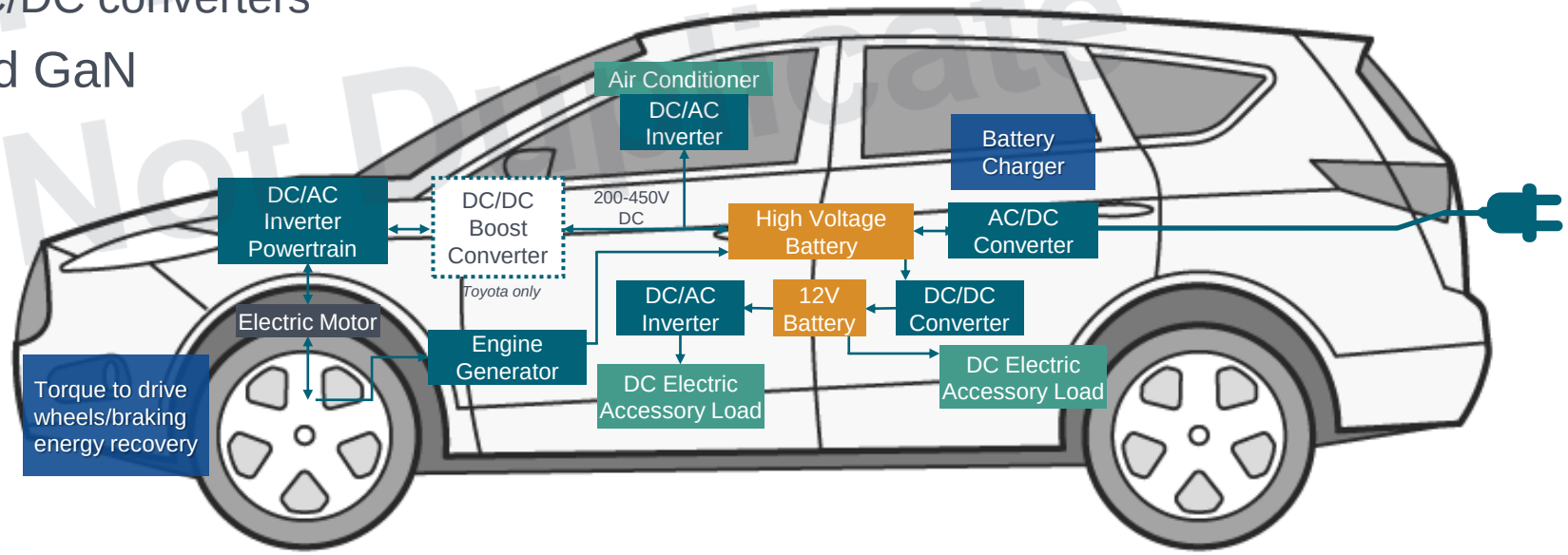
Analog	Sensors	MCU, GPU	RF/mmWave Transceivers	Processor + Memory
Power	Overmolded	LQFP	fcCSP	SiP
Dual LF	Exposed Die	CABGA		
MLF®	Cavity	FCBGA	WLFO	
	Optical Sensor			

Source: Amkor

Powertrain for EV

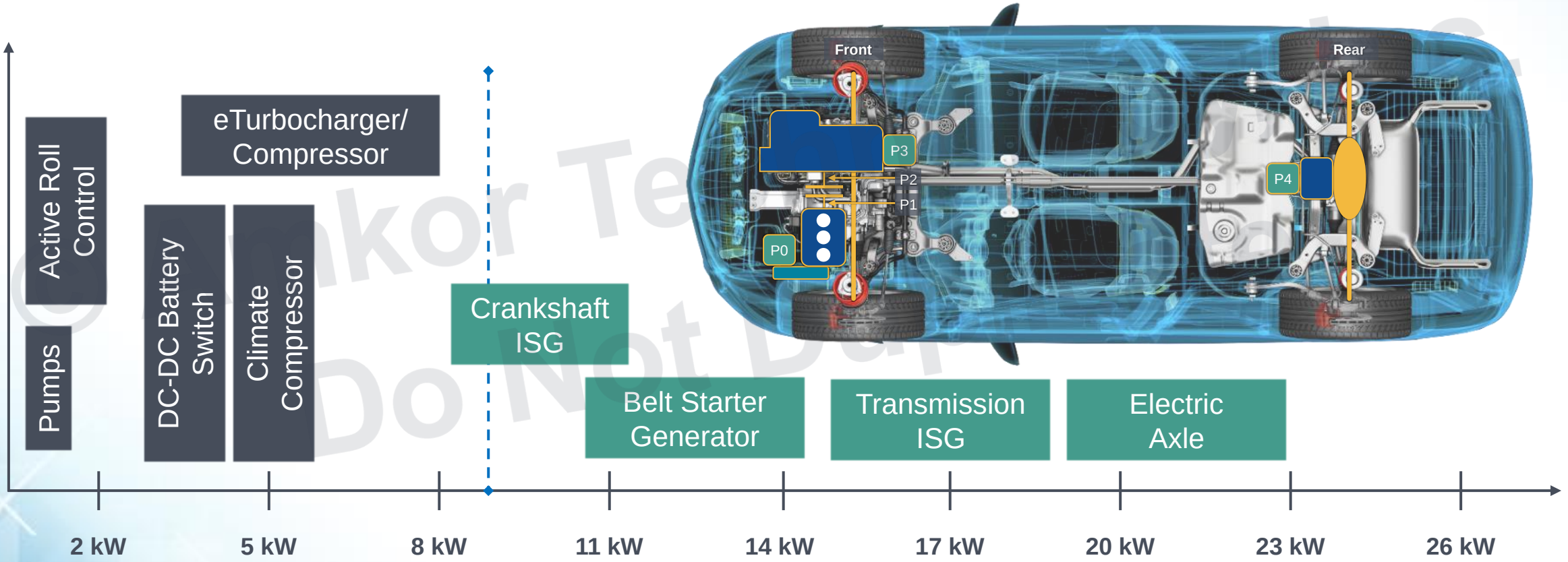
- Core of the powertrain
  - Creates power for CV and EV to efficiently transmit power
  - The powertrain of an electric vehicle consists of a motor that generates power, power electronics that control electric characteristics and a battery pack that stores electric energy
- Converters and inverters in EV/HEV
  - High power DC/AC inverters
  - Low/Mid power DC/DC and AC/DC converters
- High opportunities with SiC and GaN

Power Device Positioning Within an EV/HV

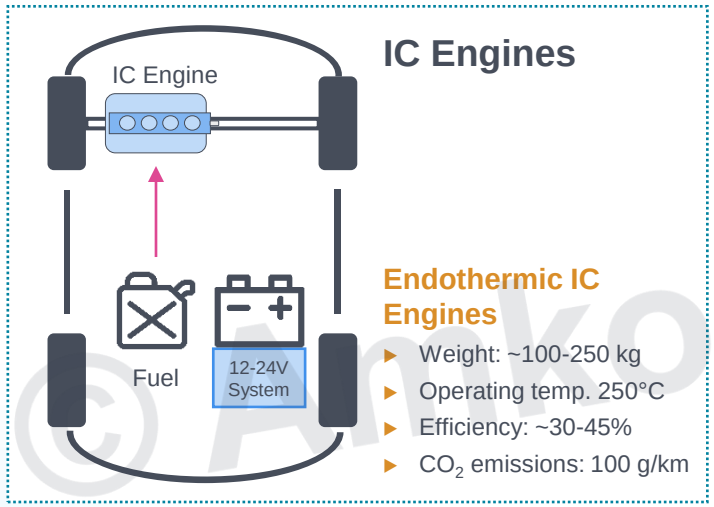


Source: Yole Power Division Reports, Yole Développement

Automotive 48V Systems: Powertrain Configurations



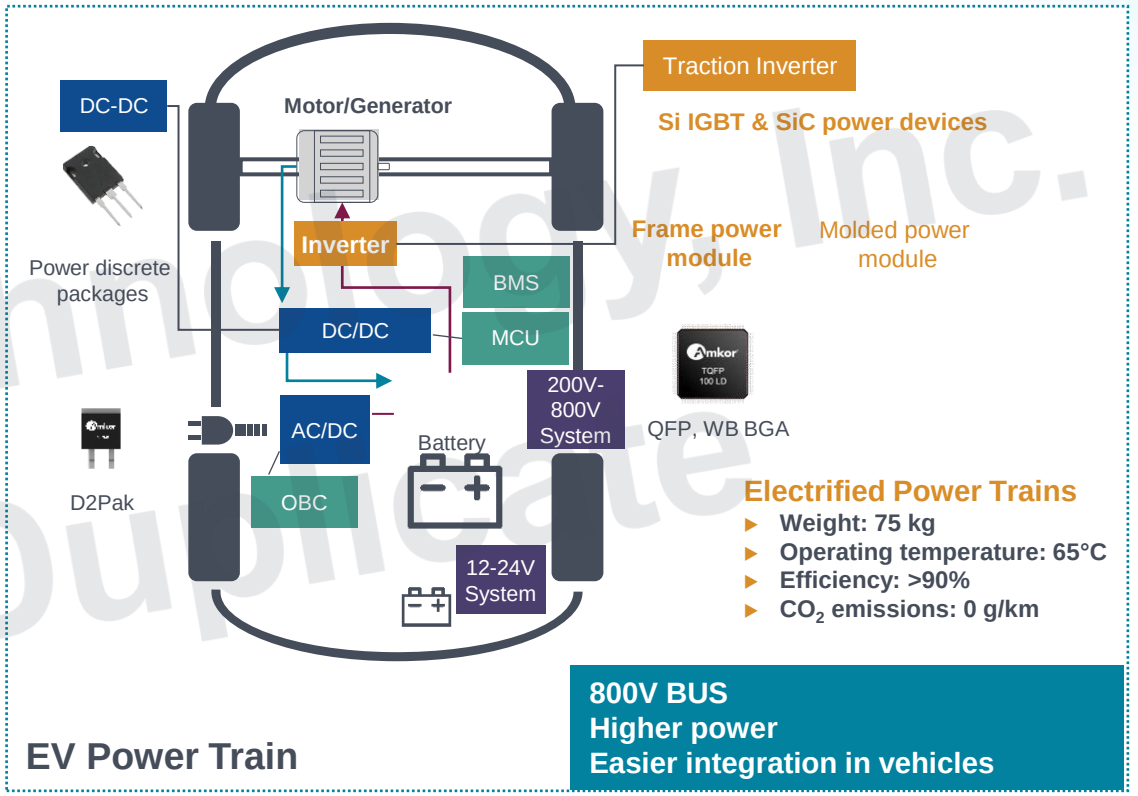
Applications of EV Power Train



IC Engines

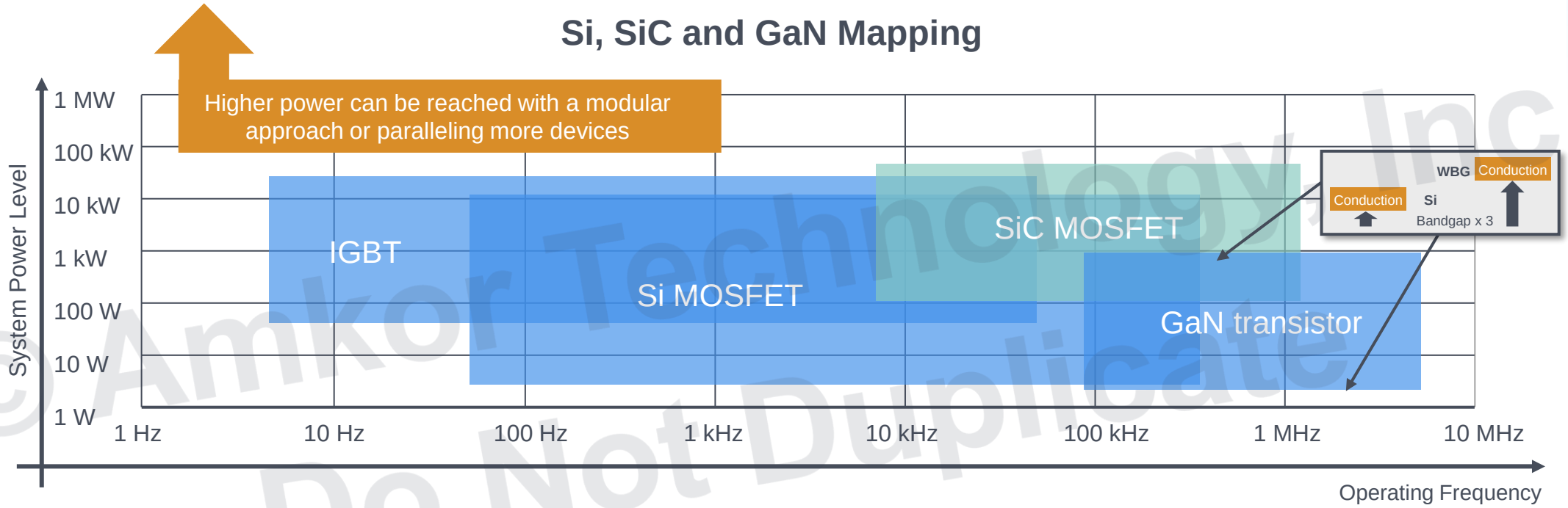
Endothermic IC Engines

- Weight: ~100-250 kg
- Operating temp. 250°C
- Efficiency: ~30-45%
- CO_2 emissions: 100 g/km



- Increasing demand for advanced leadframe packages
- Proliferation of power discrete packages
- High voltage power modules for traction inverters

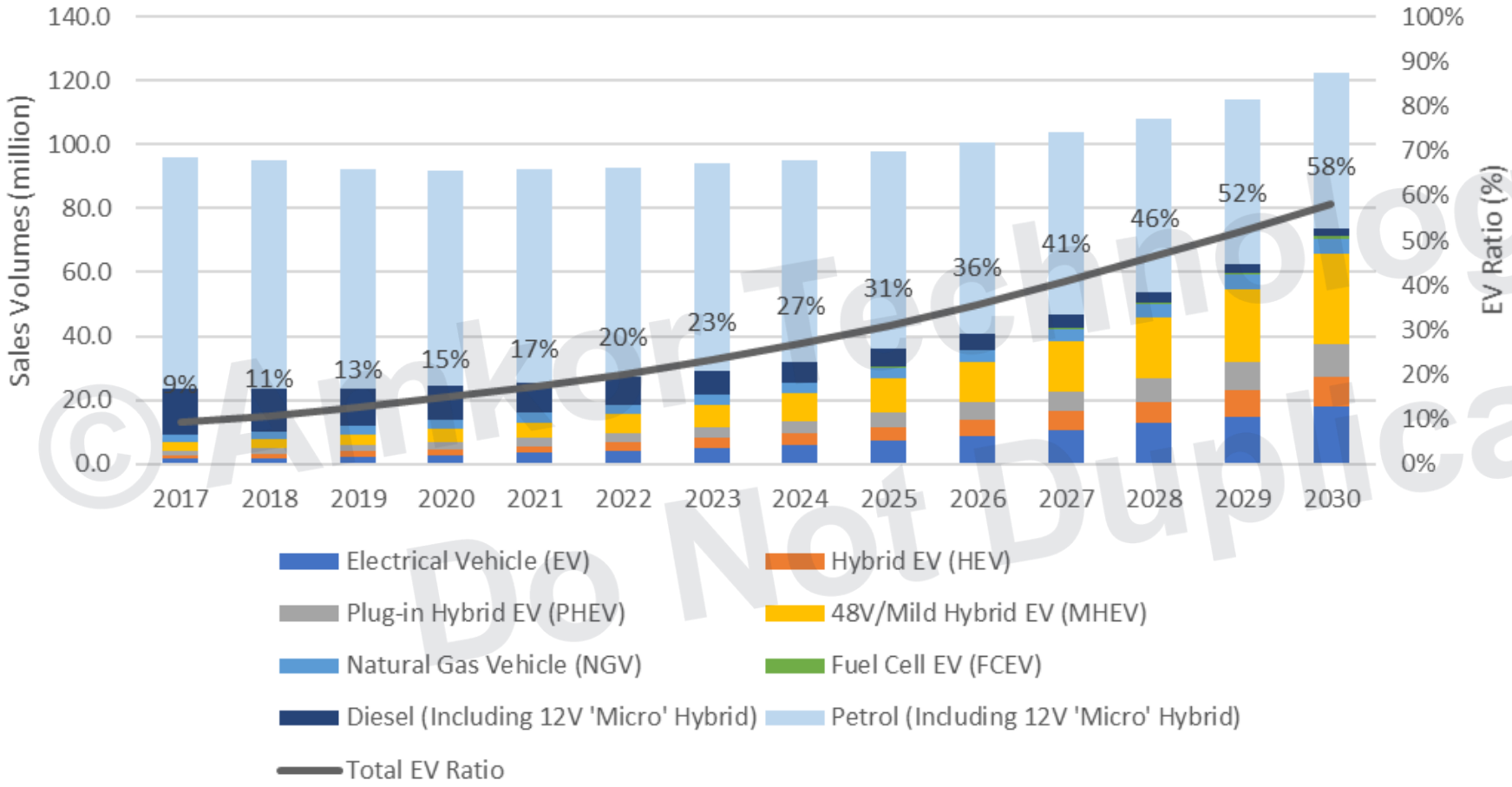
Wide Bandgap (WBG) Device Advantages



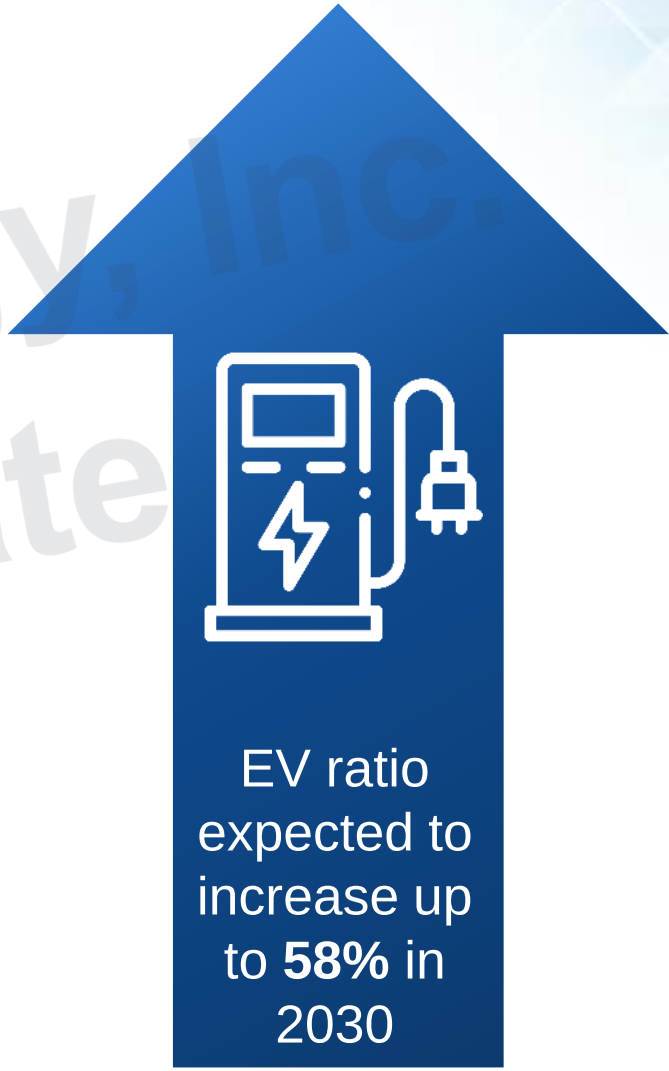
- Bandgap of a semiconductor is the minimum energy required to excite an electron from its bound state to a free state where it can participate in conduction. Wider bandgap better for the device performance, conductivity, efficiency, etc.
- SiC & GaN have ~3x the bandgap
- The higher the traction inverter system power and motor switching operating frequencies, the better the performance

Source: STMicroelectronics May 2022

Global Automotive Powertrain Forecast

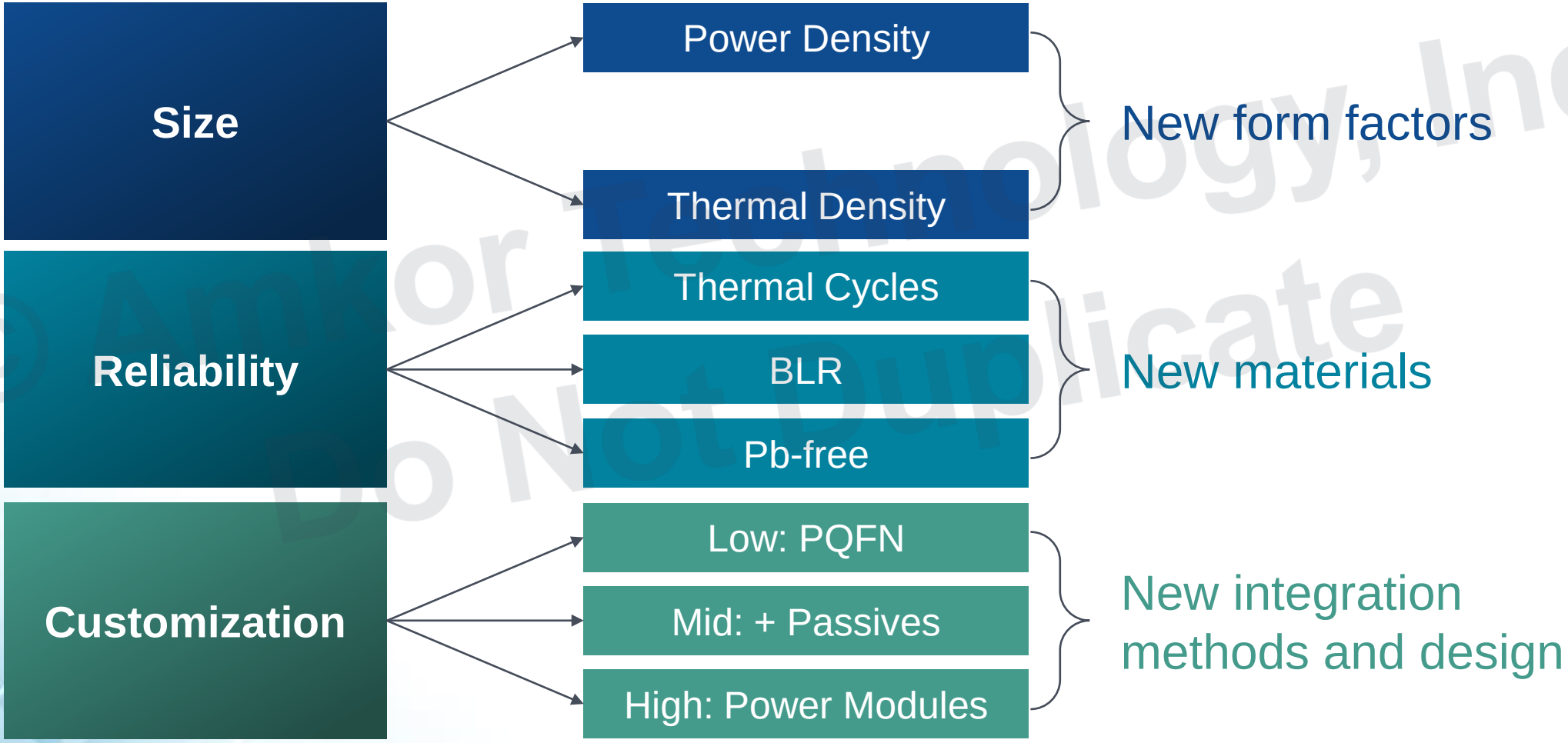


Source: Automotive from Ultima Media 2019-20



Power Discrete Packages Trends & Needs

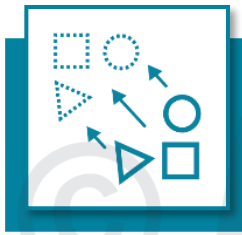
Power Packaging Challenges



Power Packaging Drivers

Performance

High current, high voltage, low loss/noise
Thermal capacity, low R_{DS}(on), AEC Grade



Integration

High voltage, high power modules, multi-voltage, multi tech FETs (Si FETs, Si IGBTs, GaN, SiC), stacked die, thicker wire, clip, FC solutions

Cost

Wide strip, sintering Cu

Reliability

AEC-Q100/101, zero delamination, BLT control, BLR

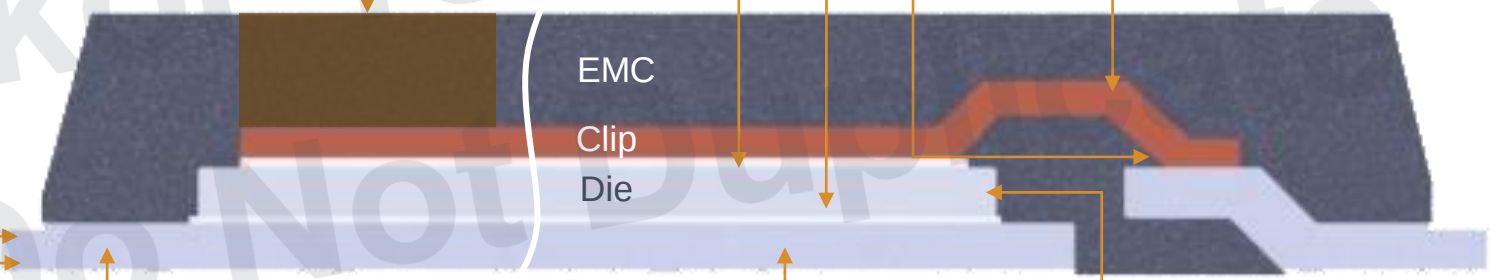
Power Packaging: Technology Drivers

Dual-side cooling

Pb-free
- Ag sintered material

Interconnection
- Cu clip
- Thick Cu wire
- Al wedge bonding

QFN (small form fit, downsize)
- PQFN
- Power module



Delamination free

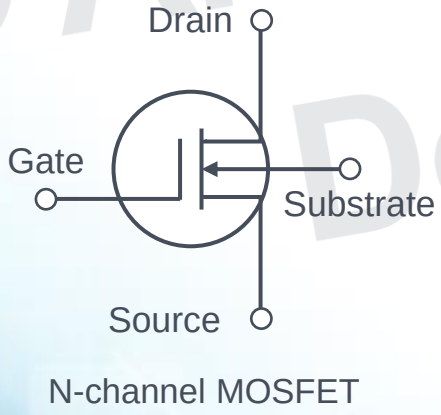
Thinner die process
- 50 µm available

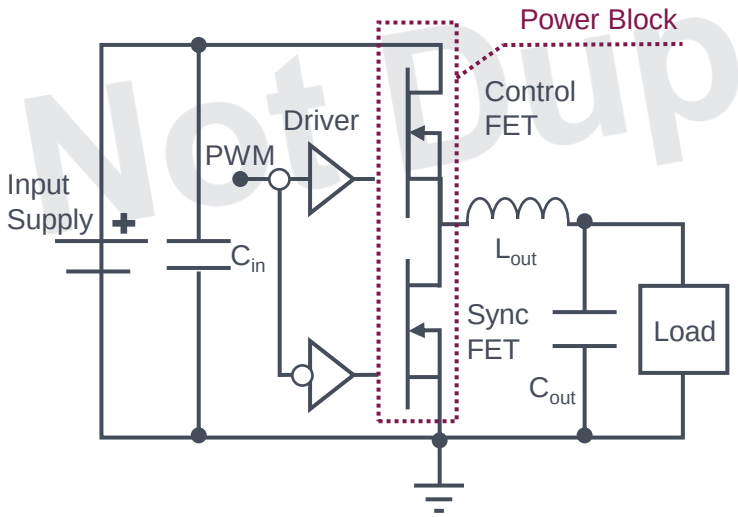
Solder wettability inspection (AOI)
- Wettable flank structure

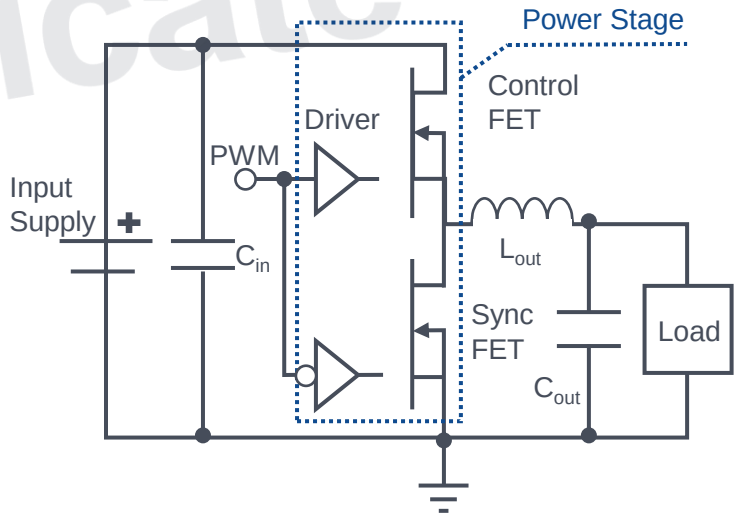
Thicker leadframe
- 8 mil, 10 mil and 20 mil LF thickness

Power Architecture

- Power block: 2x FET
- Power stage: 2x FET and driver IC
- Power module: + passives

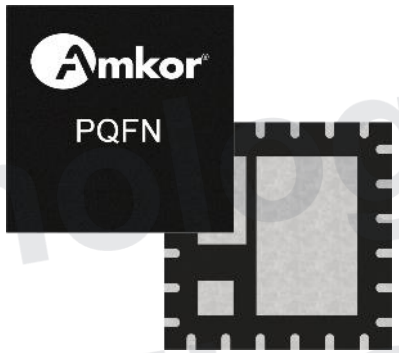


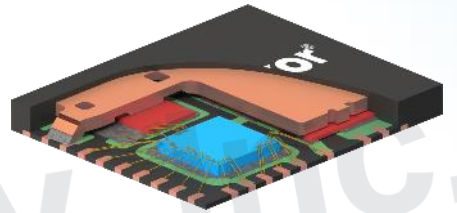




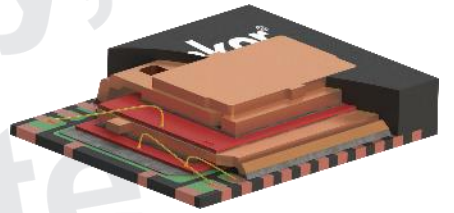
Power Packaging Drivers: PQFN Overview

- Standard package platforms
  - Discrete FETs
  - Dual FETs
  - Stacked FETs
- Interconnection technology
  - Cu clip/Cu wire
  - Al wedge bond
  - Cu clip/Cu clip
  - Wire/Cu clip combination

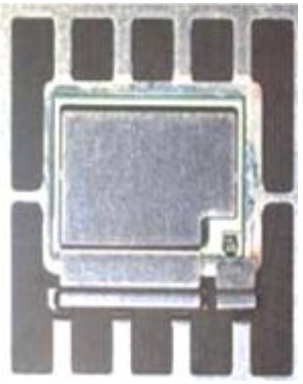


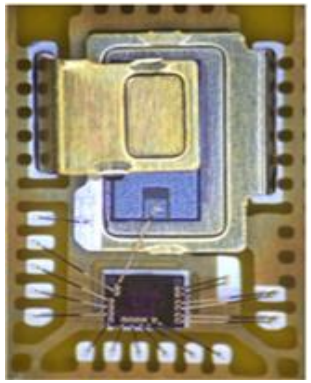


PQFN Dual FET



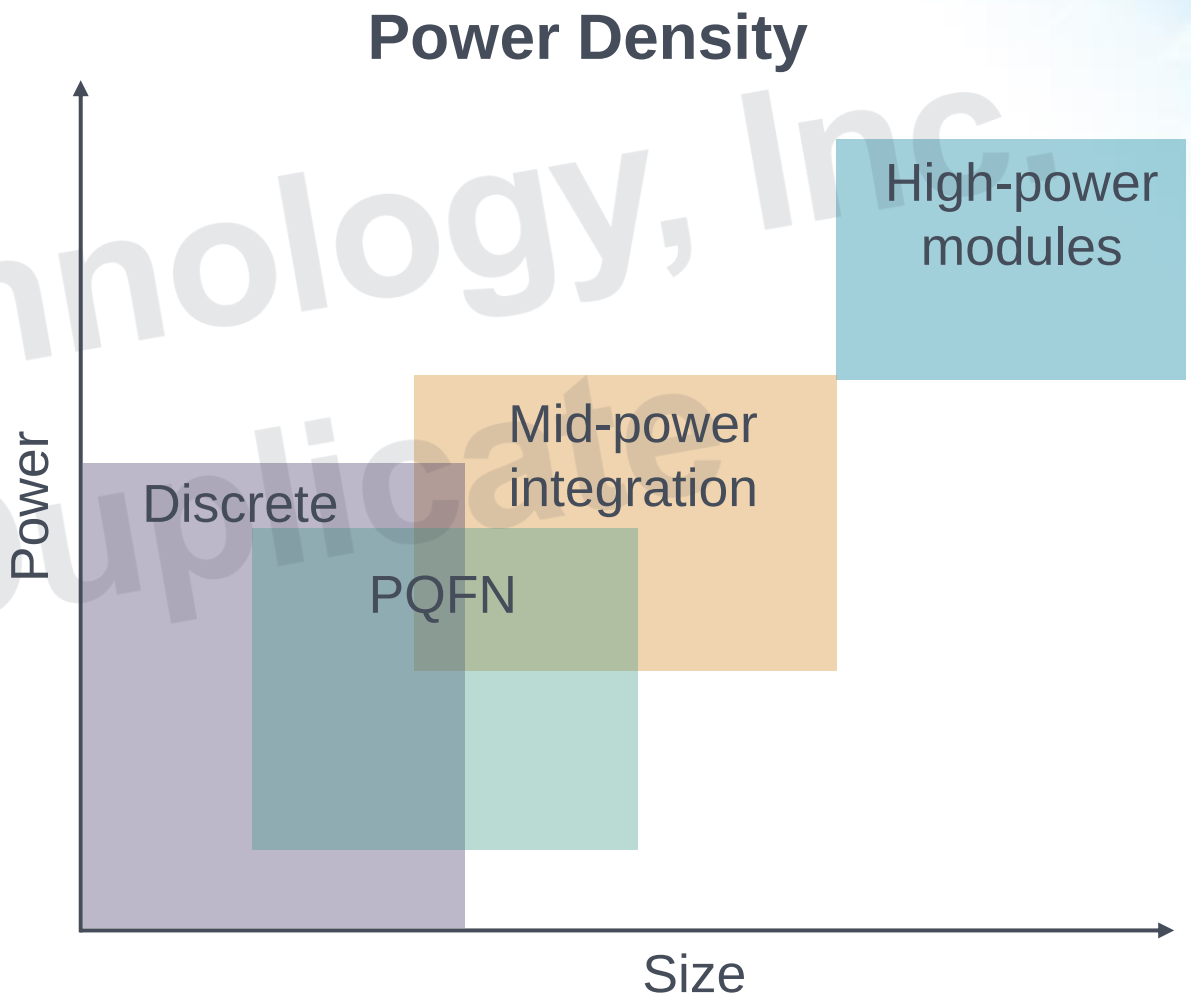
PQFN Multi-stack FET



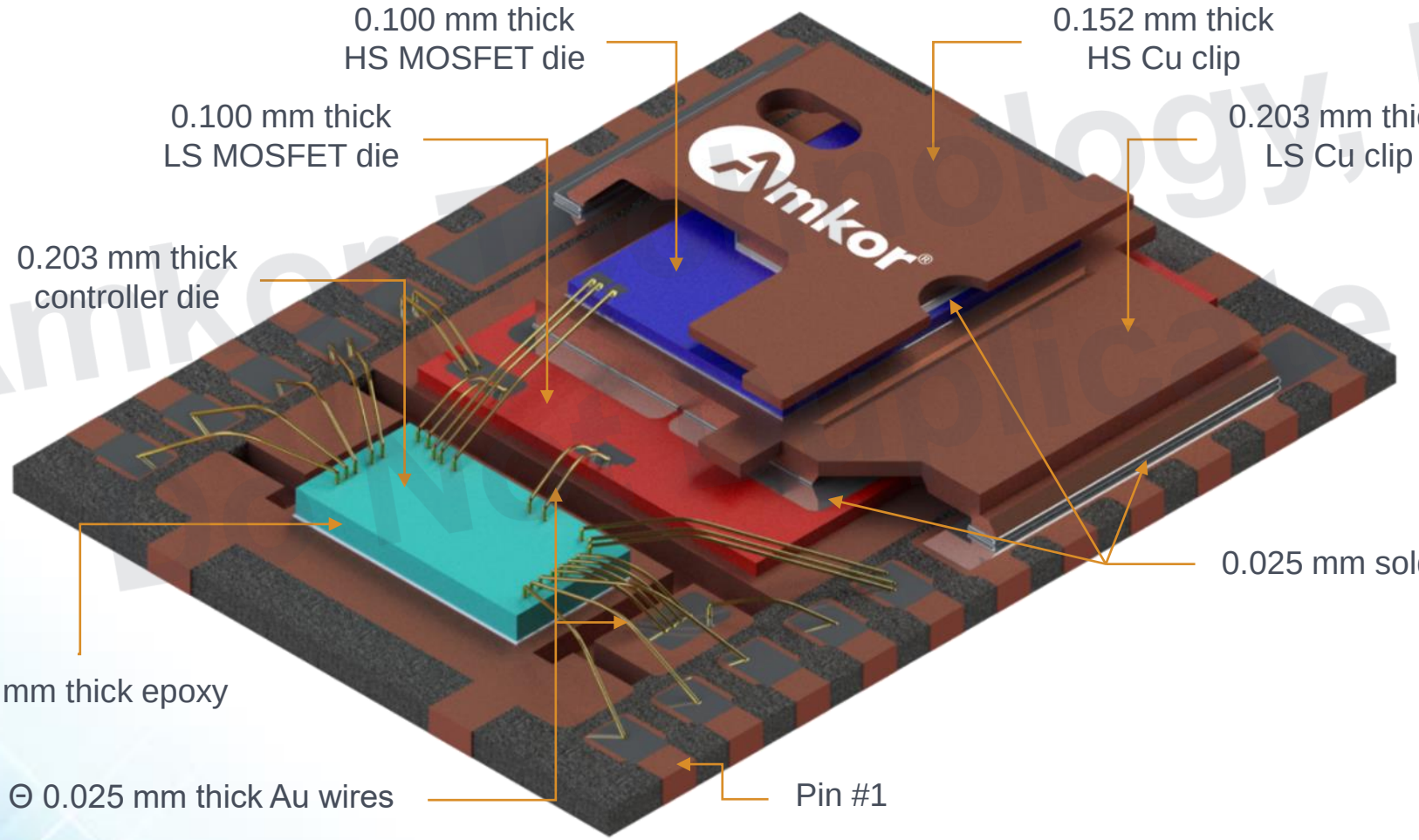


Package Integration in Power Semiconductors

- Vectors for discrete and integrated power
  - Low resistance/inductance
  - Dual-sided cooling
  - Reduced form factor
  - Add controller/logic/passive
- Gaps
  - High density packaging
  - Universal formats for discrete and integrated use

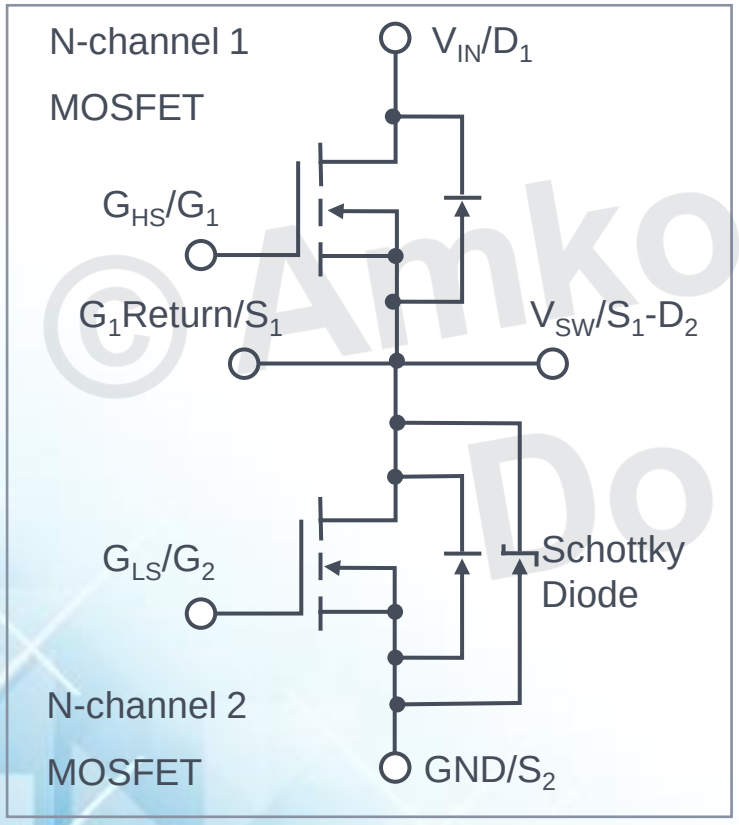


Power QFN Structure – Power Stage



DC/DC Converter

- Dual N-channel, 25V MOSFET



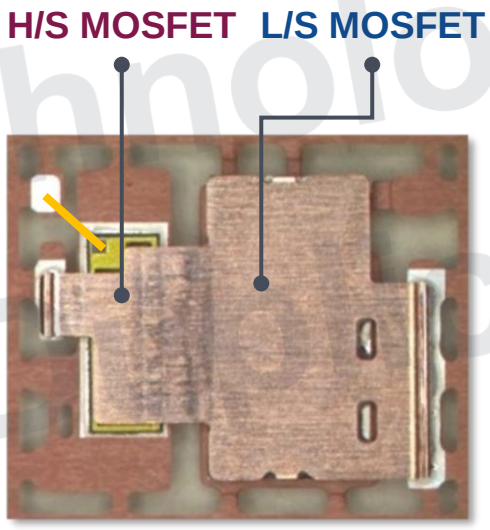
Source: Mouser Electronics

High Side Drain

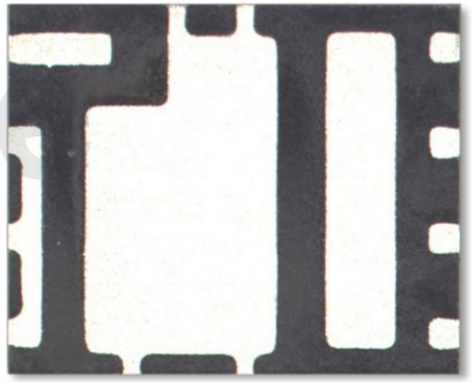
High Side Source

Low Side Drain

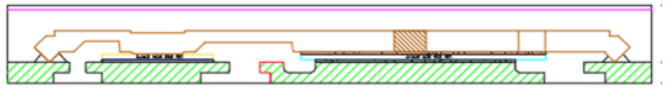
Low Side Source



Top View



Bottom View



SECTION "A–A"

Power Packaging Trends: Integration Paths

Low- to Mid-Power

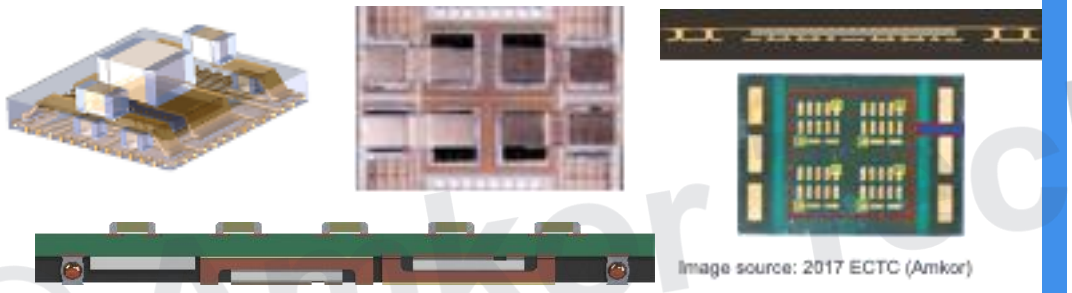


Image source: 2017 ECTC (Amkor)

High Power

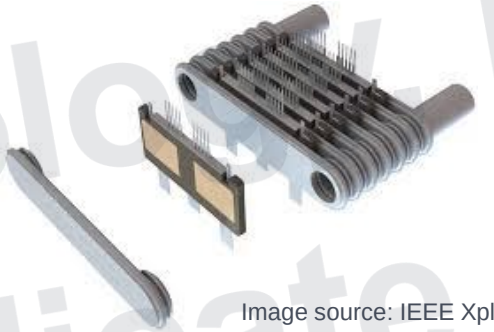


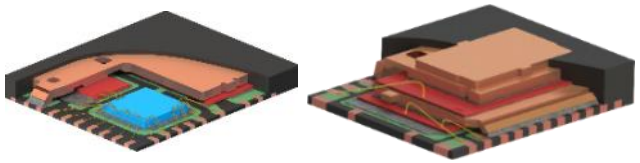
Image source: IEEE Xplore

Divergent Paths

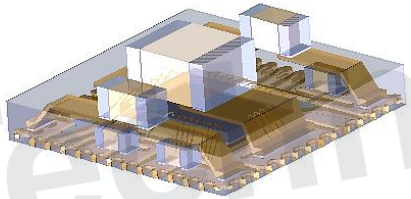
- PQFN derivatives
- Embedded
- Dual-sided module

- Large body (~50 mm++)
- Overmolded leadframe (dual-sided)
- Specialized thermal substrates

Power Packaging Drivers: Evolution of PQFN/PMIC Integration



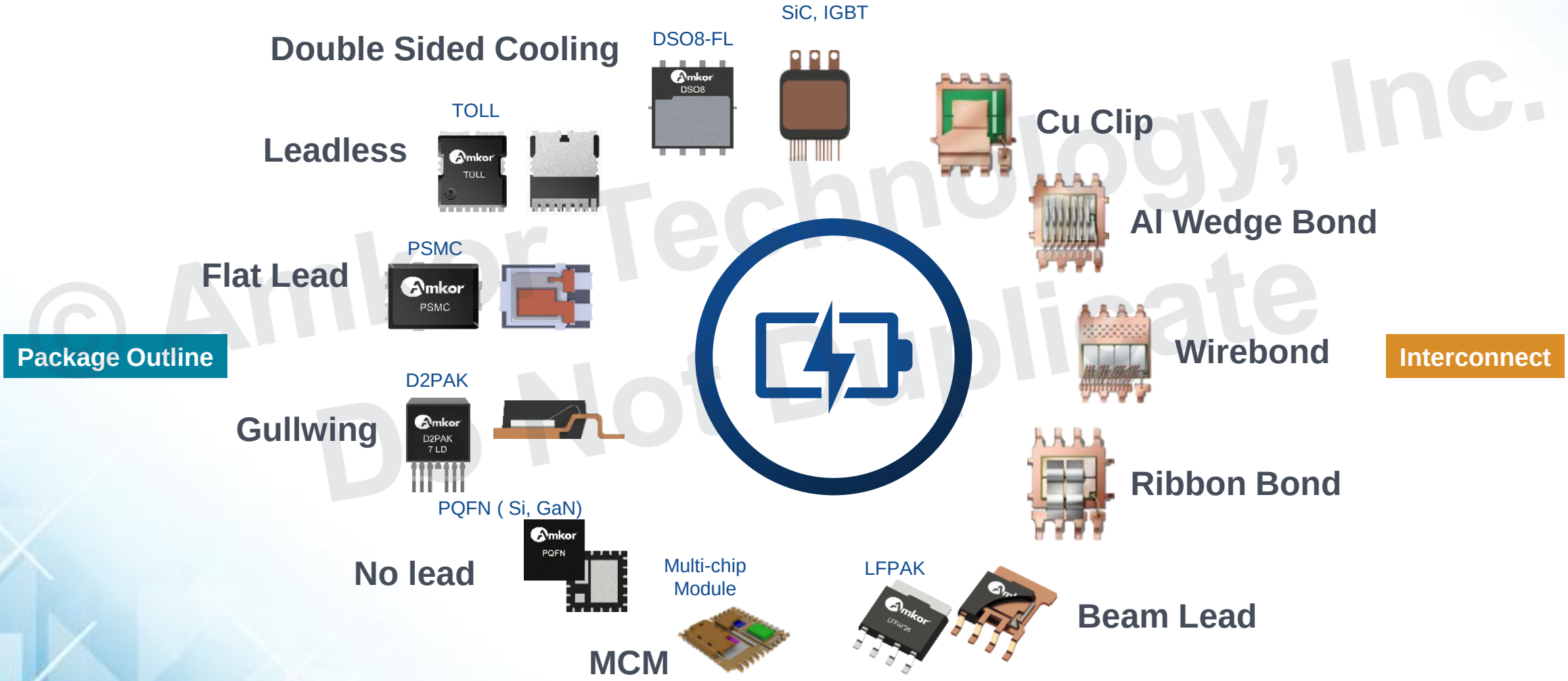
- Multi-die
- Clip and wire capable
- Stacked MOSFET or side by side
- Cu to Cu process



- Integrated inductor and passives for electrical efficiency
- Uses exposed Cu from clip

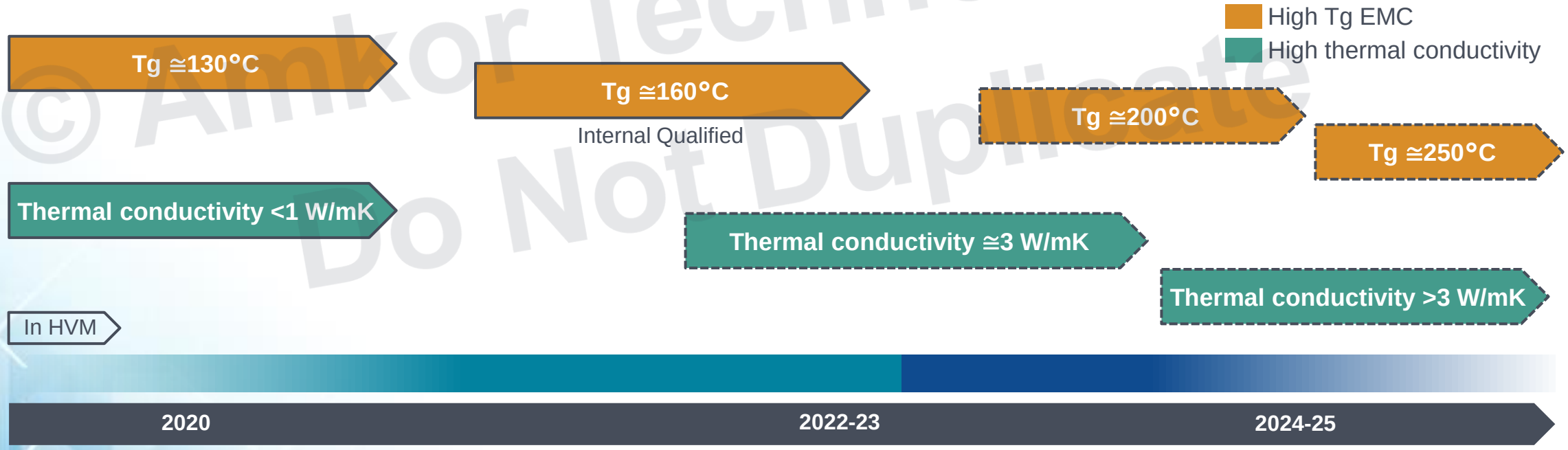
- Reduce inductor electrical path
- Form factor reduction
- Auto/Mobile/Network markets

Amkor Power Package Solutions



High Thermal Epoxy Mold Compounds(EMC)

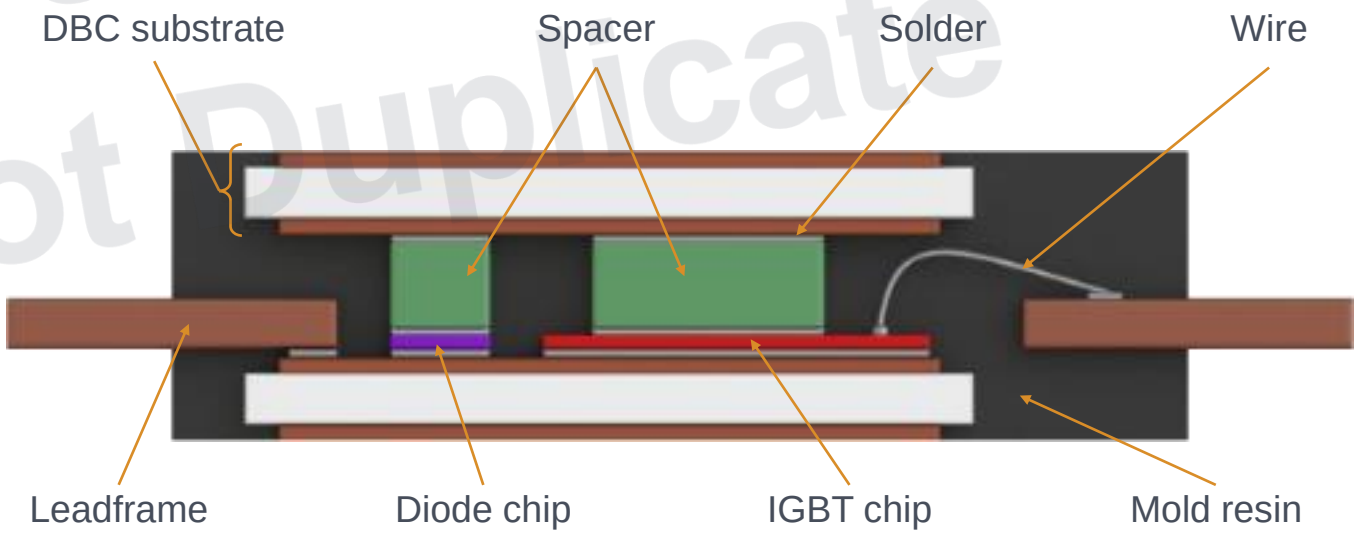
- 3 approaches to high thermal EMC
  - Improved heat resistance for high operating temp
  - Low stress for stress relief of die
  - High thermal conductivity for high operating temp



Power Modules for xEV Automotive Systems

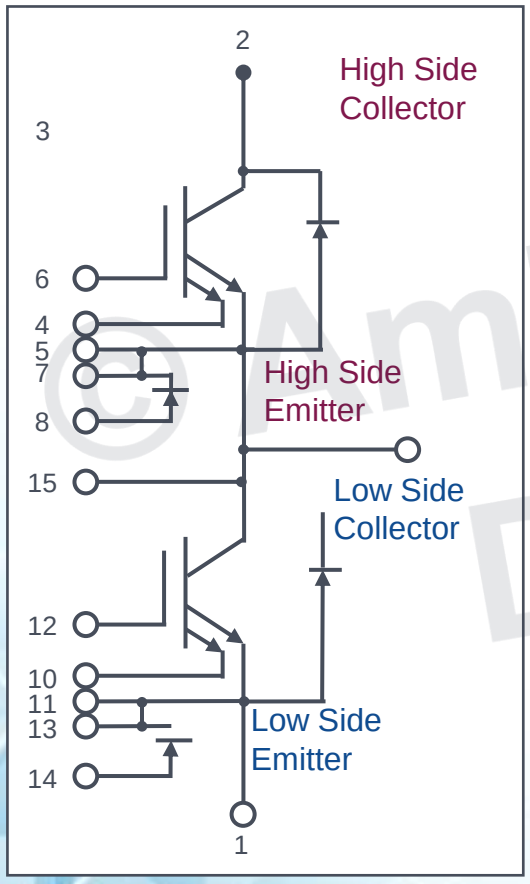
High Power Modules

- Highly customized solutions
- All trending towards similar architecture
  - Leadframe + DBC/ceramic
  - Soldered/Sintered components
- Applications
  - IGBT, SiC, GaN
  - Inverters
  - DC/DC



IGBT Module – Traction Inverter

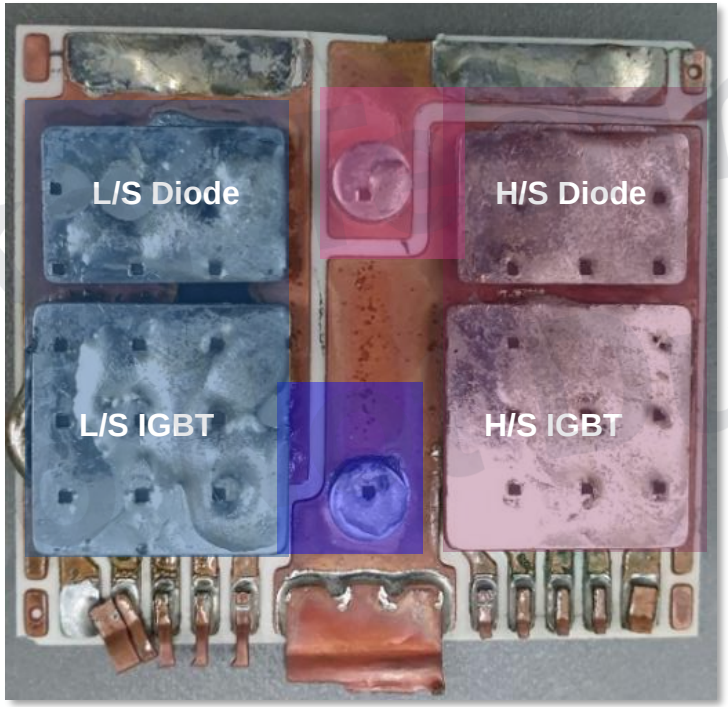
- VE-Trac, IGBT module, 750V



Source: Mouser.com

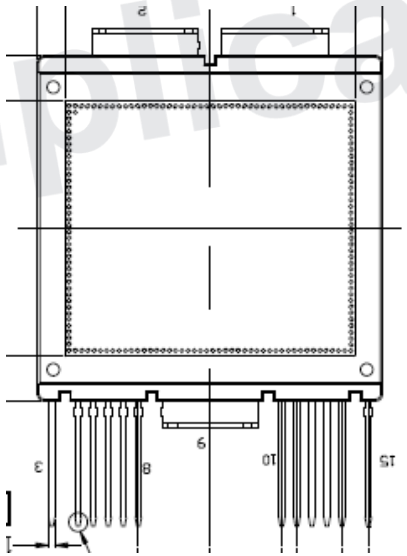
1 – L/S Emitter

2 – H/S Collector



9 – Phase Out

Top View

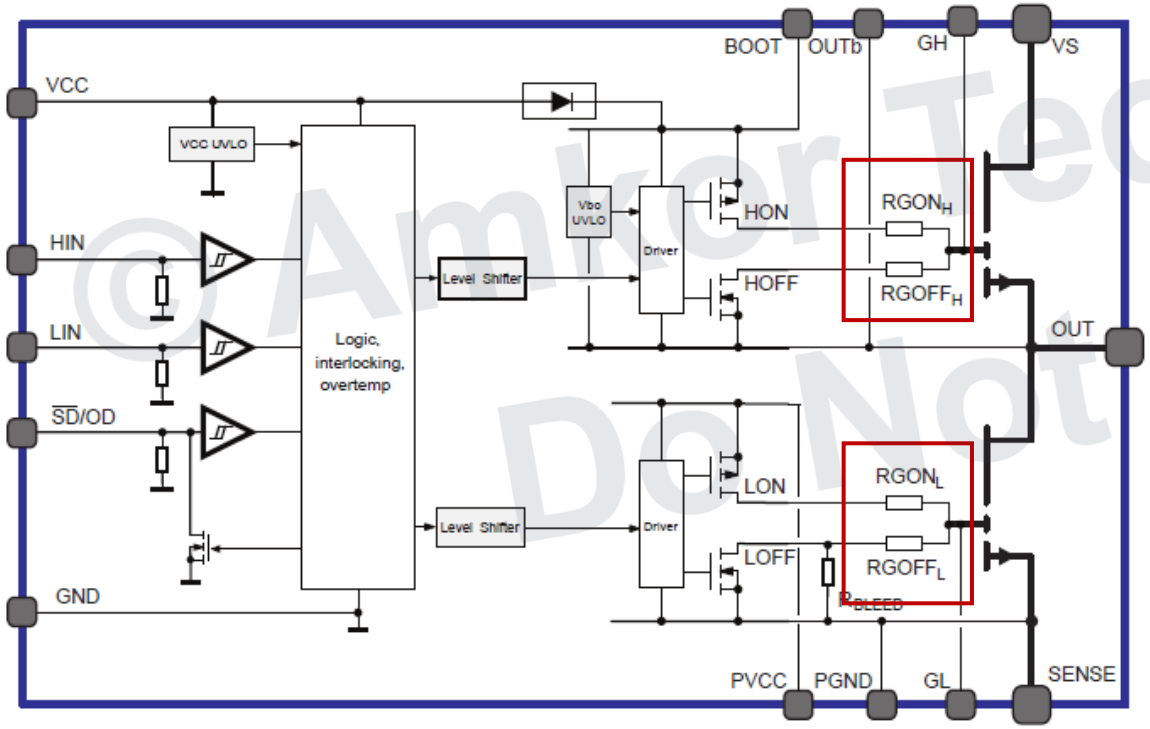


80 kW~400 kW
(Unit 1~Unit 6)

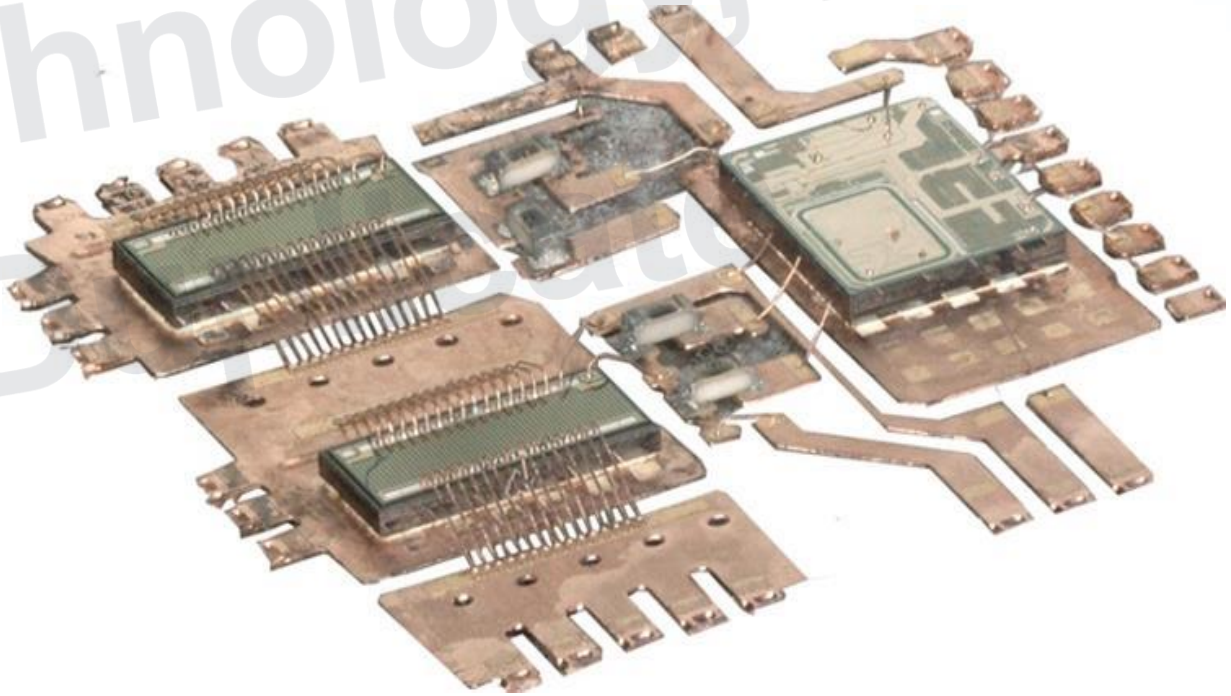
Source: onsemi.com

SiP Power Module

- 600V SiP integrating half bridge gate driver and high voltage power GaN transistors



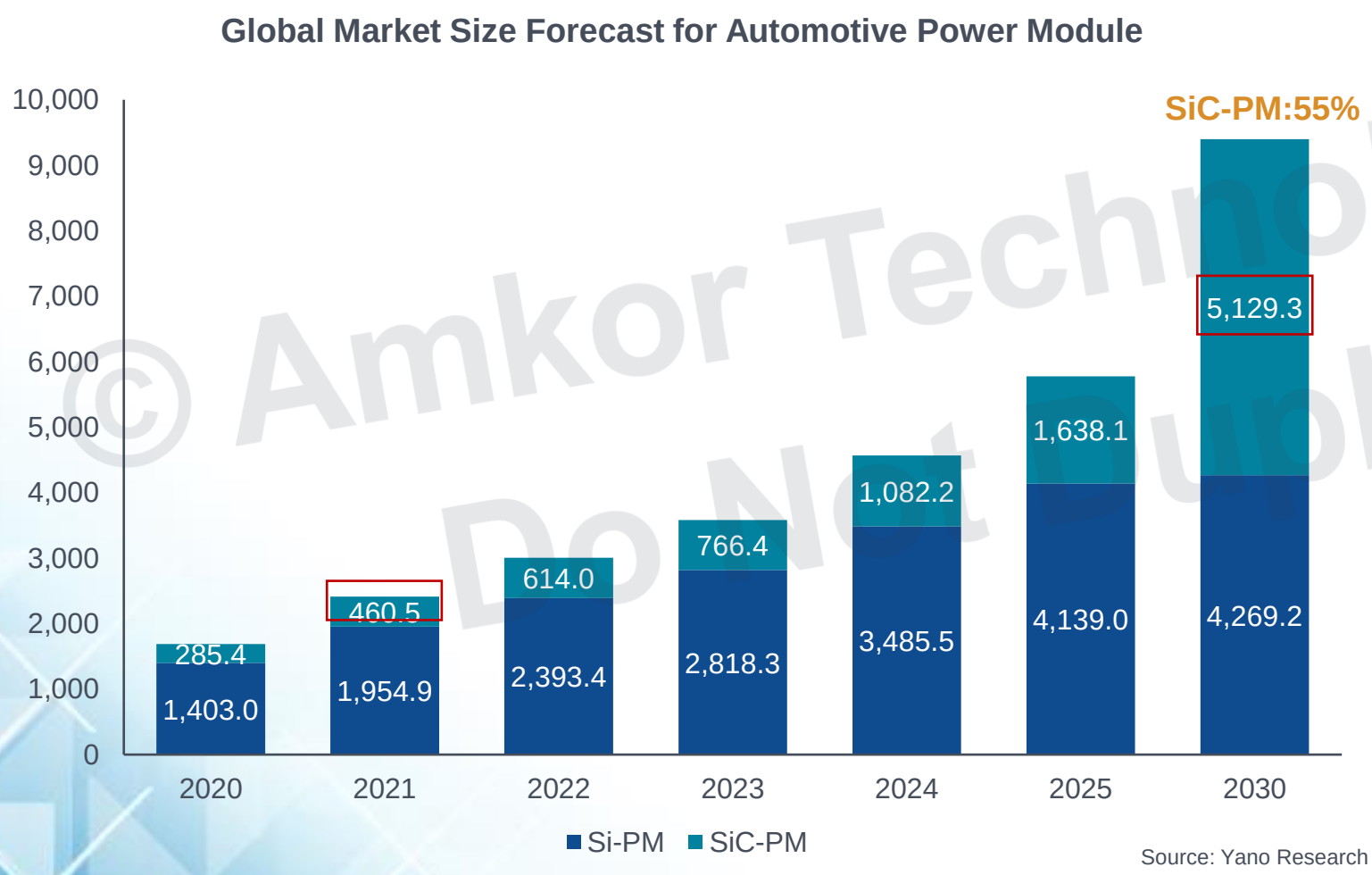
Source: STMicroelectronics. MASTERGAN1 Data Sheet



Source: SYSTEMPlus, 2020

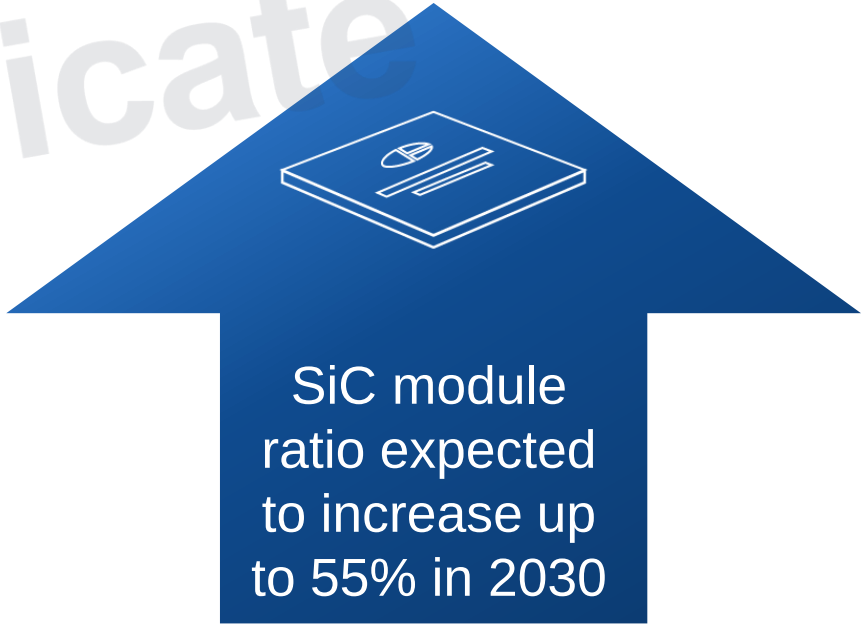
SiC Power Module for Automotive

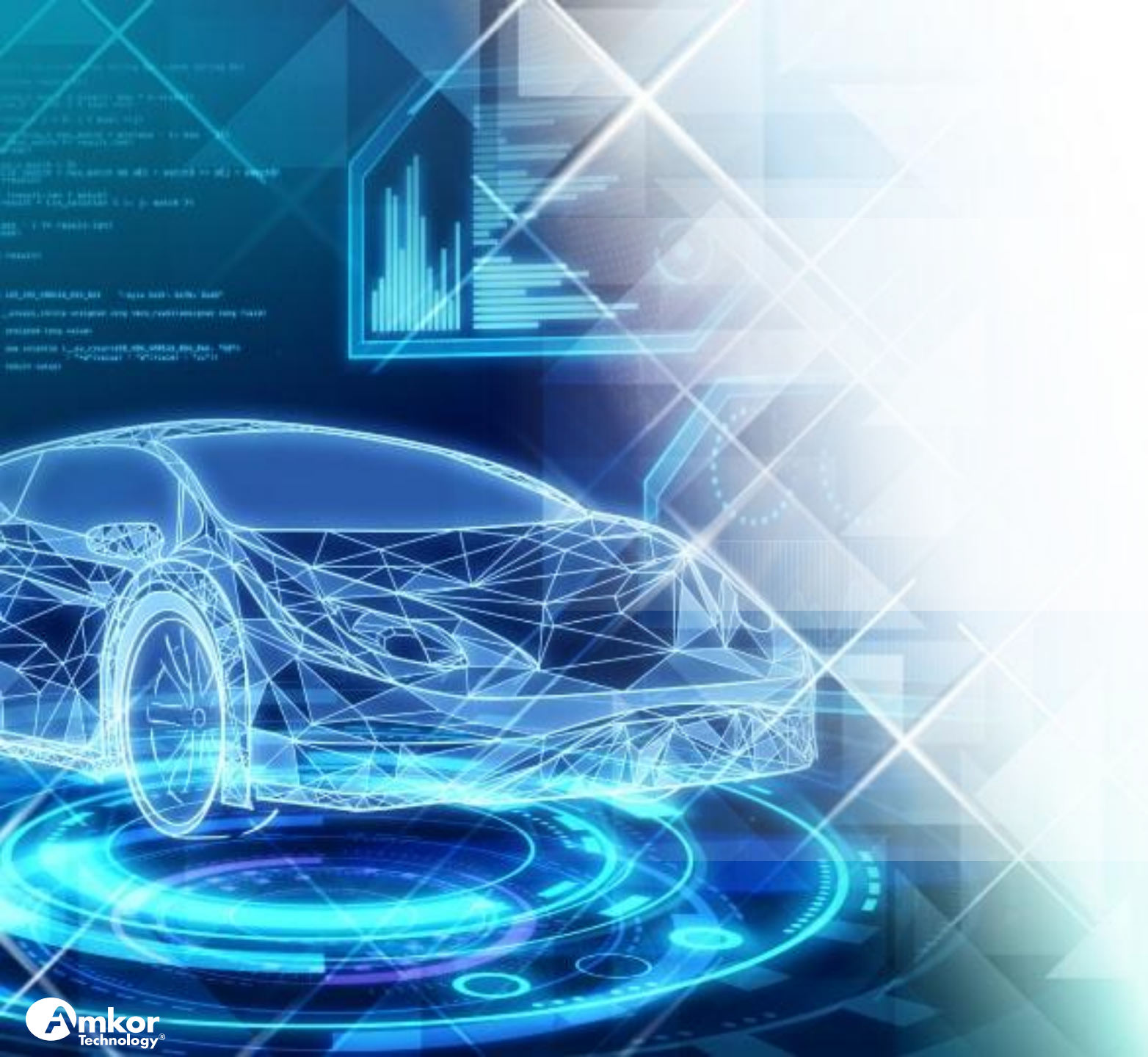
($ in millions)



Source: Yano Research

	2021	2030	
Module (Total)	2415 M$	9399 M$	390% UP
SiC Module	461 M$	5129 M$	1,112% UP





Summary

Automotive Power Package Trends – Summary

- Si ➔ WBG
  - SiC, GaN
- Solder ➔ sintering material
  - Better thermal performance, higher reliability, lower resistance
- Wirebond ➔ clip
  - Lower inductance, high current capacity
- One sided ➔ double sided cooling
  - High thermal dissipation
- Single die package ➔ power modules system integration

Thank You