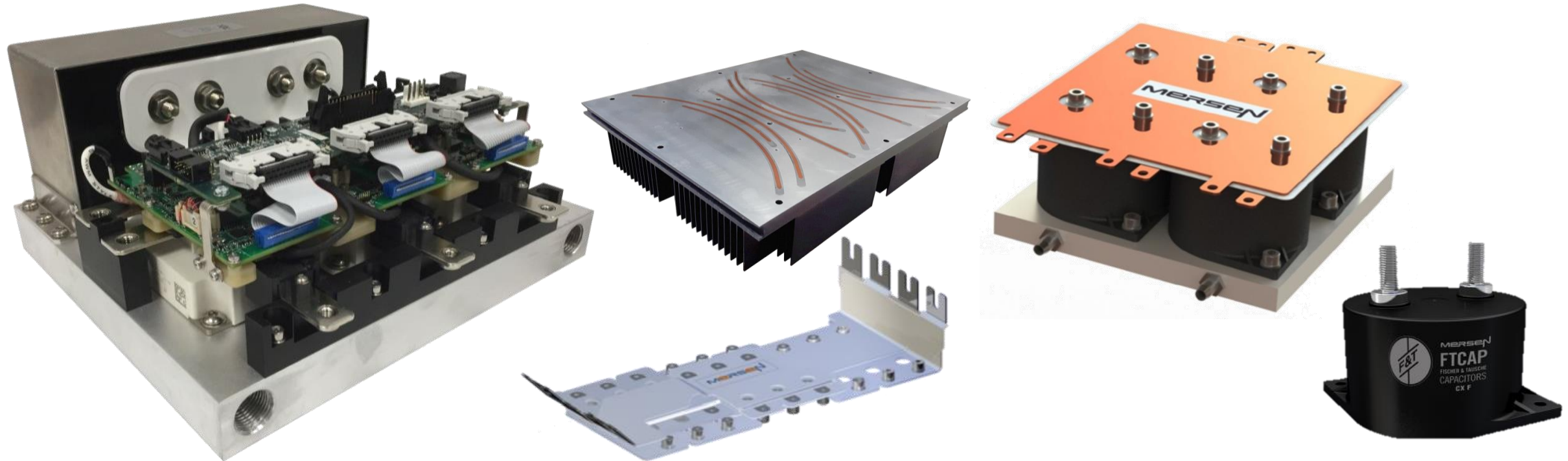




HIGH PERFORMANCE COOLING AND LOW-INDUCTANCE BUSBAR-CAPACITOR SOLUTIONS FOR SIC INVERTER

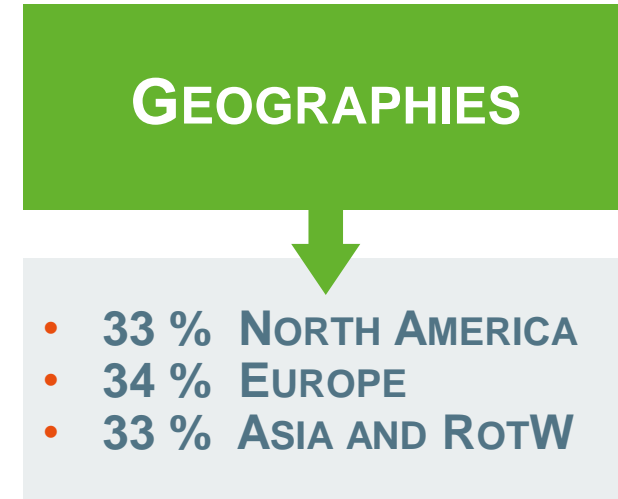
PowerAmerica Annual Meeting – Raleigh, NC - Feb 2020



MERSEN IN BRIEF

A FRANCE-HEADQUARTERED TRADED COMPANY. MERSEN USA CORP. IN ROCHESTER-NY

* As of December 31, 2019



ADVANCED MATERIALS

ANTICORROSION EQUIPMENT

World's no. 1-2 in graphite equipment



GRAPHITE SPECIALTIES

World's no. 1-2 in high-temperature applications



POWER TRANSFER TECHNOLOGIES

World's no. 1-2 in brushes for industrial motors



ELECTRICAL POWER

ELECTRICAL PROTECTION & CONTROL

World's no. 2 in industrial fuses



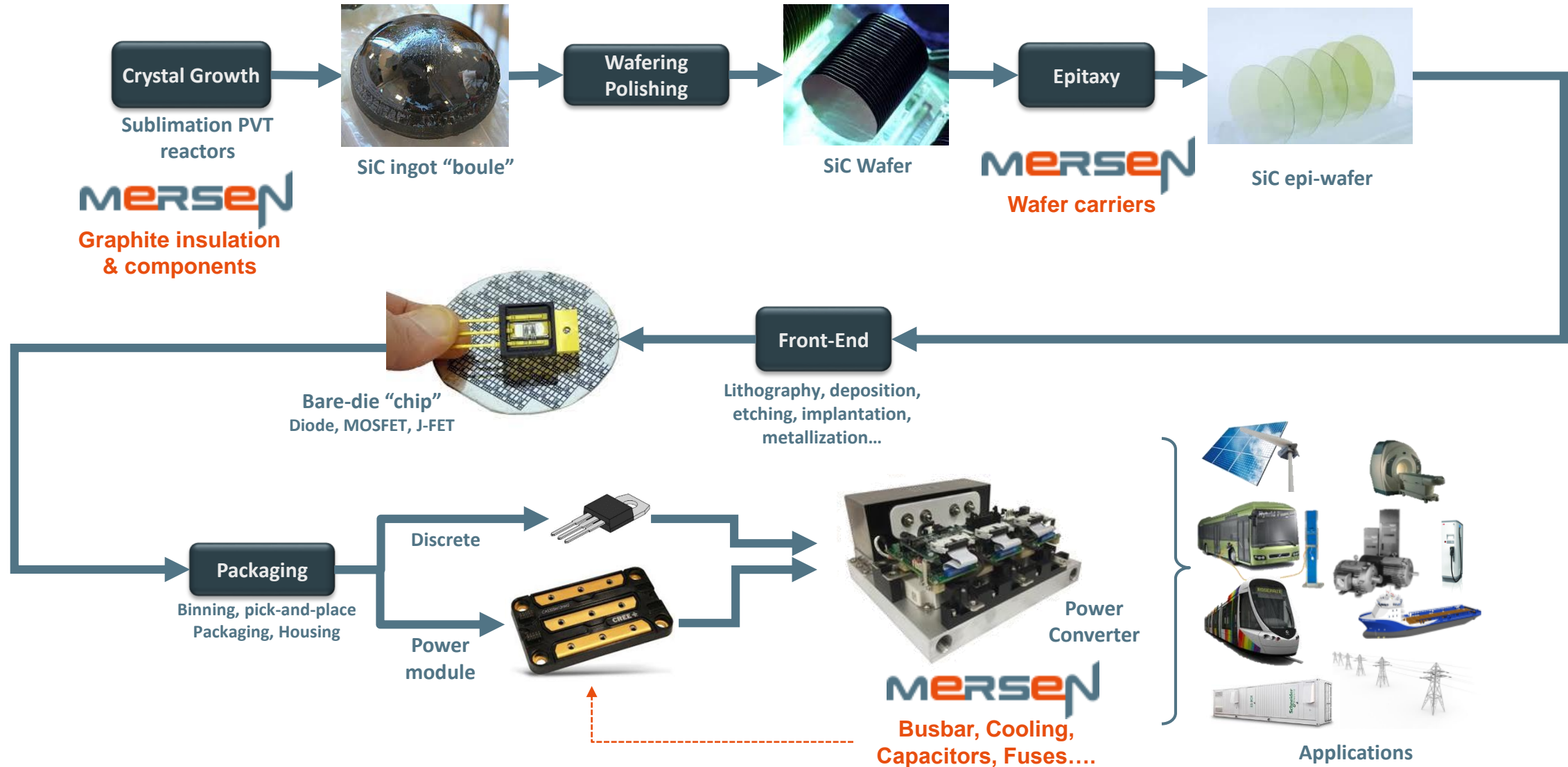
SOLUTIONS FOR POWER MANAGEMENT

World's no. 2 in passive components for power electronics

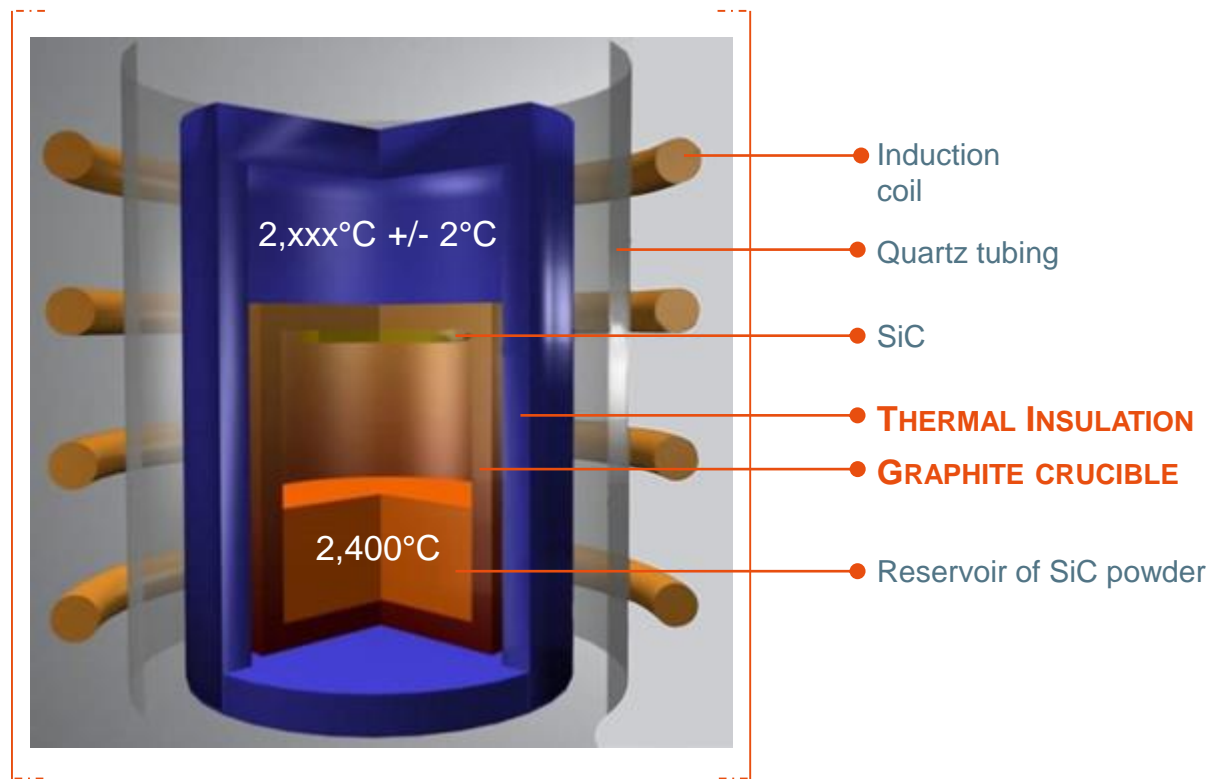


INTRODUCTION: MERSEN IS ACTIVE ALL OVER THE SiC VALUE-CHAIN

CRYSTAL GROWTH, EPITAXY AND POWER CONVERSION



MERSEN HAS A COMPREHENSIVE RANGE OF GRAPHITE AND INSULATION SOLUTIONS FOR SiC PRODUCTION



Graphite crucible

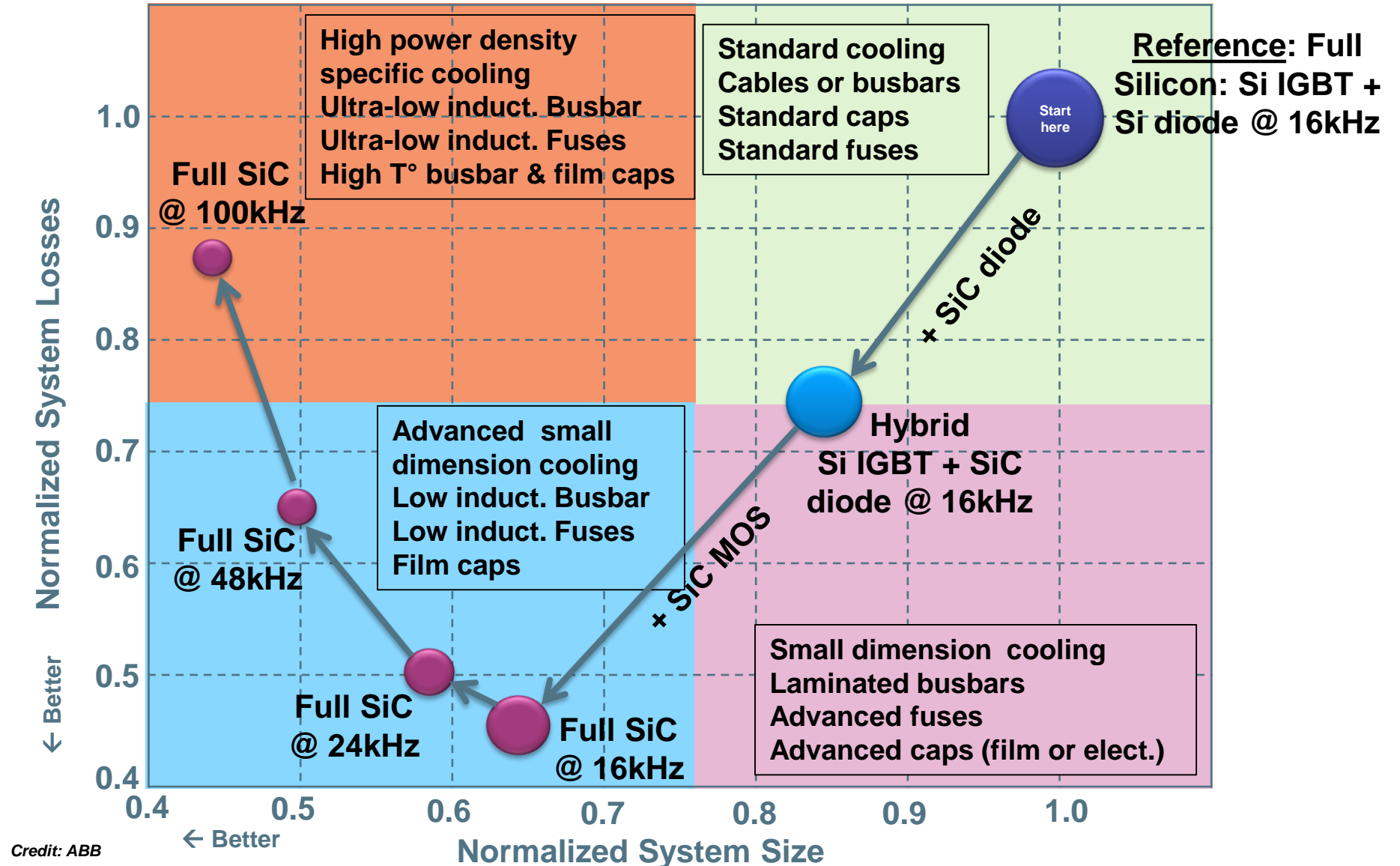
- contributes to the chemical composition of the single crystal
- controlled CTE, controlled reactivity with the gases, controlled thermal conductivity
- extreme purity (7N) of the graphite

CALCARB® insulation

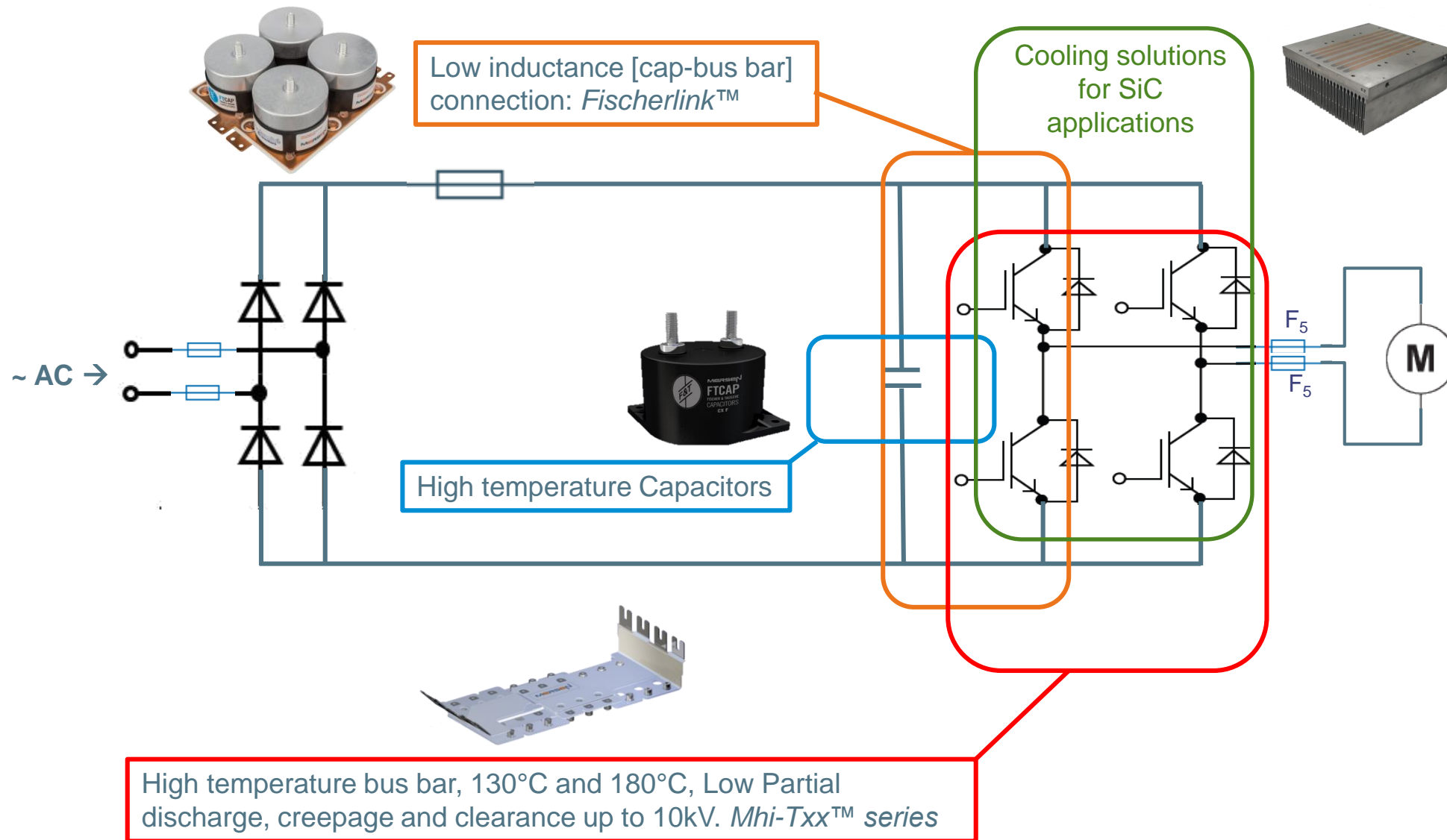
- spatial consistency,
- low thermal conductivity at 2,400 C
- ability to be precision machined
- high purity

Running temperature	Cycle duration	Ingot weight
2,400° C	3-5 days	5-10 kg

INFLUENCE OF SILICON CARBIDE ON SELECTED POWER COMPONENT SPECIFICATIONS



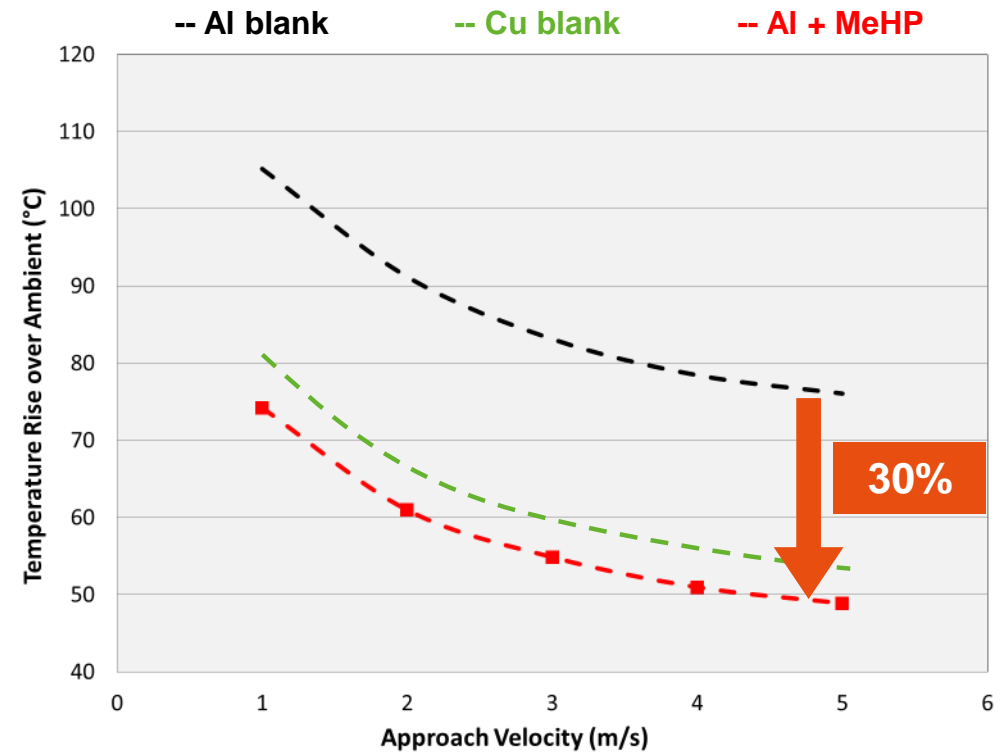
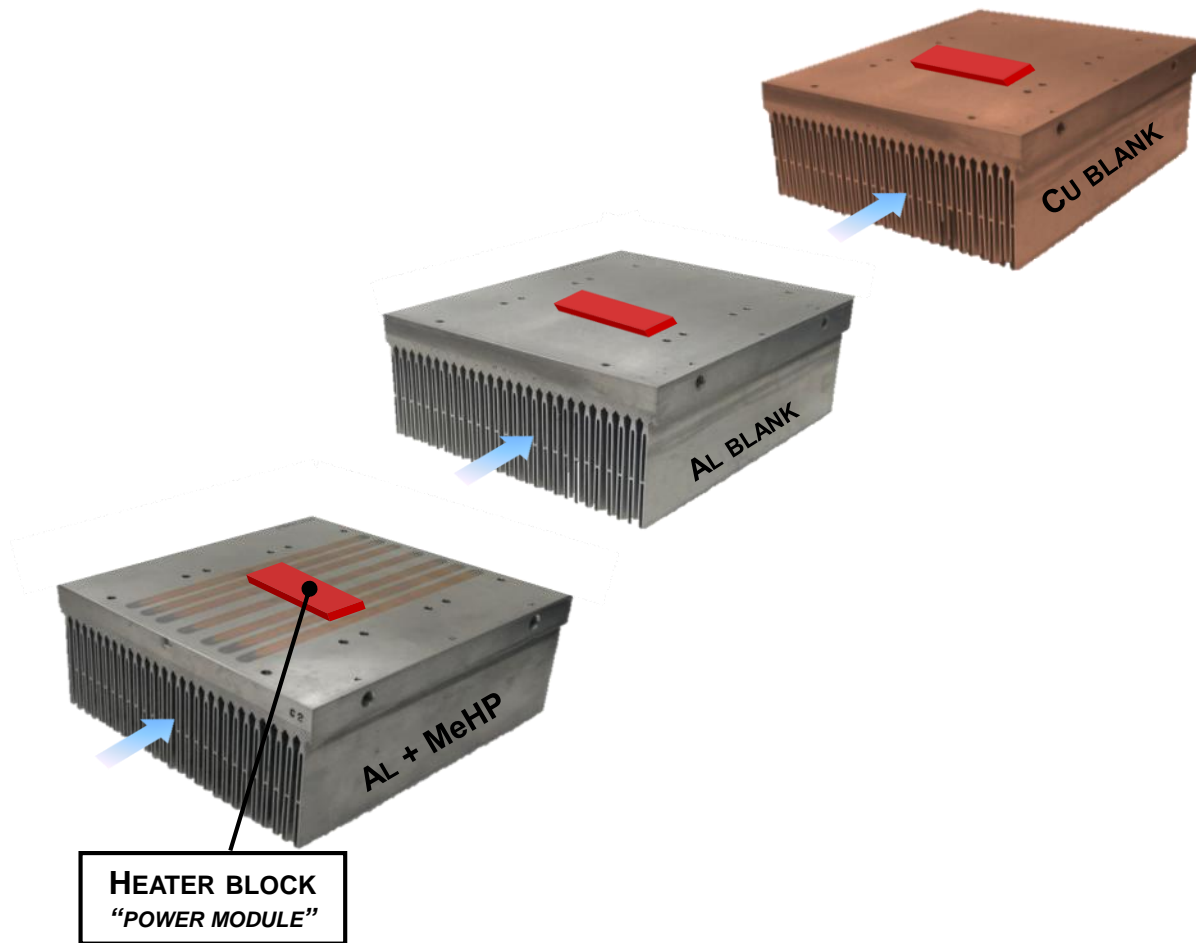
ADDRESSING SiC APPLICATIONS WITH MERSEN LINE OF PRODUCTS



EMBEDDED HEAT-PIPE: PUSHING THE LIMITS OF AIR COOLED HEAT-SINK

~30% REDUCTION IN T° RISE COMPARED TO STANDARD AL HEAT-SINK

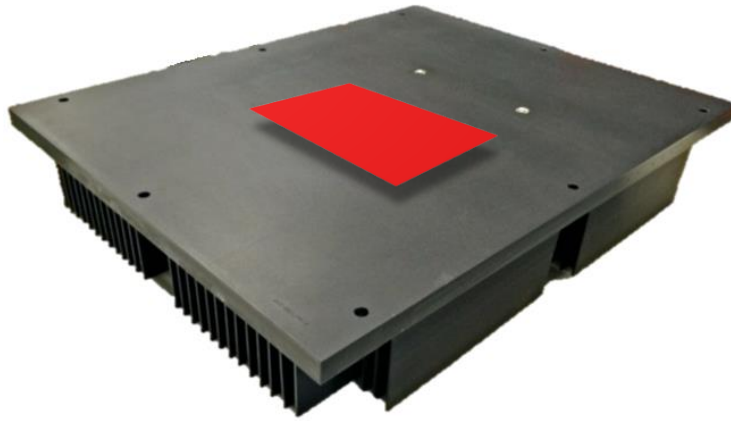
- A HEATER BLOCK, SIMULATING A POWER MODULE, HAS BEEN PLACED AT THE SAME LOCATION ON 3 DIFFERENT HEAT SINKS (AL+MEHP, AL AND CU) WITH SAME GEOMETRY. T° RISE IS MEASURED AT THE HEATER LOCATION AS A FUNCTION OF AIR VELOCITY



	Al blank	Cu blank	Al + MeHP
Average T° rise	Ref = 1	-23%	-30%
Cost comparison	Ref = 1	x 4	x 1.25
Weight	Ref = 1	x 3.5	1

IMPACT OF eHP ON SiC MODULE THERMAL SPREADING

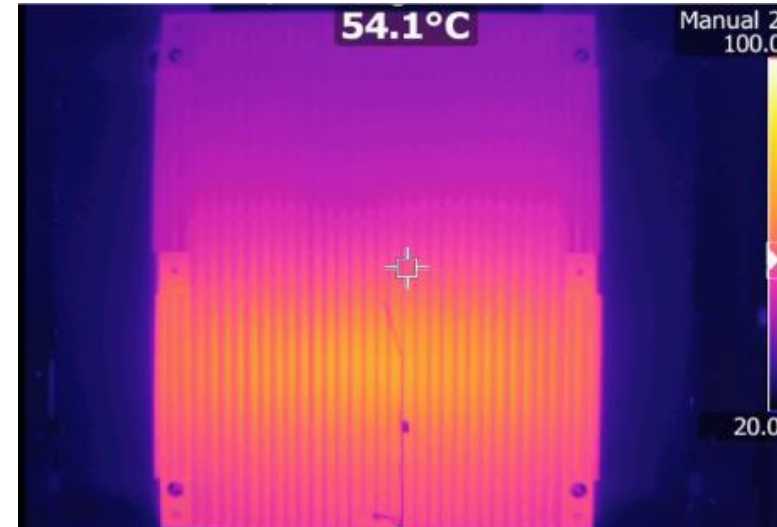
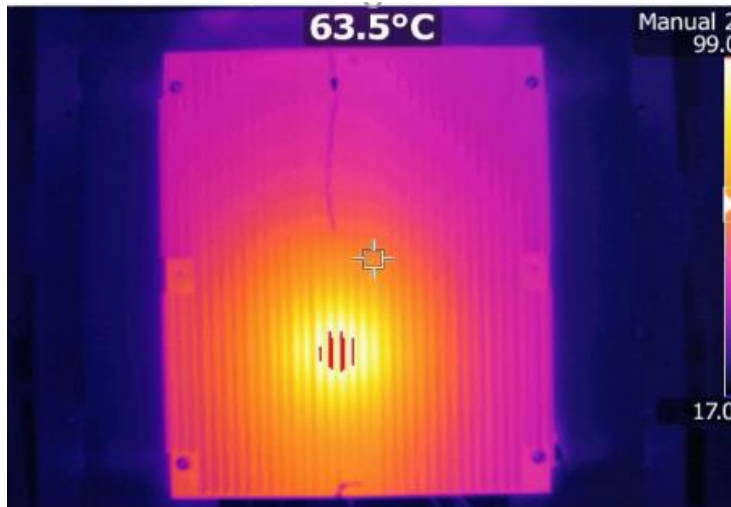
NO HOT-SPOT ANYMORE!



BLANK HEATSINK

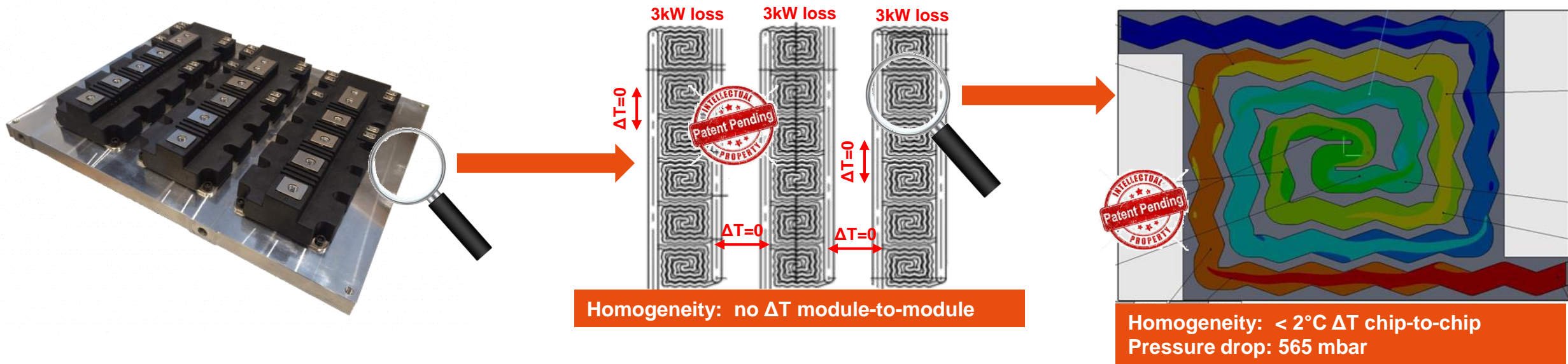


EMBEDDED HEAT PIPE MeHP
(INSERTED INSIDE THE BASEPLATE)



ISO MAXX™: THE ULTIMATE LIQUID COOLING SOLUTION FOR MODULES

No ΔT MODULE-TO-MODULE, NO ΔT CHIP-TO-CHIP



- AN INNOVATING COUNTER-FLOW “WAVY SPIRAL” DESIGN, HAS BEEN DEVELOPED FOR IMPROVING THERMAL MANAGEMENT OF LATEST GENERATION OF SI & SIC POWER MODULES. IT OFFERS:
 - **Better thermal performances:** $R_{th} \sim 6^\circ\text{C}/\text{kW}$
(EG 50%, 250 mm modules, 3kW power losses and 5 liter/min per component.)
 - **Lower pressure drop** than all existing designs ($\sim 600\text{mbar}$)
 - Thermal **homogeneity** chip-to-chip (all chips at the same T°) and module-to-module on a multi-module cooling plate
 - **Compact** design: distance between modules can be optimized \rightarrow Inverter **size reduction**
 - **Modular** solution : covers all PrimePACK™ types, whatever the number of modules on the plate
 - **Cost competitive** compared to others efficient designs

RECENT TRENDS IN WBG POWER CONVERSION

HOW TO REDUCE STRAY INDUCTANCE WHILE INCREASING OVERALL POWER DENSITY AND JUNCTION T° ?

Reduce stray inductance together with higher T_j

New module design

Power module makers are working on new designs for their power modules in order to stay competitive against press-packs for high-voltage devices. The most popular solution is **reducing the distance between internal connections**



Use of external laminated busbar with low inductance connection

Outside the module, using **laminated busbar** offers strong reduction of parasitic inductance



Use of internal laminated busbar

Along with the emergence of SiC, the switching frequency reaches several ten's of kHz. **Internal laminated bus bar** can offer a real added-value to decrease the inductance while connecting the chips together

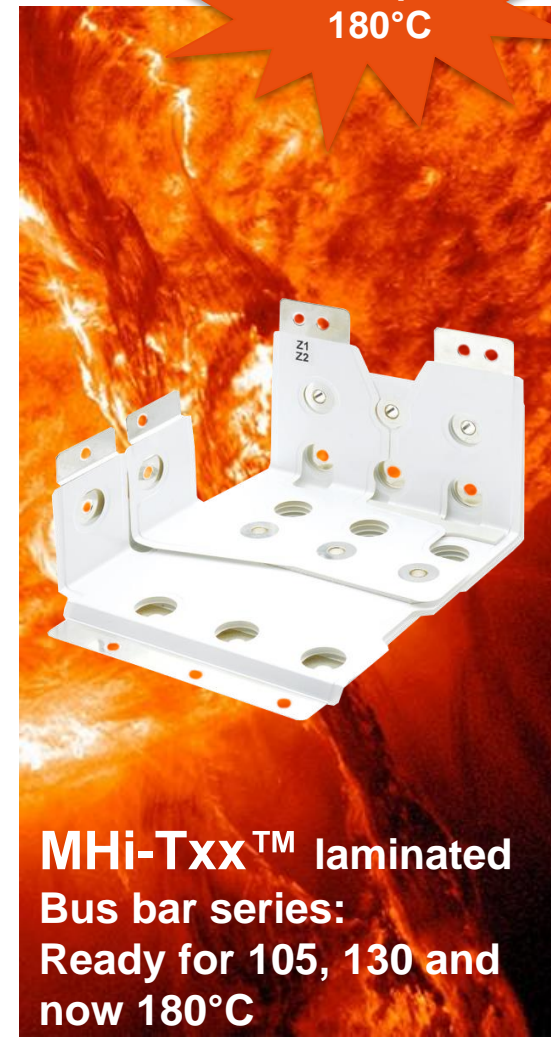
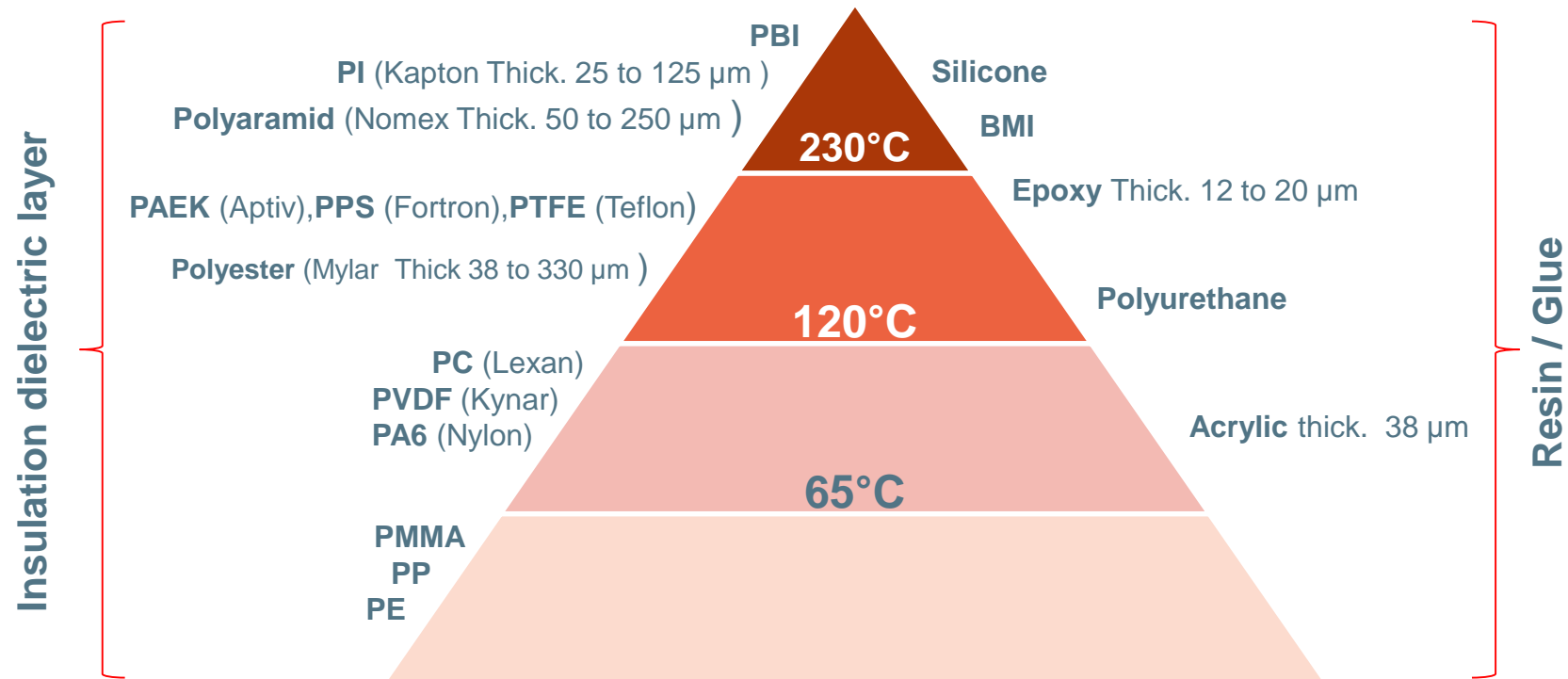
LAMINATED BUS BAR: HOW TO MATCH WBG MODULE HIGH T° REQUIREMENTS ?

SELECTION OF INSULATION AND RESIN MATERIAL AS A FUNCTION OF OPERATING T°

■ A PERFECT MATCHING [INSULATION – RESIN/GLUE]

- In order to perfectly match customer' specifications, Mersen aims at selecting the right material (Insulation and Resin / Glue) with the highest Temperature, Voltage and Mechanical resistance, keeping insulation as thin as possible (to meet low inductance value requirements)

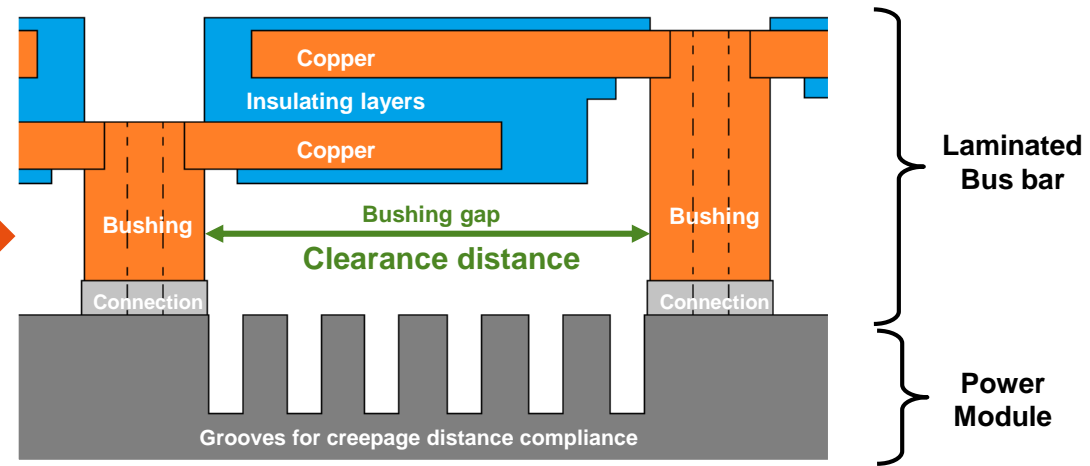
■ EXAMPLES OF MATERIAL SELECTION AND RELATED THICKNESS RANGE AS A FUNCTION OF MAX. OPERATING T°:



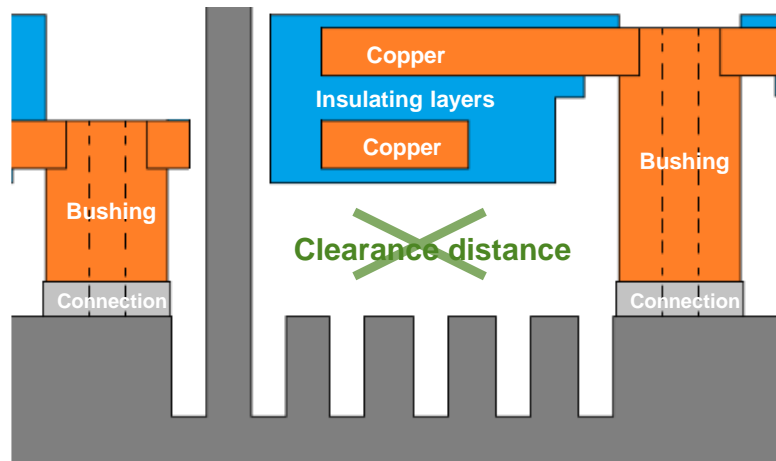
HOW TO DECREASE CLEARANCE DISTANCE IN POWER MODULE DESIGN ?

CONFORMAL BUS BAR IS AN ENABLER...

Today's industry standard

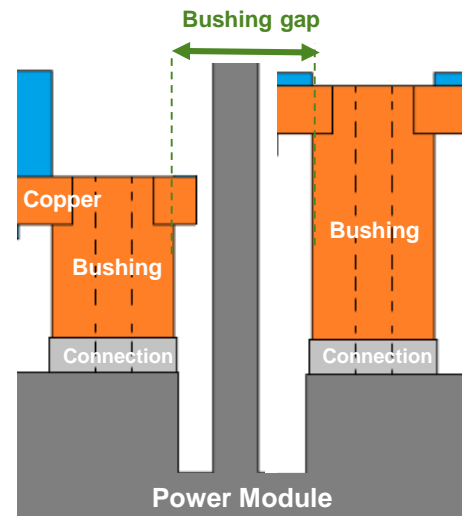


STEP 1

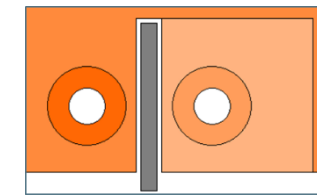


Additional tall insulating barrier on power module housing

STEP 2



Removal of intermediate grooves



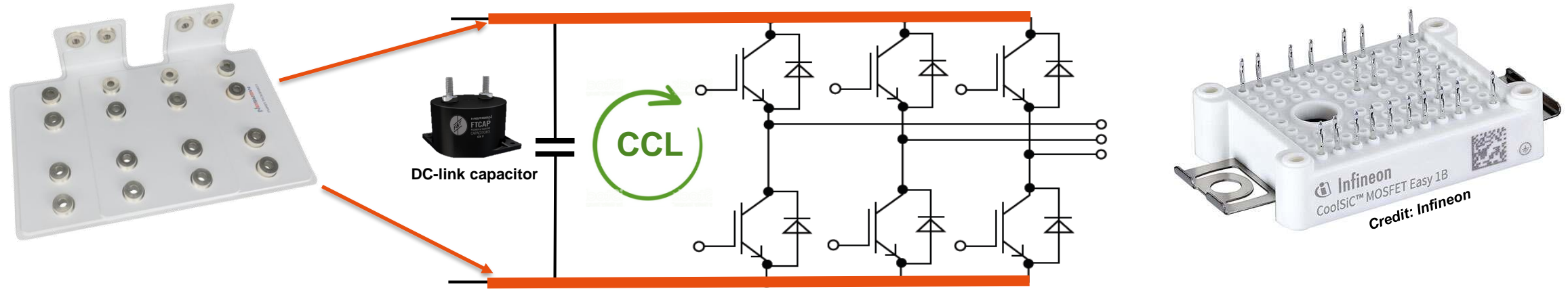
Top view of the bushings gap with tall insulating barrier and conformal bus bar design



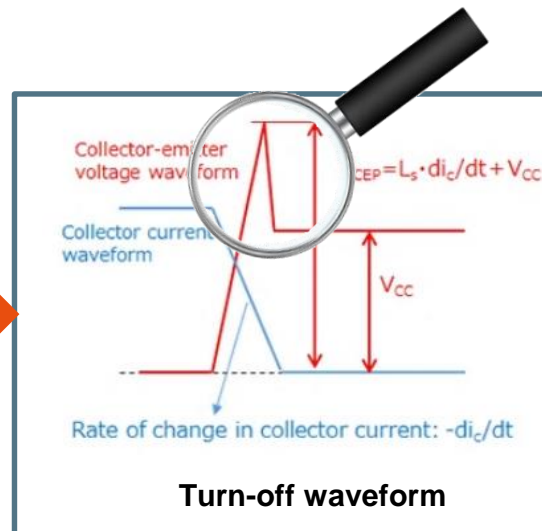
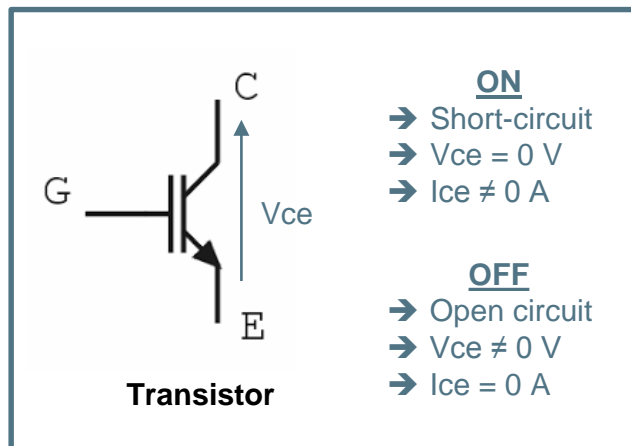
Gap between bushings can be significantly reduced → More compact module design

INDUCTANCE FUNDAMENTALS IN POWER CONVERTER DESIGN

HIGH INDUCTANCE CREATES VOLTAGE OVERTHOOT AND SURGE AT COMMUTATION



CCL: Commutation current loop

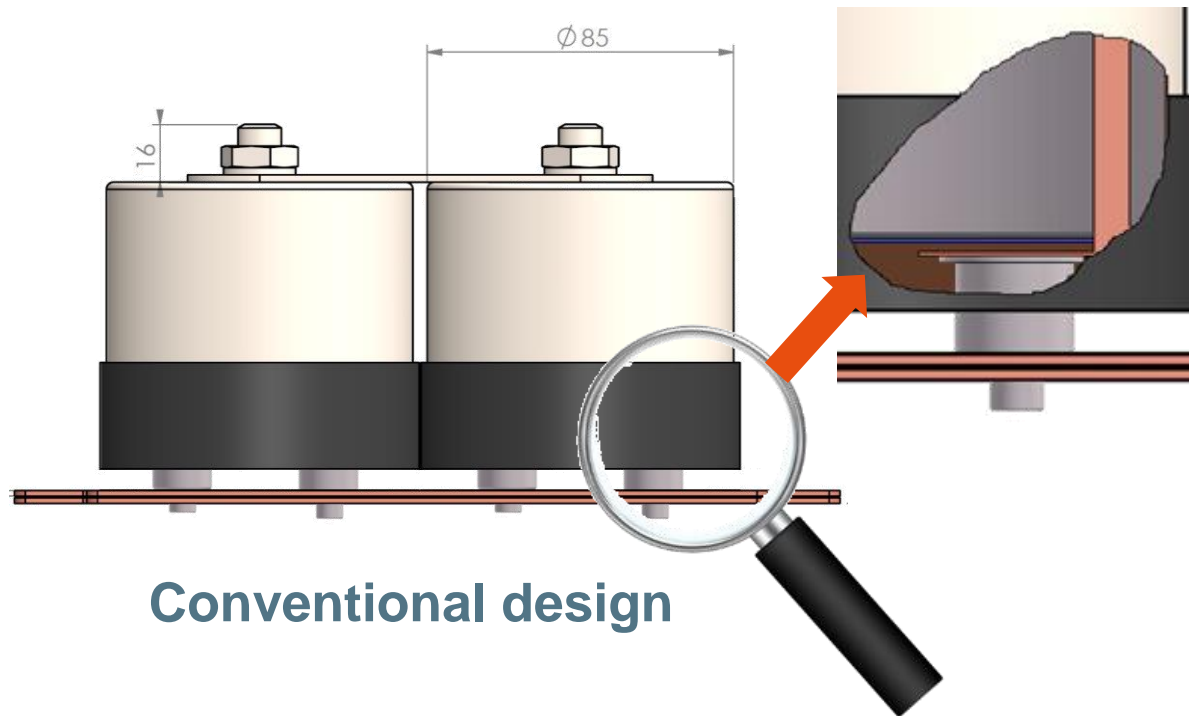


$$\text{Surge voltage} = L_s * \frac{di}{dt}$$

$L_s = \text{inductance of CCL}^*$

LOW-INDUCTANCE [BUS BAR-CAP] CONNECTION FOR SiC DC-LINK

FISHERLINK™



Conventional design



Mersen FischerLink™

- SHORTER CONNECTION OF THE CAP WINDING TO THE BUSBAR BY **DIRECT CONNECTION OF THE WINDING TABS TO THE BUSBAR BY LASER WELDING**
- Up to **+20 % capacitance** in a given volume (e.g. from 400µF to 480µF @ 1100 Vdc | 4-cap assembly)
- Extremely low inductance **<9nH**
- Capacitors and busbars packaged together as **sub-assembly** and single part #
- Pre-assembled and **100% tested** before delivery → ready for final assembly

INTERNAL LAMINATED BUSBAR FOR WBG POWER MODULES

SOLUTIONS TO HANDLE 180° Tj @ 100 KHz Fsw... AND BEYOND !

■ THE AIM:

- Get very low internal inductance by
 - laminated/symmetrical bus bar structure
 - Maximizing metallic conductor overlap
- 50% reduction in switching loss for higher switching frequency (> 20KHz)
- Safe turn-off possible at large current without snubber capacitor

■ THE ACHIEVEMENT

- Our bus bars can now handle up to **200°C Tj** with inductance as low as **35nH** and a lifetime operation of **25 years**

Customer A

GaN module, 160°C Tj

Customer B

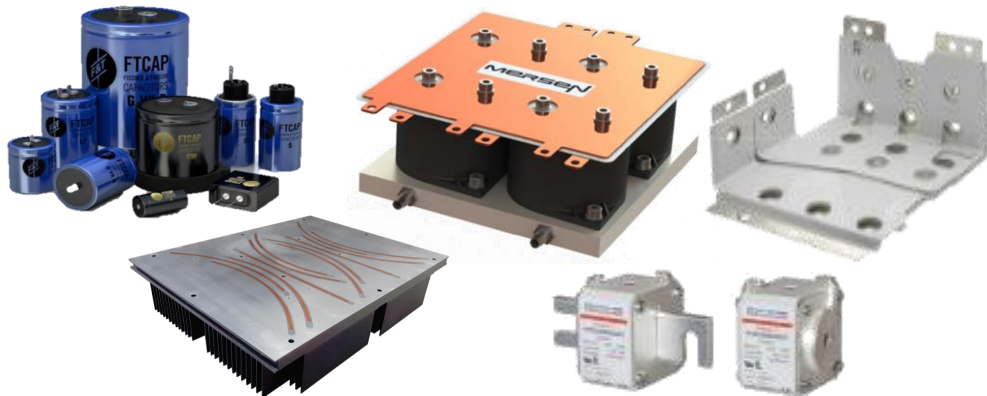
SiC 1,700 V module
150°C Tj

Customer C

SiC 1,200 V module
180°C Tj

SYNTHESIS AND CONCLUSION

- WE ARE GLAD OF BEING (*FINALLY* 😊) PART OF POWER AMERICA COMMUNITY !!
- NOW THAT WBG HAVE REACHED THE **EXPECTED MATURITY, AT SEMICONDUCTOR LEVEL**, IT IS COMMONLY ADMITTED THAT REMAINING **ISSUES RELATE TO PASSIVE SURROUNDING COMPONENTS** (CAPS, MAGNETICS, CONNECTIONS, THERMAL MANAGEMENT, FUSE...)
- MERSEN POSITIONS HIMSELF NOT ONLY AS A STAND-ALONE COMPONENTS SUPPLIER BUT ALSO AS **SOLUTION PROVIDER** MADE OF 2 OR MORE COMPONENTS, **CO-DESIGNED** AND PERFECTLY **OPTIMIZED** TOGETHER
- LET US KNOW YOUR CIRCUIT TOPOLOGY ALONG WITH YOUR PHYSICAL, ELECTRICAL, MECHATRONIC, THERMAL, **EMI CONSTRAINTS**: **WE CAN DEFINITELY EASE YOUR JOURNEY IN MODULE AND/OR INVERTER DESIGN**



Co-design &
optimization

