



MERSEN SOLUTIONS FOR EV / HEV

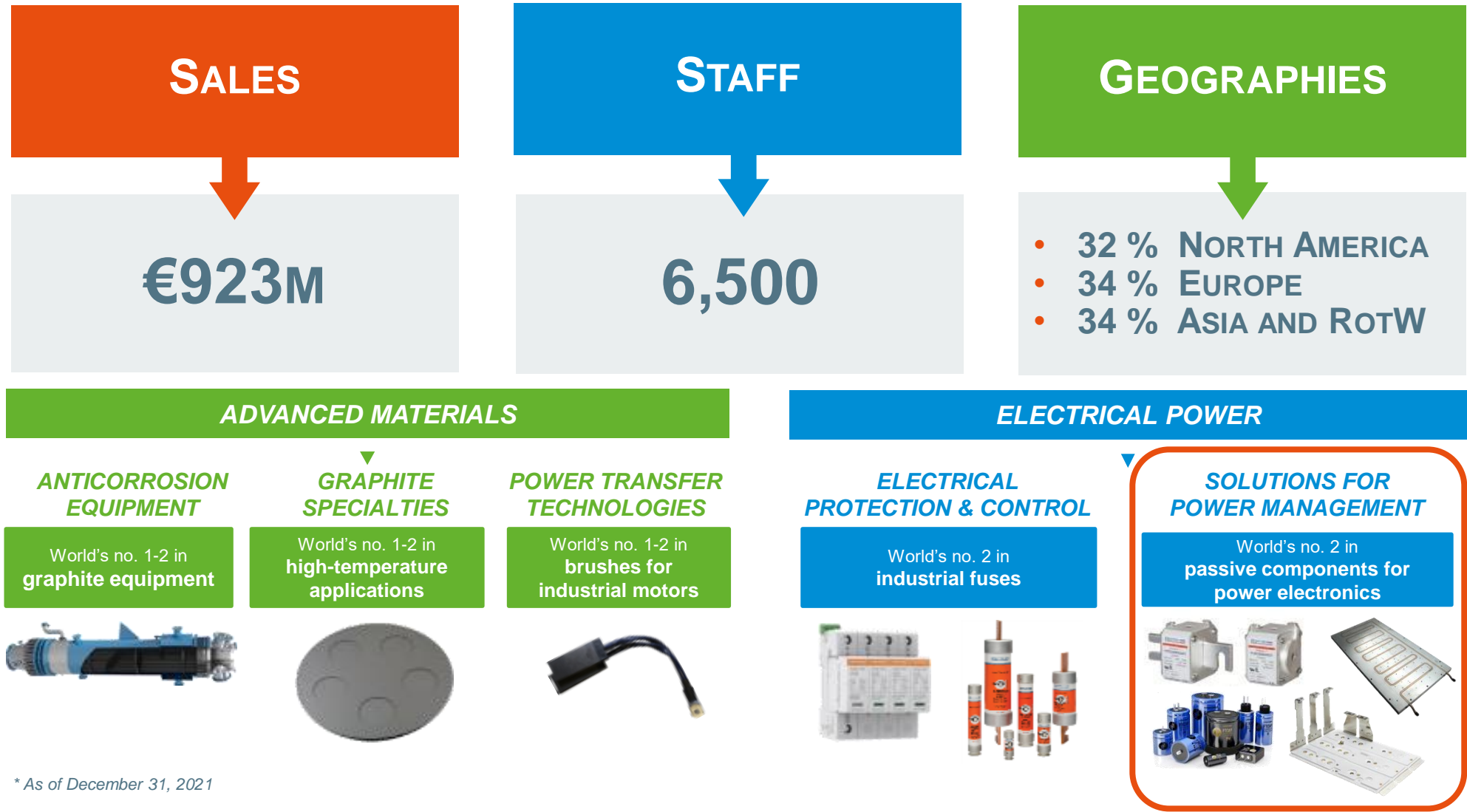
March 2022



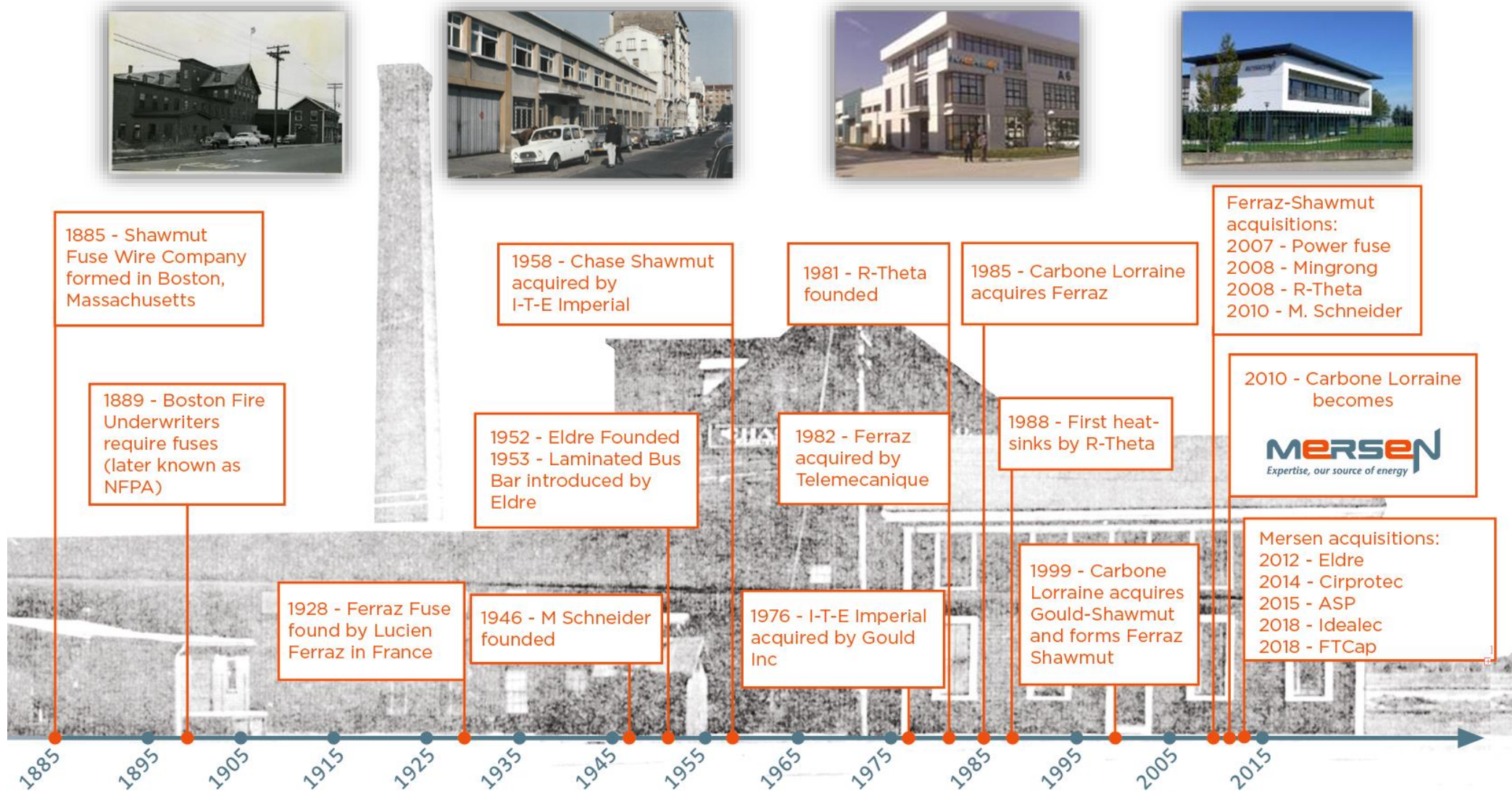
- Public
- Internal
- Confidential

MERSEN IN BRIEF

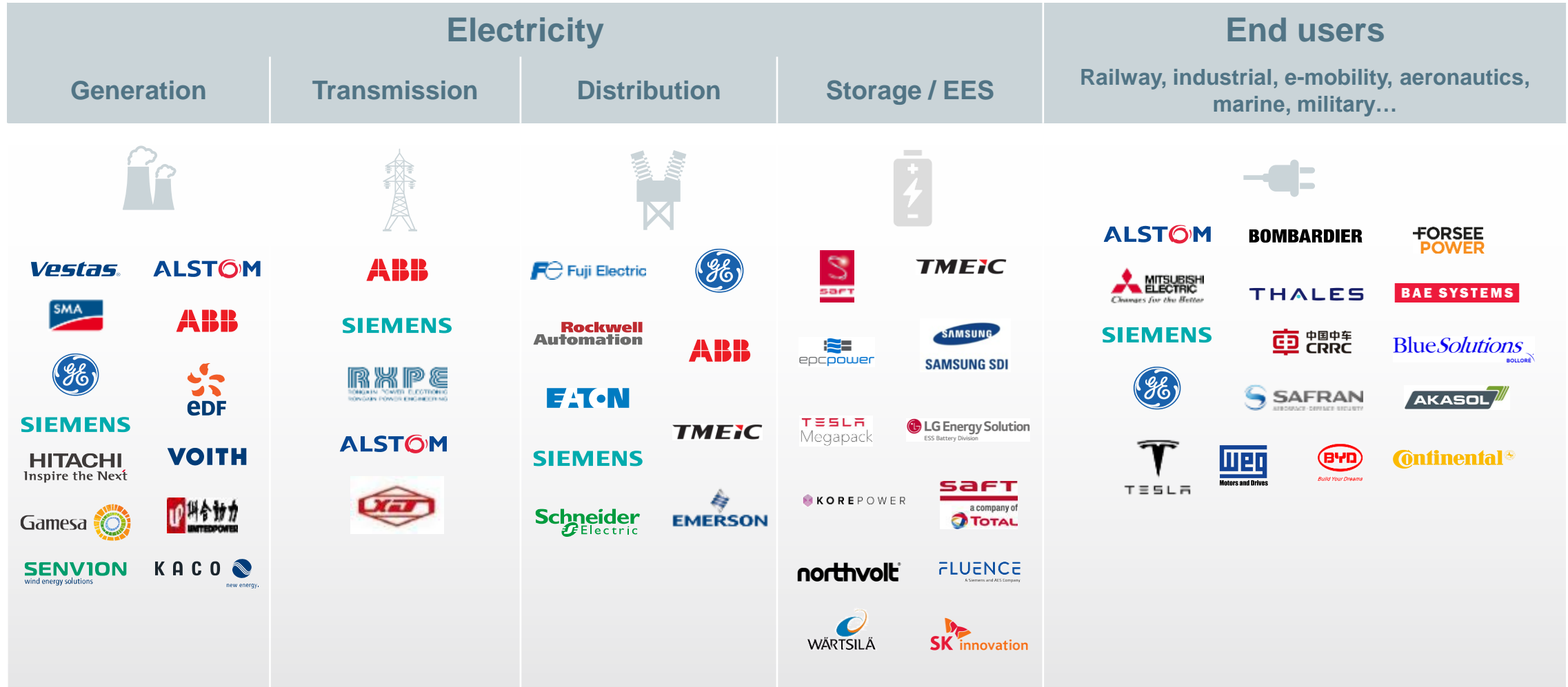
A FRANCE-HEADQUARTERED TRADED COMPANY WITH GLOBAL POSITIONS



OVER 130 YEARS OF EXPERIENCE



OUR CUSTOMERS ALONG THE ELECTRICAL POWER VALUE-CHAIN



SPM PRODUCT PORTFOLIO

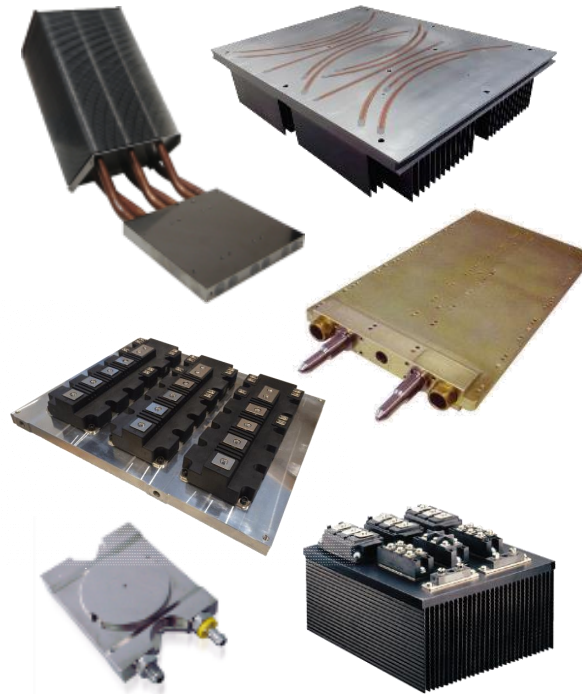
HIGH-SPEED FUSE AND HYBRID PYRO-FUSE

- UL Round and Square Body
- British Standard AC Protection
- IEC Cylindrical and Square Body (French / DIN)
- AC Low and Medium Voltage
- DC Rated For Traction
- DC protection for EV and EES



COOLING SOLUTIONS

- Air and Liquid Cooled Heatsinks
- Embedded Heat-Pipe Heatsinks
- Heat-pipe Assemblies



BUS BAR

- Laminated / Multi-layer
- Flexible / High T° / Low L
- Battery cell connection
- Powder Coated



CAPACITORS

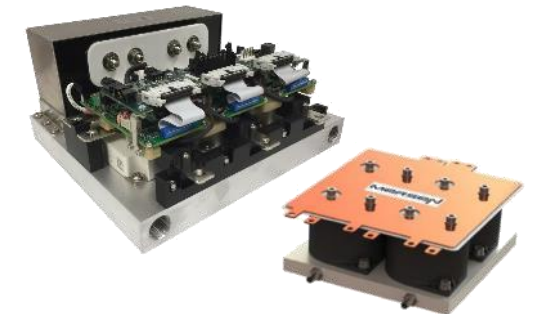


- Customized capacitors:
 - Film
 - Electrolytic
 - Sub-assembly



SUB-ASSEMBLY & POWER STACK REFERENCE DESIGN

- [Cap - bus bar] modules
- Inverter design optimization



MERSEN SOLUTIONS FOR POWER MANAGEMENT

A GLOBAL AND DEDICATED MANUFACTURING FOOTPRINT



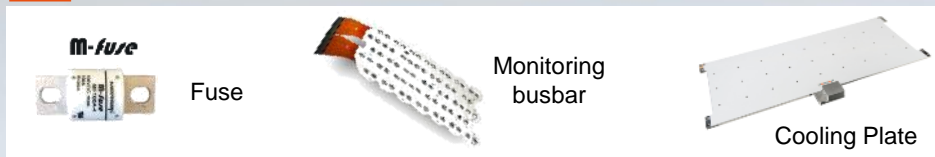
MERSEN SOLUTIONS FOR EV/HEV



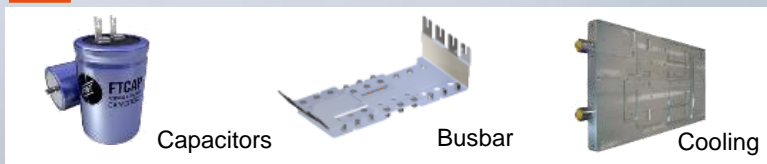
One of 16 Trophée Andros 2021, 100% electric race car, equipped with Mersen Busbar and Fuses

MERSEN SOLUTIONS IN EV/HEV APPLICATIONS

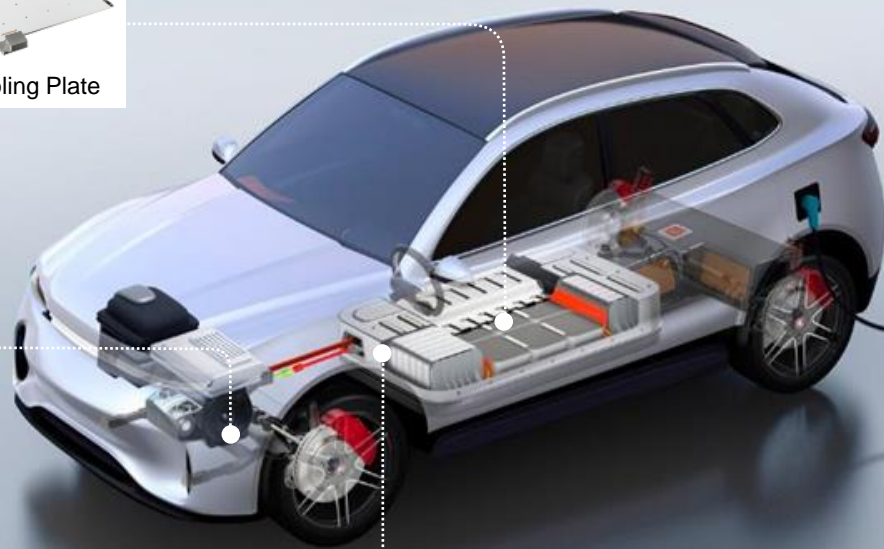
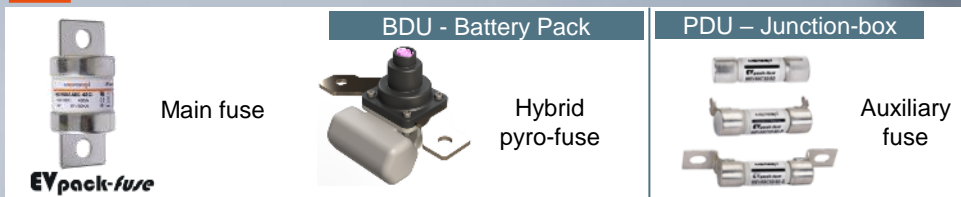
BATTERY MODULE



POWER INVERTER



ELECTRICAL PROTECTION OF VEHICLES



DC FAST CHARGING STATION 50kW-350kW+



DC BATTERY OVER CURRENT PROTECTION

MAIN AND AUXILIARY FUSE AND
PYRO-FUSE



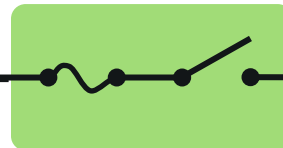
EV TYPICAL PROTECTION SCHEME

Main battery pack

1 to 16 battery modules assembled in series/parallel



Main protection (main fuse + DC contactor)



500 to 1,000 Vdc
Up to 600 A

1x (or 2x)



EVpack-fuse®

or



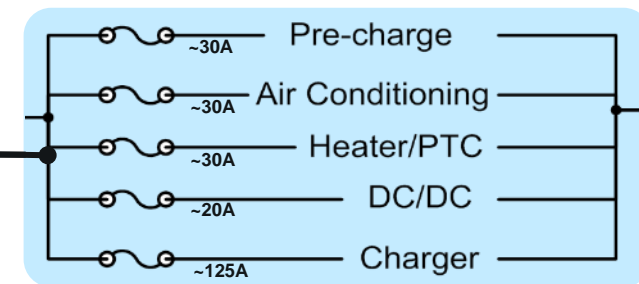
Hybrid pyro-
fuse

(500V or 1000Vdc)



Inverter +
Motor

Aux. protection



500 → 1,000 V

4x to 8x



10 → 50 A for aux.

+ 1x

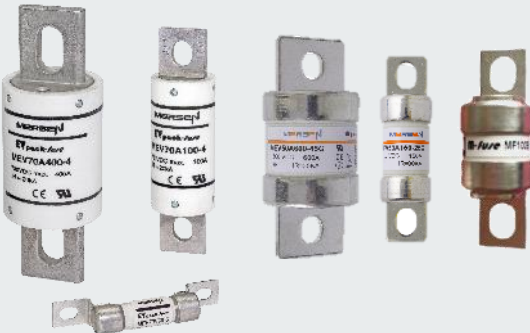



EVpack-fuse®

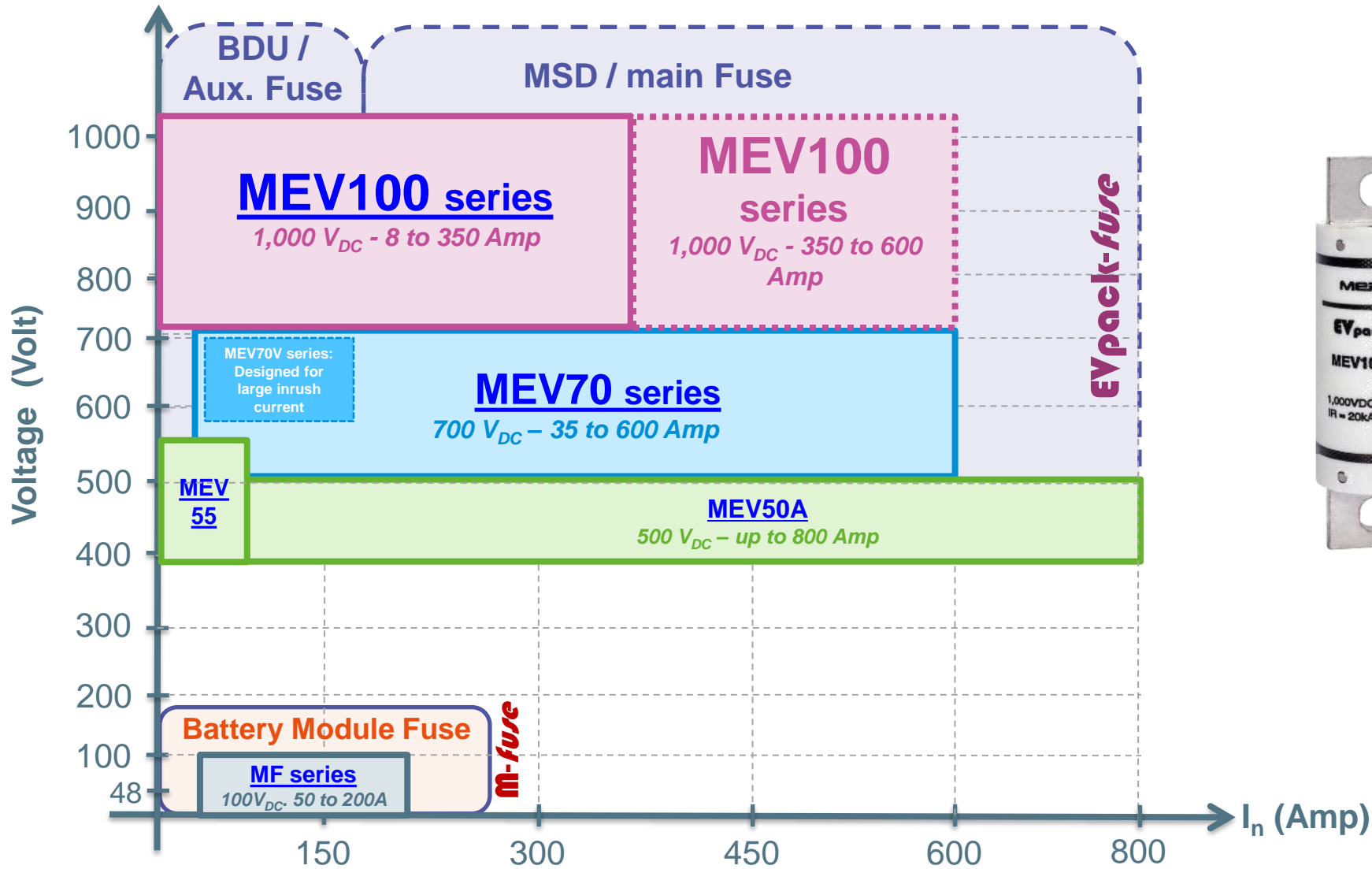
Up to 150A for
charger⁽²⁾

DC PROTECTION FOR EV BATTERY

2 TECHNOLOGY PATHS

	Monolithic technology	Hybrid pyrofuse technology
Product range	EV_{pack-fuse}	Hybrid pyro-fuse: PSS-X2
Core technology	<i>DC-Fuse</i>	<i>Pyro actuator + Fuse</i>
Value-proposition	Ultra fast-acting fuses (for large fault currents) Cost-effective & proven technology DC specific design	Fast-acting protection < 3ms Low-cost technology Close-to-zero conduction loss Operates for small or large fault current Very compact size High cycling performances High inrush current capabilities
Visuals		 <div>Jointly developed with Autoliv</div>

8 DC FUSE SERIES FOR BATTERY PROTECTION



PRODUCT HIGHLIGHT: MEV50A SERIES – 500VDC EV FUSE



PERFORMANCE

- Low Minimum Breaking Capacity (4xIn or 2kA) to secure contactor protection
- High interrupting rating of 30kA to address all types of battery
- Highly energy efficiency with low power losses
- Excellent cycling capability
- Compliant with ISO 8820 and international electrical standards



FEATURES & BENEFITS

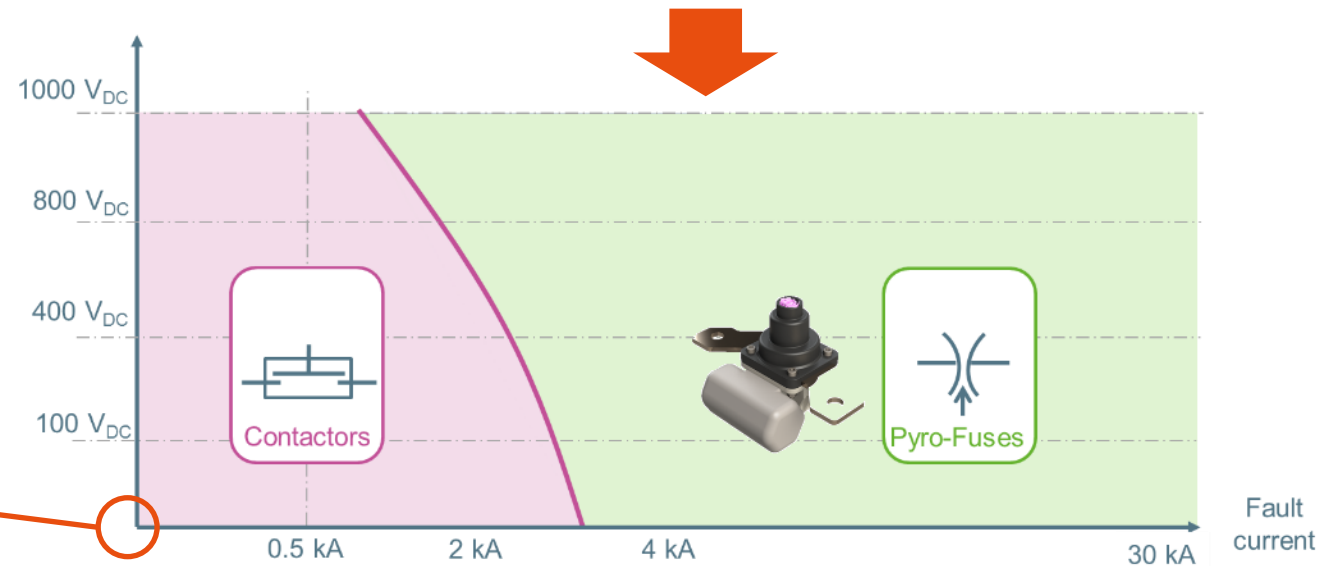
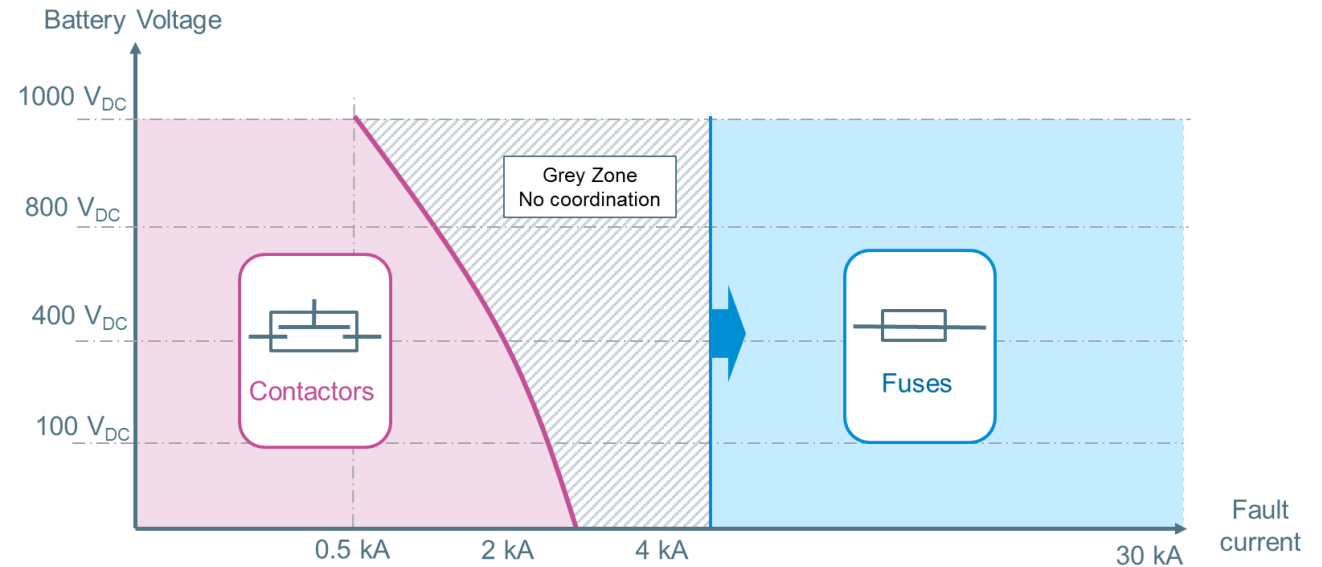
- Voltage: 500VDC - L/R \leq 2.5ms
- Ratings from 60 to 800A
- 5 compact sizes
- Long life cycle
- Visual identification code & serial number for traceability
- Customizable design
- Tested and validated with market leading contactors (Panasonic, Hongfa, TE, etc.)



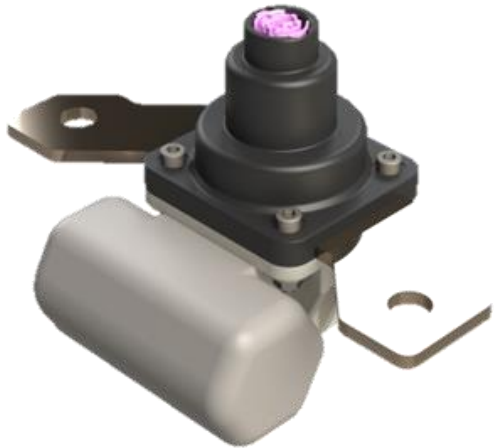
HYBRID PYRO-FUSE (PSS-X2) FUNDAMENTALS

HOW PYROFUSE ALLOWS BETTER COORDINATION WITH CONTACTOR WHATEVER THE VOLTAGE & CURRENT

- WITHIN EV BATTERY PROTECTION SCHEME, FUSE AND CONTACTOR SHOULD COORDINATE TOGETHER WHATEVER CURRENT AND VOLTAGE CONDITIONS.
- IN REALITY IT'S NOT !
A "GREY ZONE" REMAINS WHERE NONE OF THEM CAN SAFELY OPERATE
- PYROFUSE ALLOWS EXTENDING THE "FUSING" OPERATION TOWARDS SMALLER CURRENT AND ENABLES FULL COORDINATION
- PYROFUSE IS NOW ALSO REQUESTED TO OPERATE EVEN IF NO CURRENT (0-AMP)



PYRO-FUSE PSS-X2 : PRODUCT SPECIFICATIONS



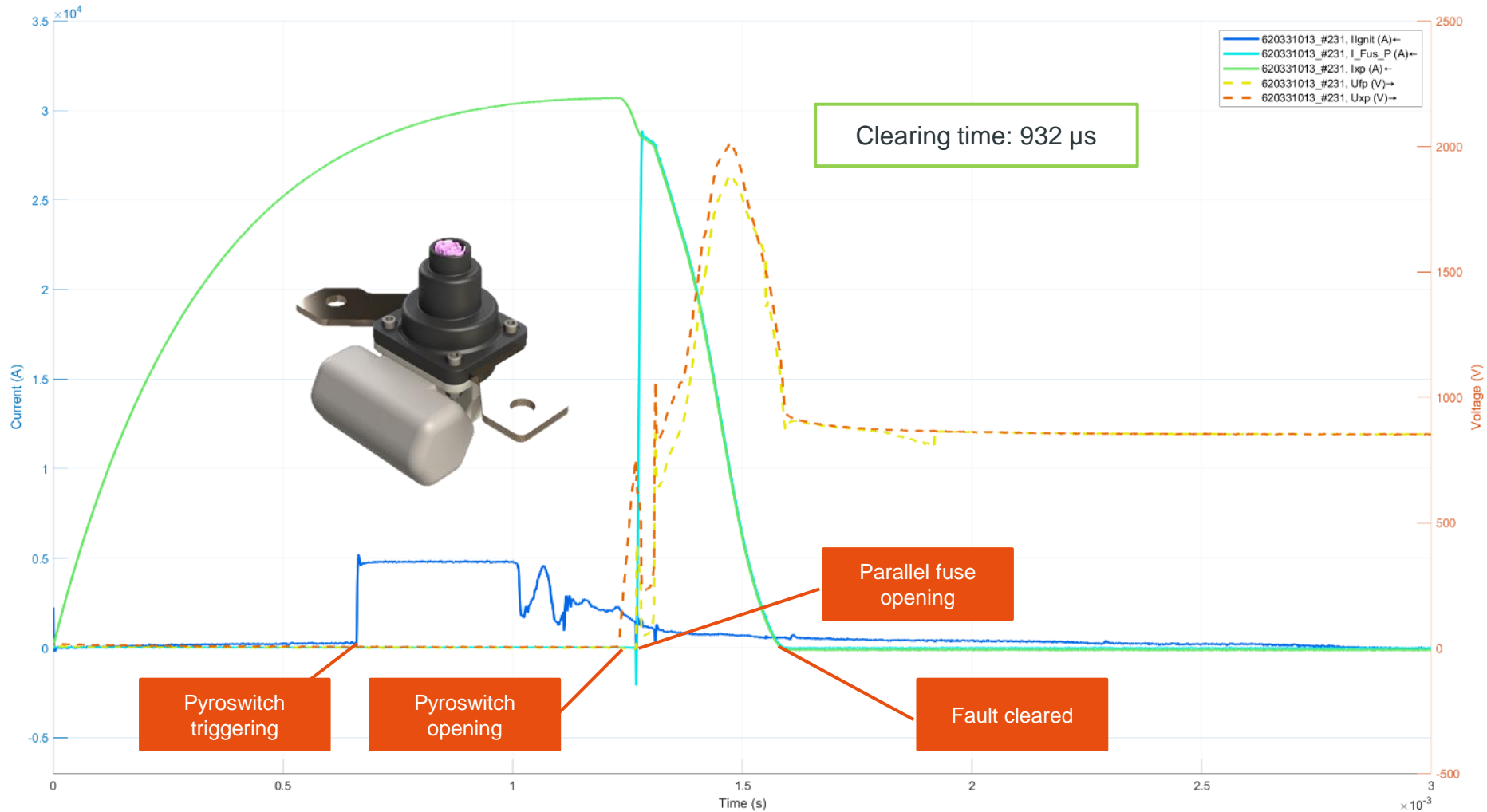
Specifications		Units	ADS1000
Max Voltage		Volts	1000
Continuous Current Rating at 85°C		Amps	400
Interrupt Current at 1000VDC		Amps	30,000*
Clearing Time @ 10 μH	at 10kA	ms	3
	at 25kA	ms	1
Minimum Breaking Current		Amps	0
Max Resistance before opening		μΩ	< 50
Weight		Grams	< 400
Operating Temperature		C	-40°C / +105°C
Isolation Resistance after Trigger at 1000VDC		MΩ	>10
Trigger signal connexion			squib connector (ABX5 code X)

* Tested up to 10 μH

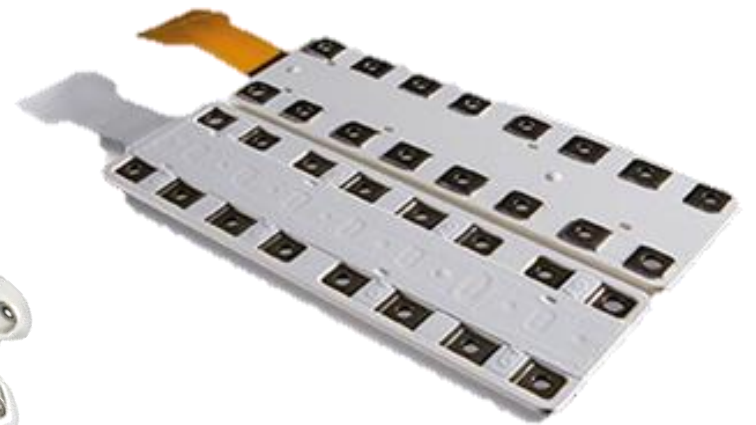
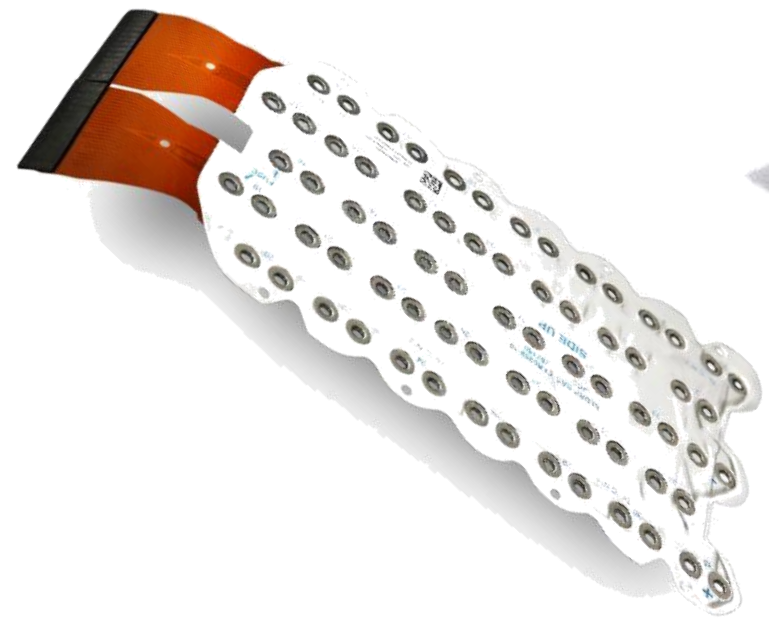
A-Samples are now available

PYRO-FUSE PSS-X2 - PERFORMANCE

LESS THAN 1 SEC TO CLEAR 30kA / 10μH / 950VDC / RT°

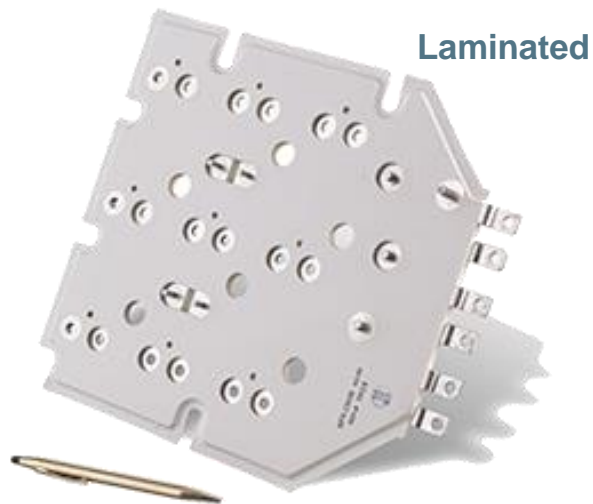


LAMINATED & MONITORING BUSBAR



ENGINEERING AND MANUFACTURING EXPERTISE

- LEVERAGING OVER 65 YEARS OF EXPERIENCE IN DESIGNING, MANUFACTURING AND TESTING BUS BAR SOLUTIONS
- GLOBAL ENGINEERING & R&D TEAMS
- EXTENSIVE IN HOUSE MANUFACTURING CAPABILITIES AND VENDOR NETWORK
- WIDE ARRAY OF BUS BAR TYPES AND VALUE ADD ASSEMBLIES
- SERVING CUSTOMERS WITH HIGH COMPLEXITY BUSINESS



MERSEN SUPPLIES 3 DIFFERENT TYPES OF BUSBAR IN THE EV INDUSTRY

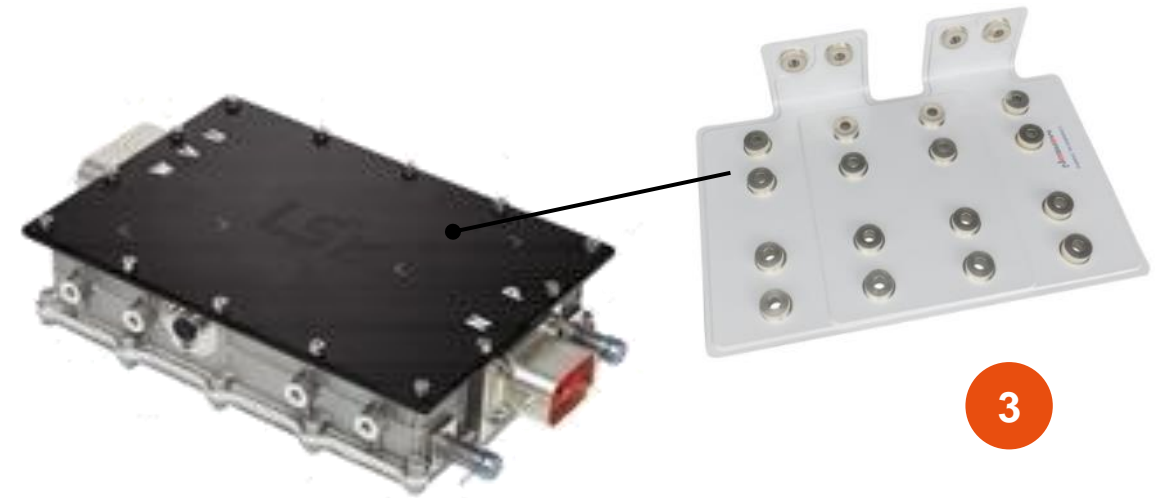
Battery busbar

To connect cylindrical, pouch or prismatic cells



Inverter busbar

To connect power electronics components



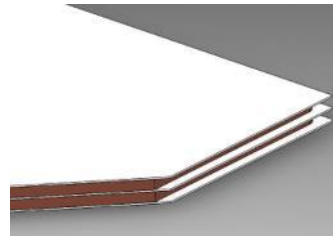
OUR BUSBAR SOLUTIONS

Powder coated busbar

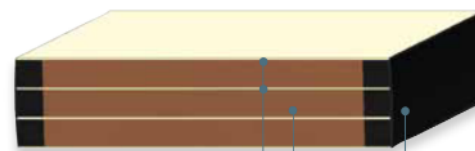


Laminated busbar

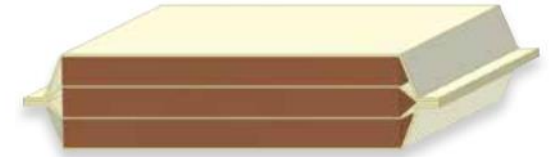
Open edge construction



Edge-filled construction



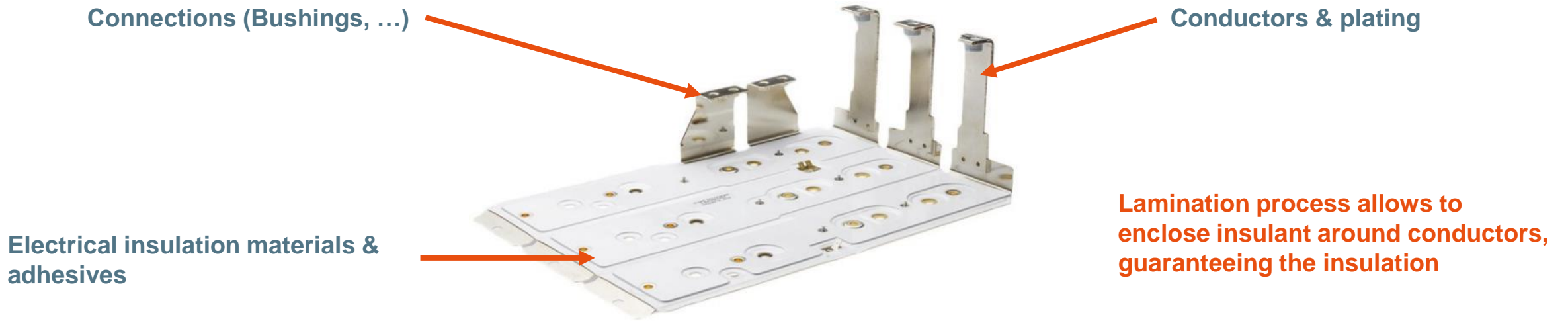
Sealed construction



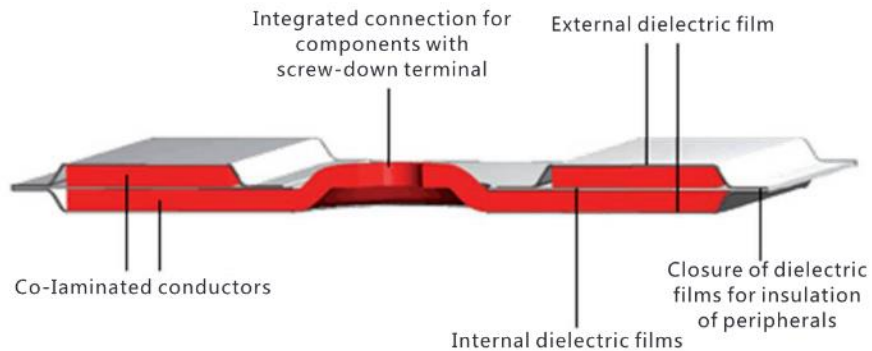
→ Each solution addresses specific needs

→ In general, sealed laminated busbar construction offers the best compromise between reliability and cost

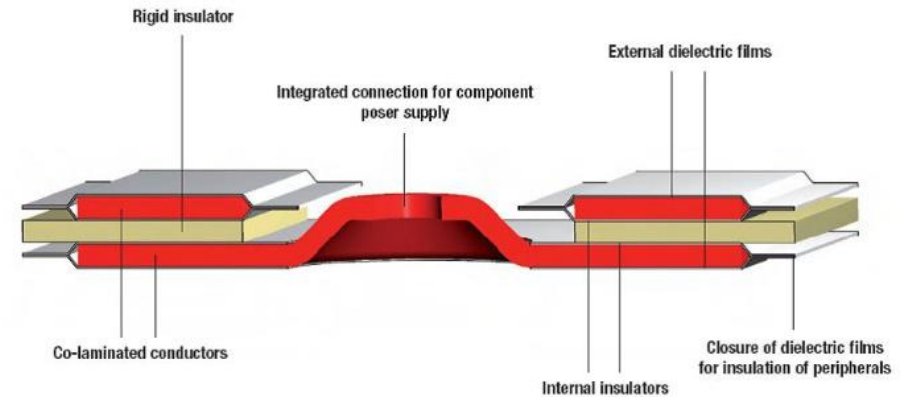
THE LAMINATED BUSBARS



Typical assembly :



When high insulation thickness is needed (e.g., Voltage >1000V), we add a rigid insulator



CONDUCTIVE MATERIALS & FINISHING



Materials that we use :

- Copper (standard : Cu-ETP)
- Aluminum (standard : 1050A)
- Other materials or grades are possible

Finishing prevents ageing and/or reduce contact resistance :

- Tin plating
 - Silver
 - Nickel (Chemical, sulfamate, Electrolytic, ...)
 - ...
 - No plating is also an option (not recommended)
- Ductile plating → Help electrical contact*
- Good ageing behavior*

Standard thicknesses :

- Conductors : From 0,5 to 6/8mm
- Plating : From <math><3\mu\text{m}</math> to 15/20 μm (or more)

BUSBAR CONNECTION SOLUTIONS

Many ways to connect components on the busbar, and busbar to the system :

Clinch stud



Standoff



Spacer



Clinch nut



Fast-on tab



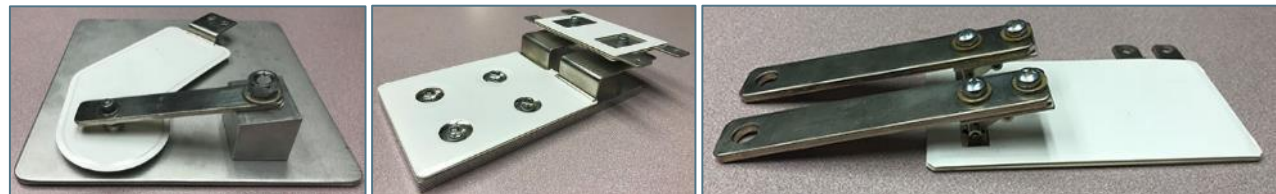
Welded power supply terminal



- Rugosity of terminals is controls to reduce at minimum the contact resistance
- Plating can be useful (and limit corrosion)

Other flexible connection solutions :

Mersen develops also flexible solutions to connect busbar with at least +/-1mm dynamic flexibility



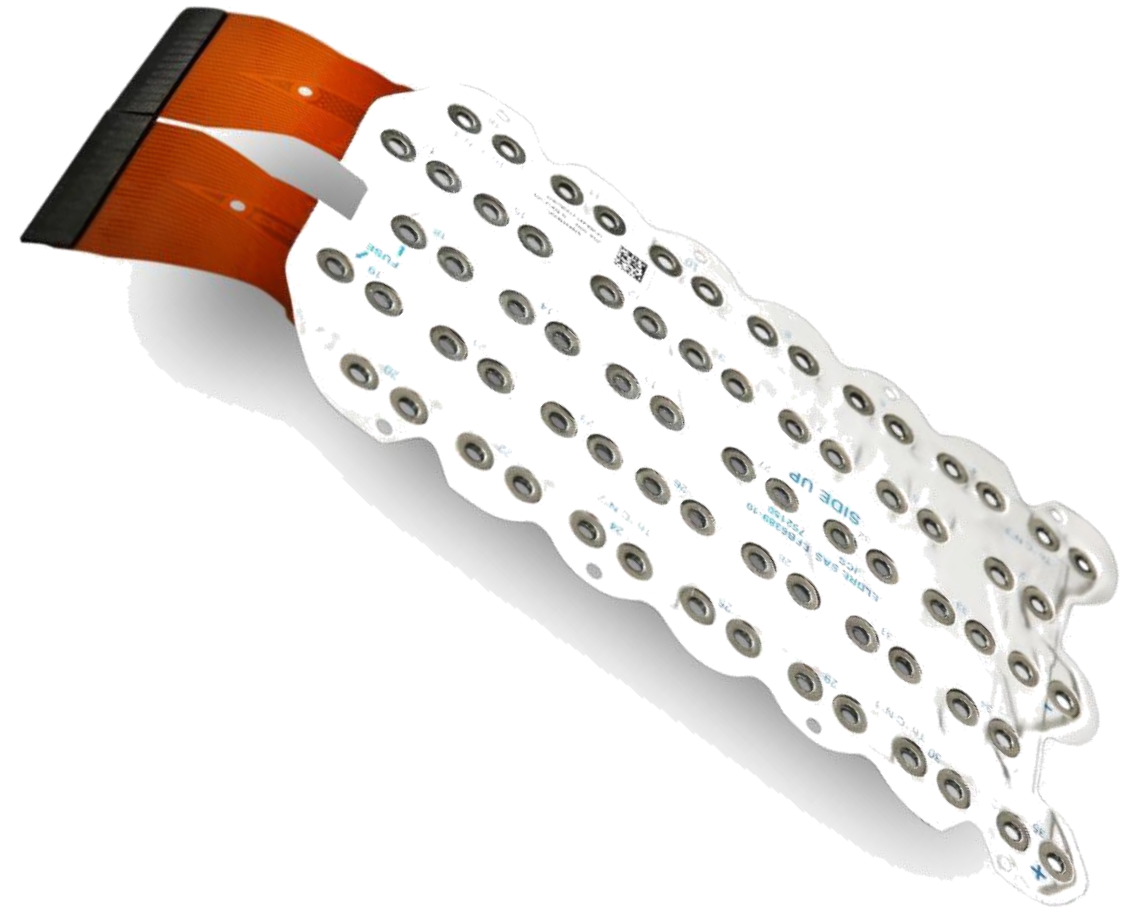
SMART MONITORING BUSBAR TO HANDLE BOTH HIGH POWER AND SMALL SIGNAL IN A SINGLE CONNECTION SOLUTION

■ ALL-IN-ONE CONNECTION SOLUTION:

- Connect Li-ion or supercap cells together
- Monitor small signals such as
 - Individual cell voltage
 - Local temperature

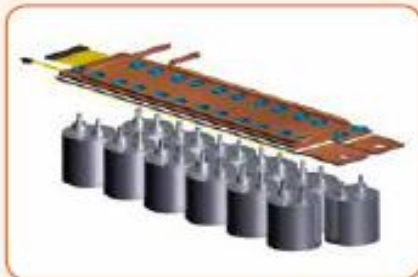
■ CUSTOMER'S BENEFITS:

- Ease assembly process
- No wiring errors
- Reduced voltage drop
- Increase current carrying capability
- High resistance to shocks and vibrations



MONITORING LAMINATED BUSBARS SOLUTIONS

LI-ION BATTERY PACKS



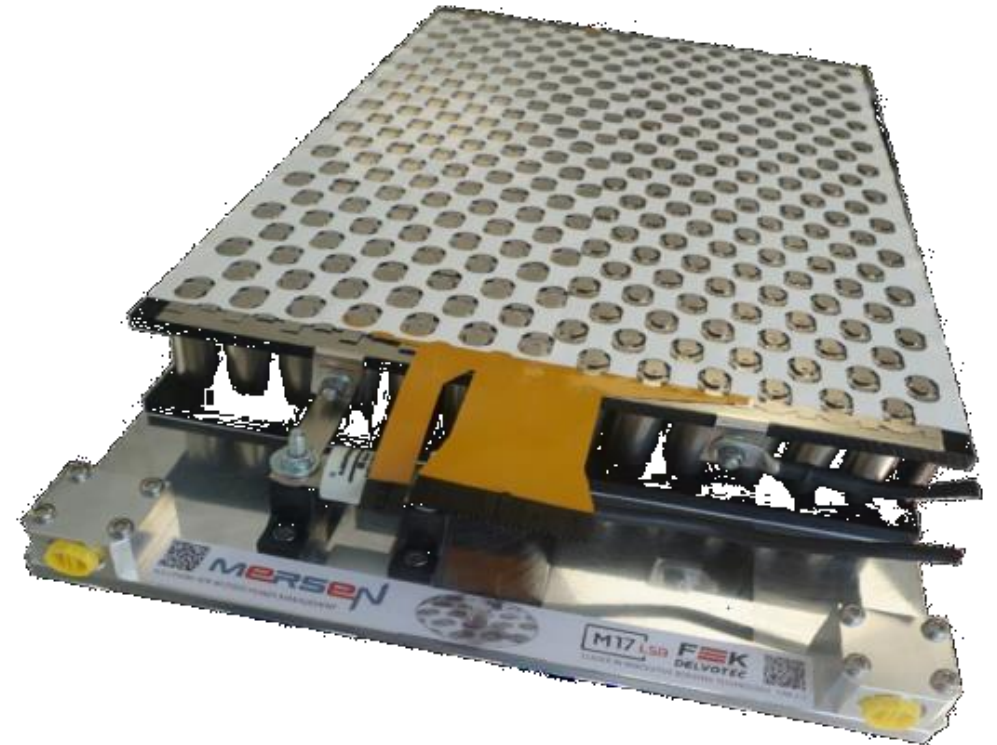
SUPERCAPACITORS





INFINI[∞]CELL: LOW-COST AUTOMATED LAMINATION PROCESS FOR MODULAR BATTERY CELL CONNECTION

INFINI[∞]CELL
Always moving ahead.



INFINI[∞]CELL, A BREAKTHROUGH TECHNOLOGY

Cylindrical Cells

Standard interconnection method :
Bus bars fixed on plastic casing + Wire bonding between cells and bus bar

Drawbacks :

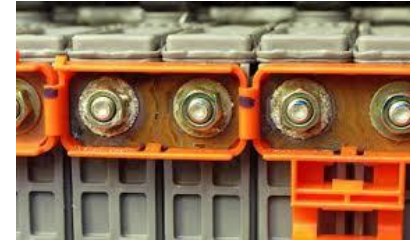
- Costs (Plastic casing, Wire bonding, ...)
- Thickness
- Monitoring not integrated



18650



46800

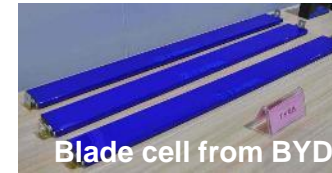


Prismatic Cells

Standard interconnection method :
Bus bars in plastic casing + Manual bolting

Drawbacks :

- No efficient thermal management
- High thickness
- Costs (Plastic casing, Manual bolting, ...)
- Low monitoring integration (wire harness)

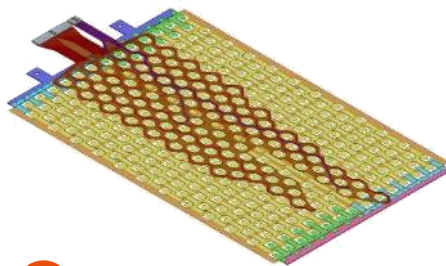


Blade cell from BYD

→ Larger cells : Thermal management becomes more challenging

INFINI[∞]CELL

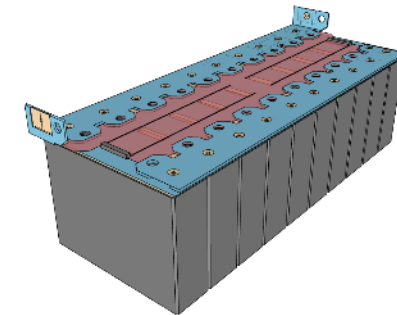
Design adapted for automated high-speed manufacturing process with high throughput



Cylindrical or Prismatic



Ultra thin busbar
(Inf. 1mm for cylindrical –
Inf. 4mm for prismatic)



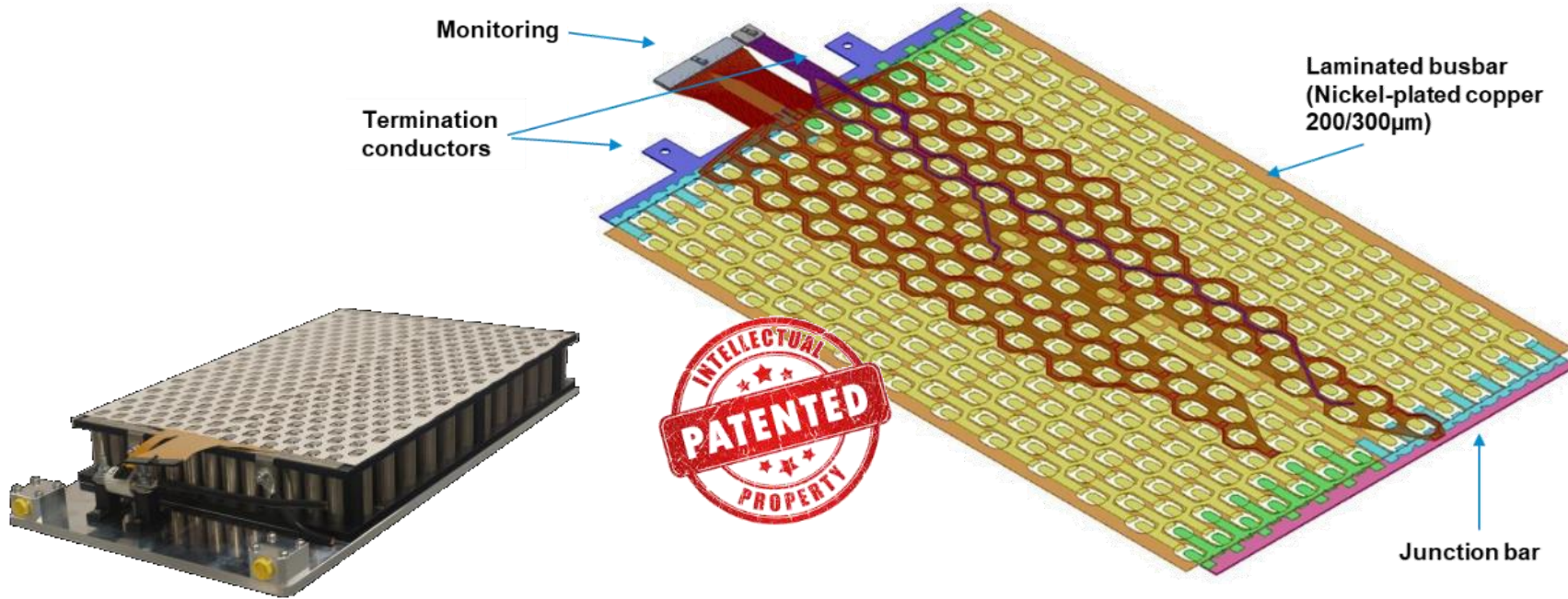
No significant overheating
(Thermoelectric simulations)

Both + and – contacts are soldered on the top. Battery bottom is free to be used for thermal management

High modularity to fit any battery module size and type

INFINI[∞]CELL: A NEW CONCEPT FOR BATTERY CELL CONNECTION

In the frame of a collaboration with laser-welding equipment manufacturer F&K Delvotec (GE) we have developed a **single-layer interleaved busbar**, connecting cells (from 18650 to 4680) and using an **automated high-speed process**:



- High design flexibility
- Ability to optimize the manufacturing assembly integration
- Suitable with copper or aluminum (cost reduction)
- Compatible with many integration processes (from wire bonding to laser welding)

A module demonstrator including:

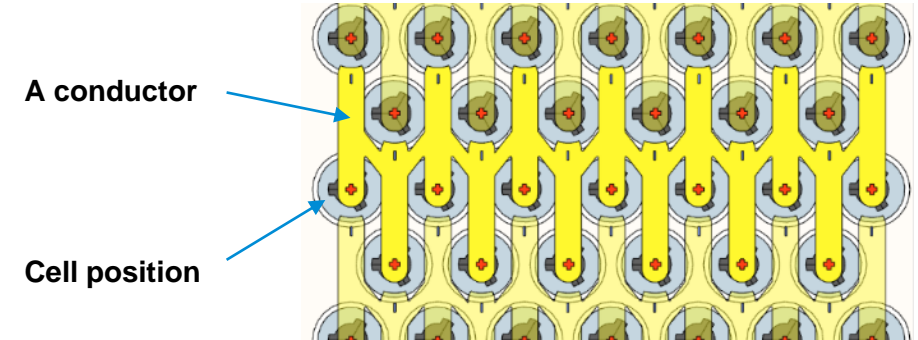
- A laminated busbar (with monitoring)
- Cooling plate
- Mersen fuse
- Laser welding by **F&K DELVOTEC**

A video of the process assembly is available here:



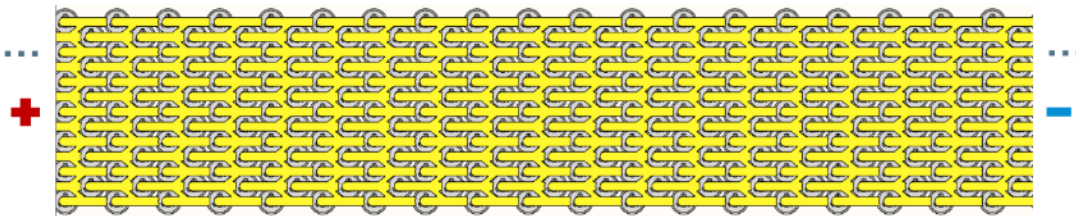
INFINI[∞]CELL CONCEPT: A FULLY FLEXIBLE PROCESS

Infini-Cell is based on a repetitive conductor pattern we can split as needed.



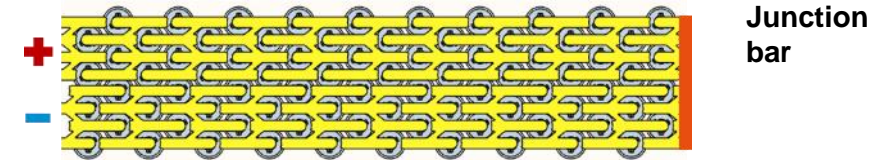
● A modular concept : To fit with most of the module configurations (XXsYYp)

Example : 19s13p



On request, foil can be split in 2 or more parts to reduce the final length. In this case, junction bar is used to connect foils together:

Example : 19s4p



● A custom concept : To fit all type of cylindrical cells

Concept is compatible with all cell's size, including most common 18650, 21700 or new 4680



INFINI[∞]CELL: COMPATIBLE WITH MANY INTEGRATION PROCESSES

INFINI[∞]CELL
Always moving ahead.

■ CUSTOM ABILITY OF INFINI-CELL MAKE IT COMPATIBLE WITH MANY INTEGRATION PROCESSES :

- Wire bonding
- Ribbon bonding
- Ultrasonic welding
- Laser welding



Adaptability to existing bonding equipments

High throughput

■ LASER WELDING PROCESS HAS BEEN DEVELOPED IN PARTNERSHIP WITH F&K DELVOTEC, A GERMAN EXPERT IN LASER WELDING EQUIPMENT AND PROCESS

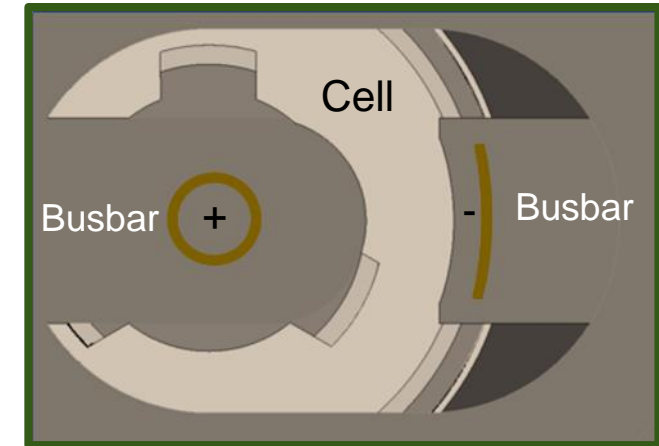
■ LASER WELDING IS >4X FASTER THAN WIRE BONDING

- 2 in 1 TAB welding (+ and – poles are soldered in one pass) is inherently >4x faster than conventional wire/ribbon insertion & cutting.

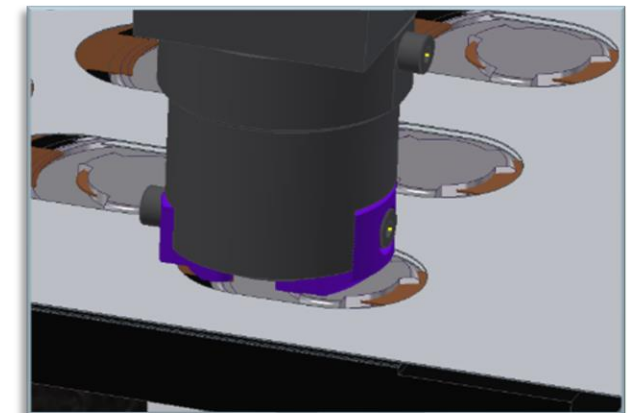
■ IT USES A POWERFUL 1kW CW 1070NM LASER IN ADDITION TO A BOND FORCE UP TO 60N APPLIED AT THE SAME TIME BY THE TOOL.

■ ZERO GAP CERTAIN

- The tool touches every weld in +/-1µm



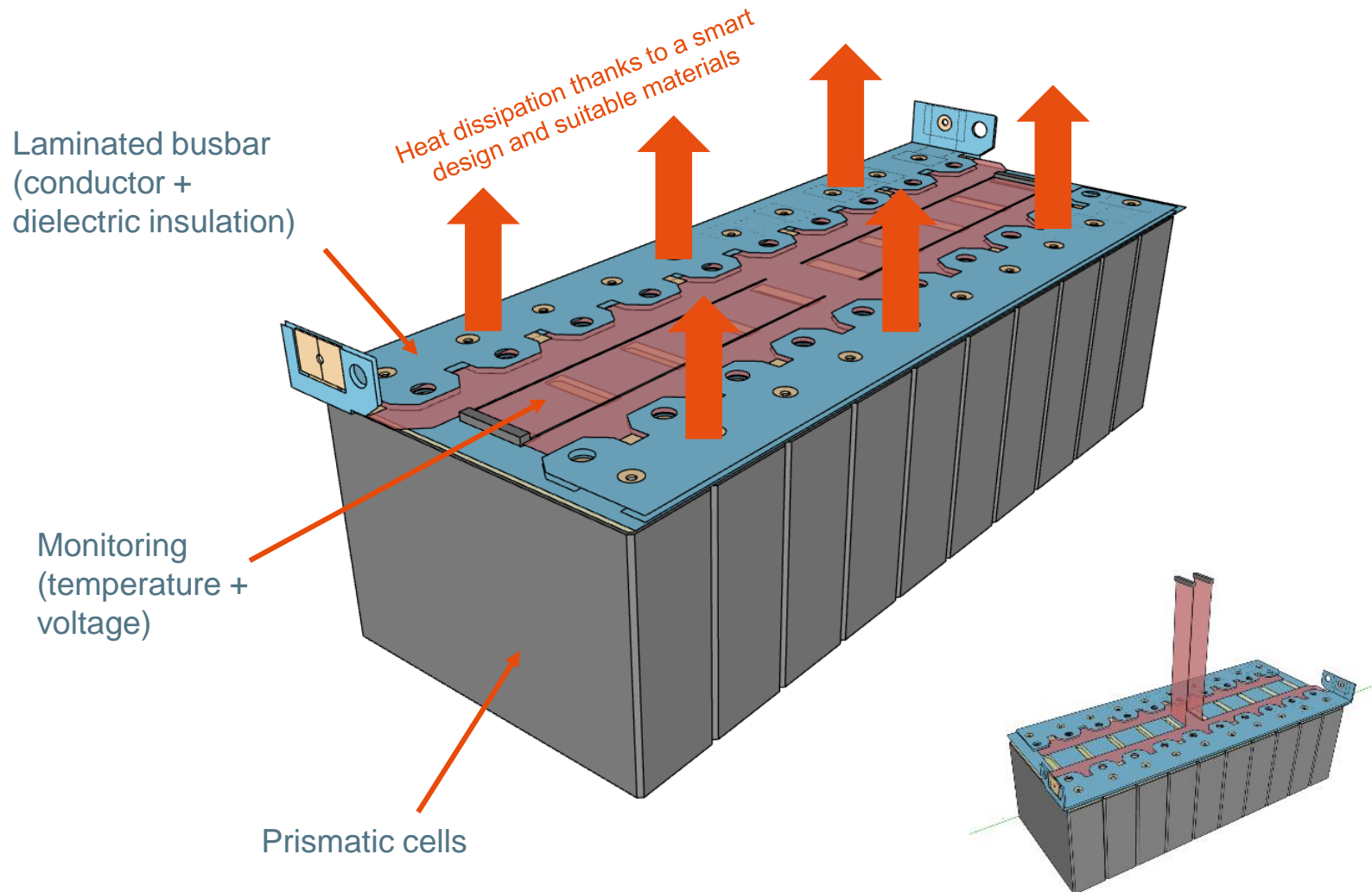
+ and – contacts are simultaneously soldered on the top of the battery cell. One on the center, one on the gasket)



Detail of the tool specifically developed by Delvotec to fit Mersen busbar design

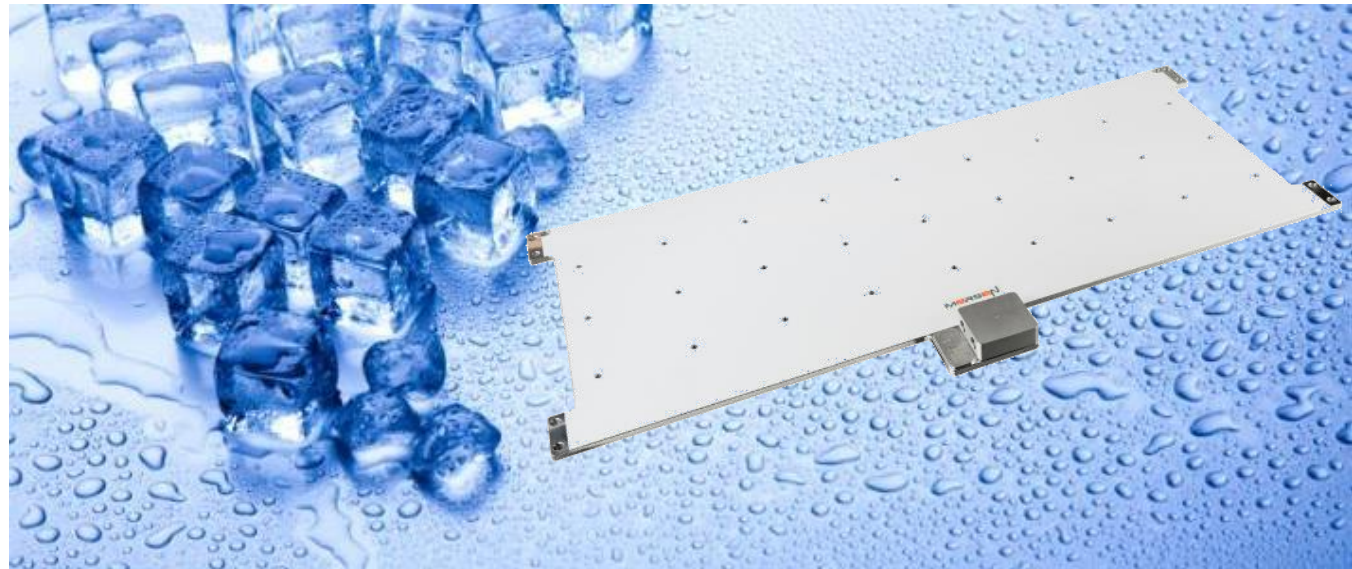
INFINI[∞]CELL FOR PRISMATIC CELLS INTERCONNECTION

INFINI[∞]CELL
Always moving ahead.



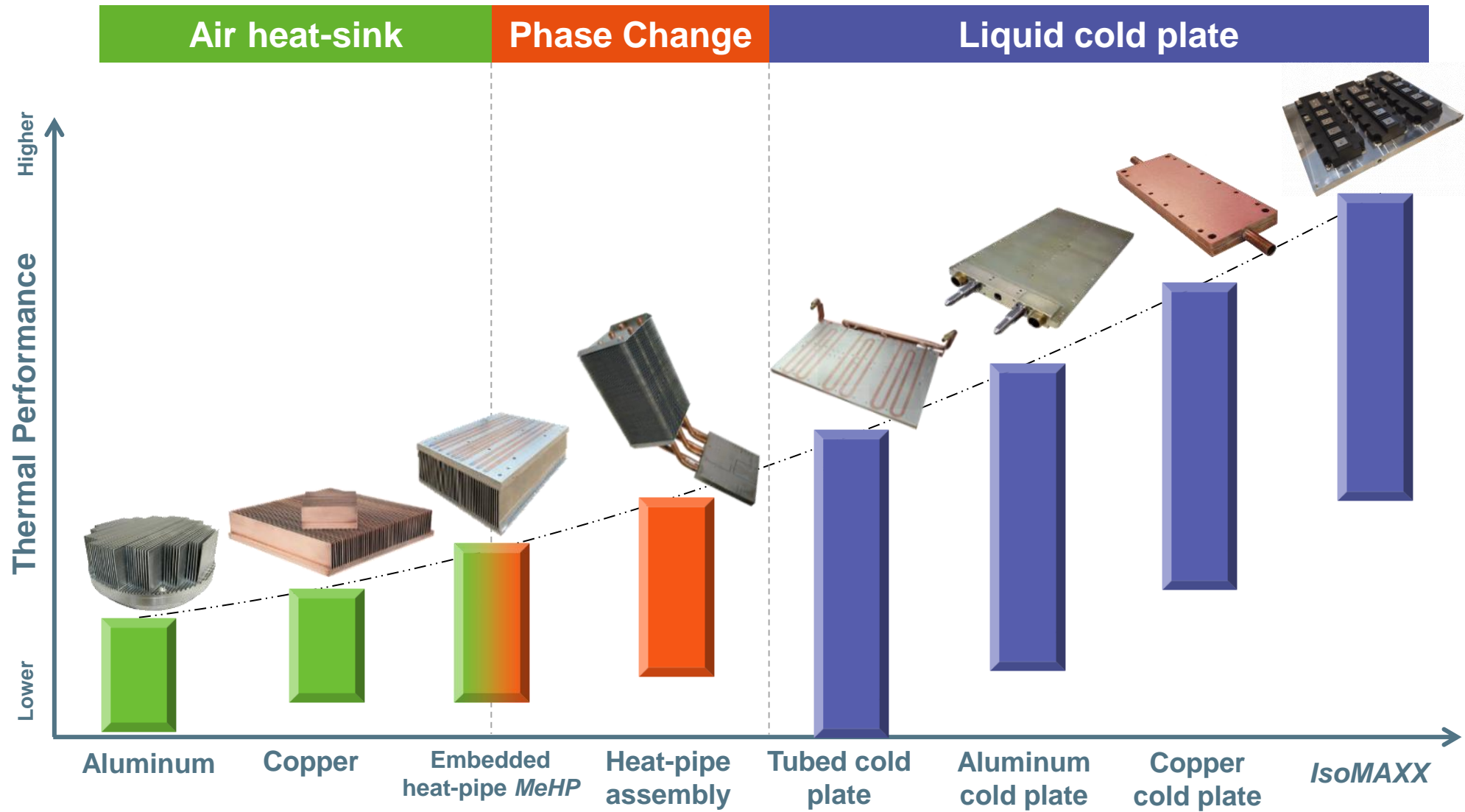
- **Custom and modularity**
- **Design for thermal spreading**
- **Copper to aluminum transition** (To reduce costs and for welding considerations)
- **Smart monitoring compatibility**
- **Suitable with many integration processes**
(Optimize manufacturing assembly / process integration (laser or wiring bonding, bolting, ...))

COOLING SOLUTIONS



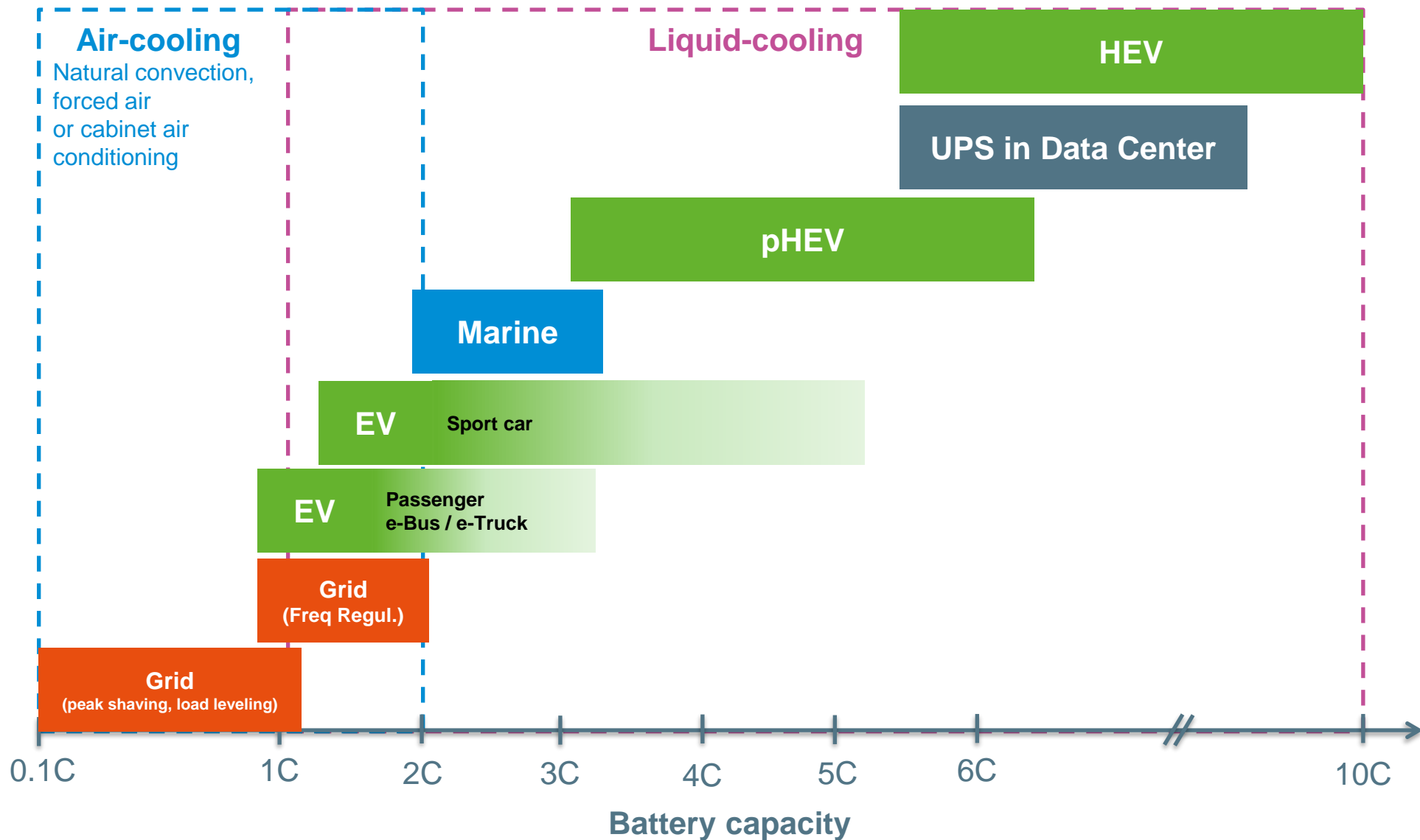
THREE COOLING TECHNOLOGIES

TO MEET CUSTOMER'S NEED AT THE CLOSEST



BATTERY USAGE SEGMENTATION

COOLING TYPE DEPENDS ON C-RATE VALUE



EXAMPLE OF 7MM-THICK AL VACUUM-BRAZED LIQUID COLD-PLATE FOR BATTERY COOLING (HERE WITH OPTIONAL DIELECTRIC LAYER)

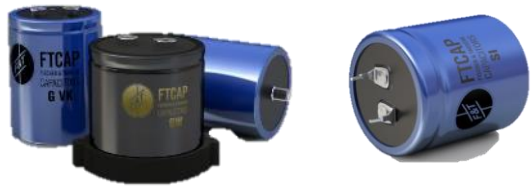


SPECIALTY CAPACITORS



A COMPLETE RANGE OF CAPACITORS AND SUB-ASSEMBLIES

Aluminum Electrolytic Capacitors



Screw Terminals

Snap-In



Motor Start

Special Type



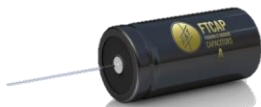
Cuboid Axial



Cuboid Radial



Solder Lug



Axial

Metalized Film Capacitors



Coax Cap



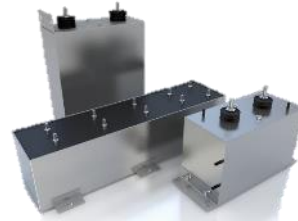
Energy Cap



High Voltage



Joule Cap



Power Box



Special Types

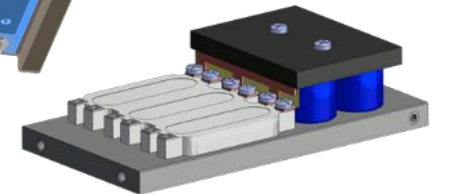
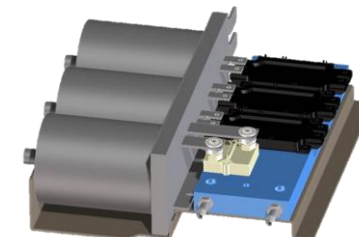
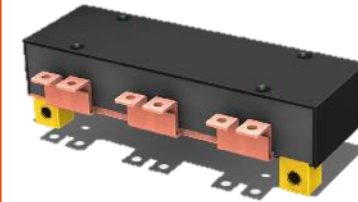
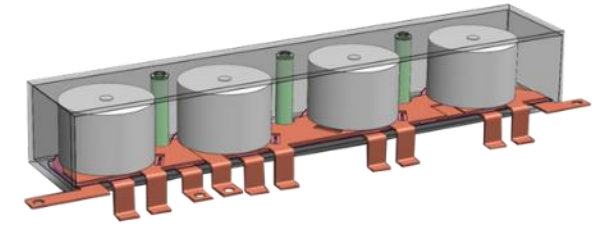


Castor Cap



Power Link

Customized value-add assembly



PRODUCT HIGHLIGHT: HIGH ENERGY FILM CAPACITORS

PERFORMANCE



- Robust design with aluminum housing
- Long life cycle
- High **peak current** rating up to **8.5kA**
- Highly energy efficiency with **lower power losses** vs competition
- Compliant with **IEC 68/1** and international electrical standards
- Self-healing polypropylene dielectric
- **Price-optimized** solution

KEY FEATURES



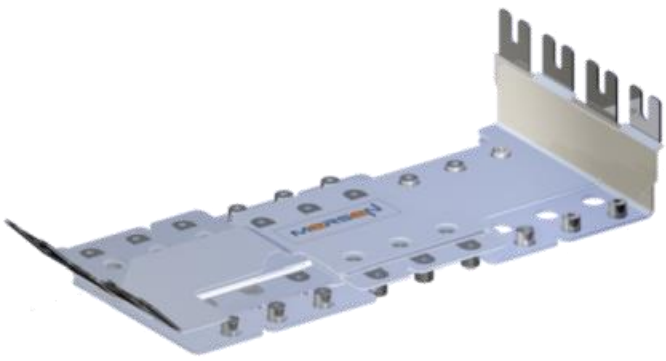
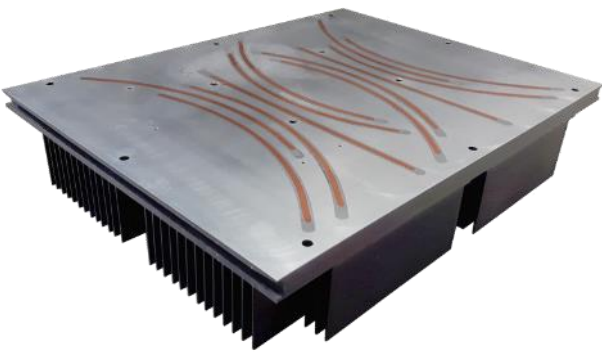
- Voltage: **600 VDC to 1500 VDC**
- Capacitances: **200 μ F to 3300 μ F \pm 10 %**
- Low-inductance: **15 nH to 60 nH**
- Ratings from **40 A to 91 A**
- Temperature range: **- 40°C to +85°C**
- 8 compact sizes: 2 diameters: **85 & 116 mm**,
4 heights: **95.5 & 107.5 & 130 & 167.5 mm**
- Visual identification code & serial number for **traceability**



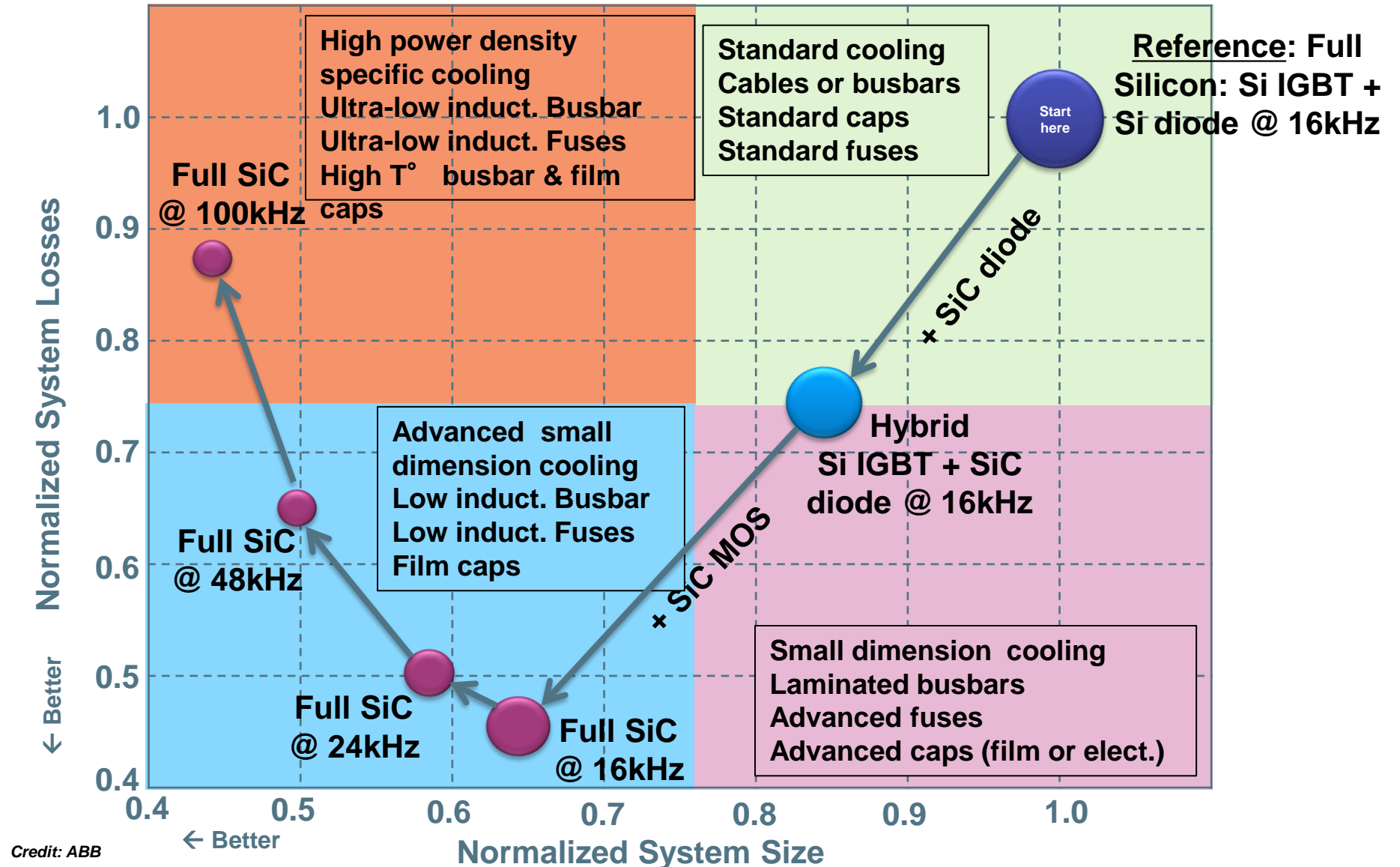
CUSTOMIZATION OPTIONS:

- Upon request, terminals with different heights for convenient busbar mounting
- Any other custom solutions on request

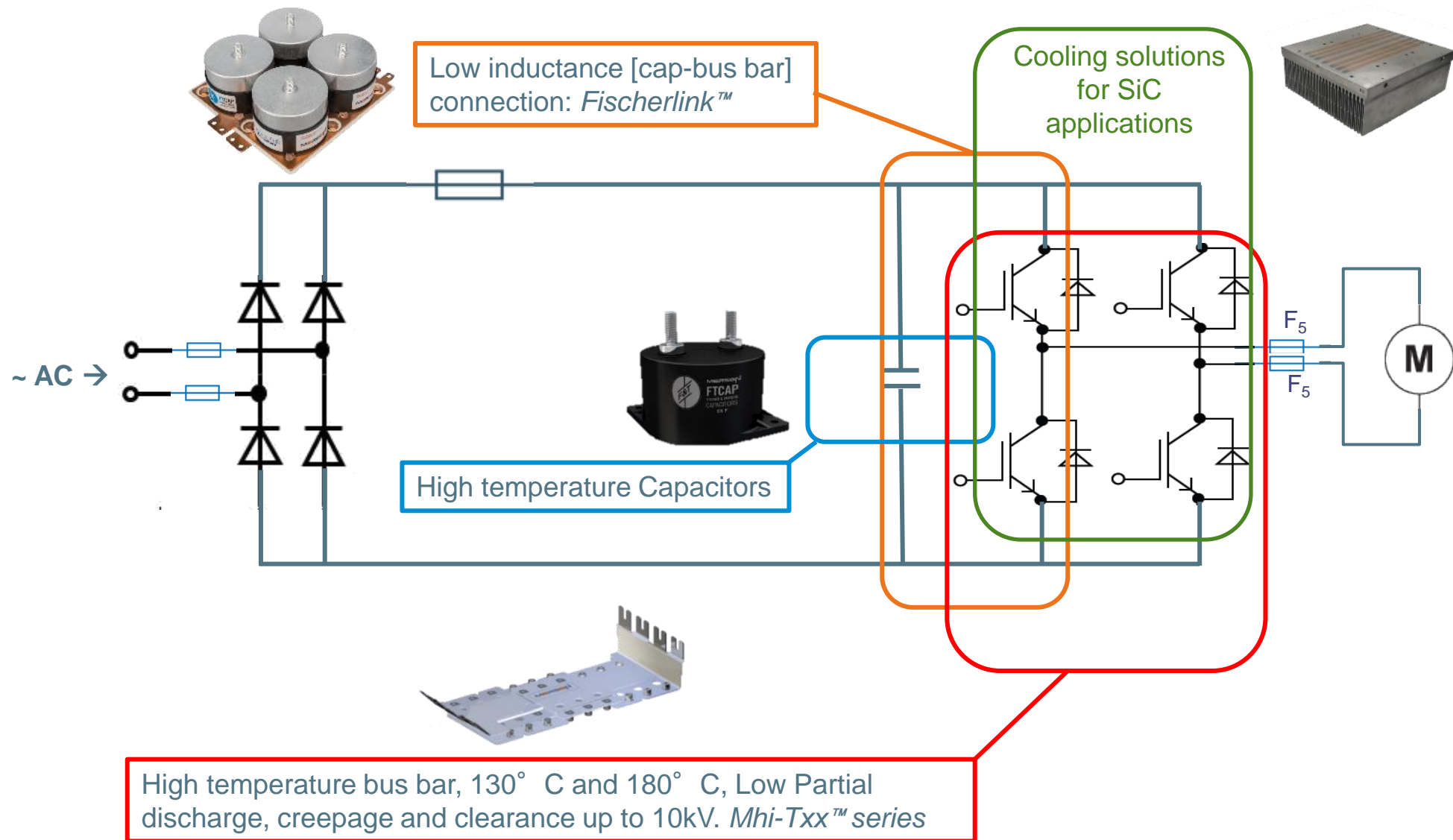
SPECIAL FOCUS ON SiC ELECTRONICS IN THE EV INDUSTRY



INFLUENCE OF SILICON CARBIDE ON SELECTED POWER COMPONENT SPECIFICATIONS



ADDRESSING SiC APPLICATIONS WITH MERSEN LINE OF PRODUCTS

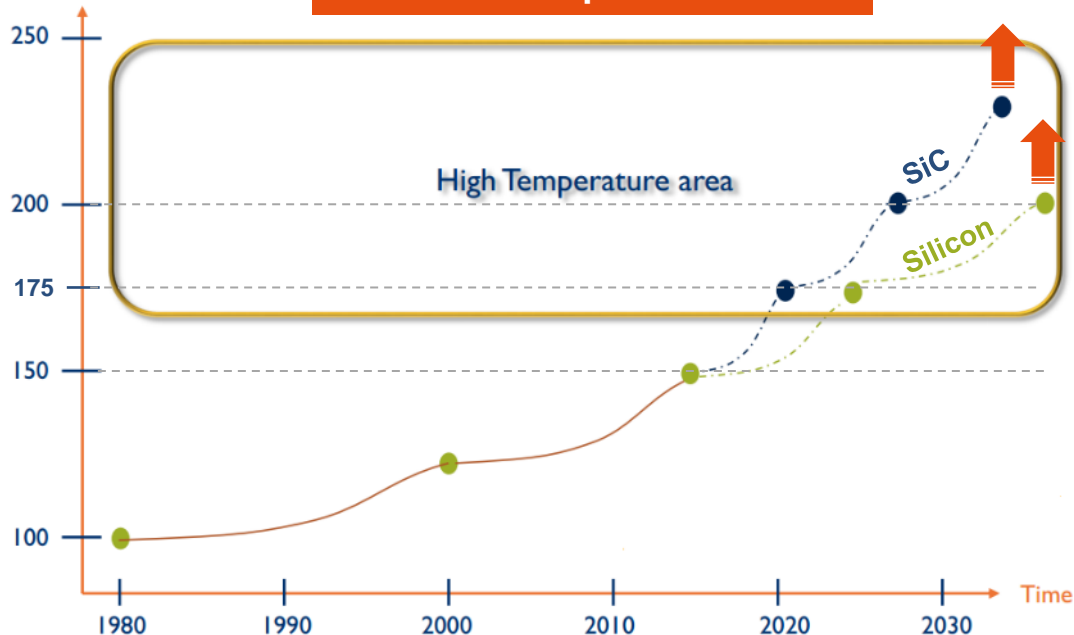


JUNCTION T° ROADMAP

A PARADIGM SHIFT...

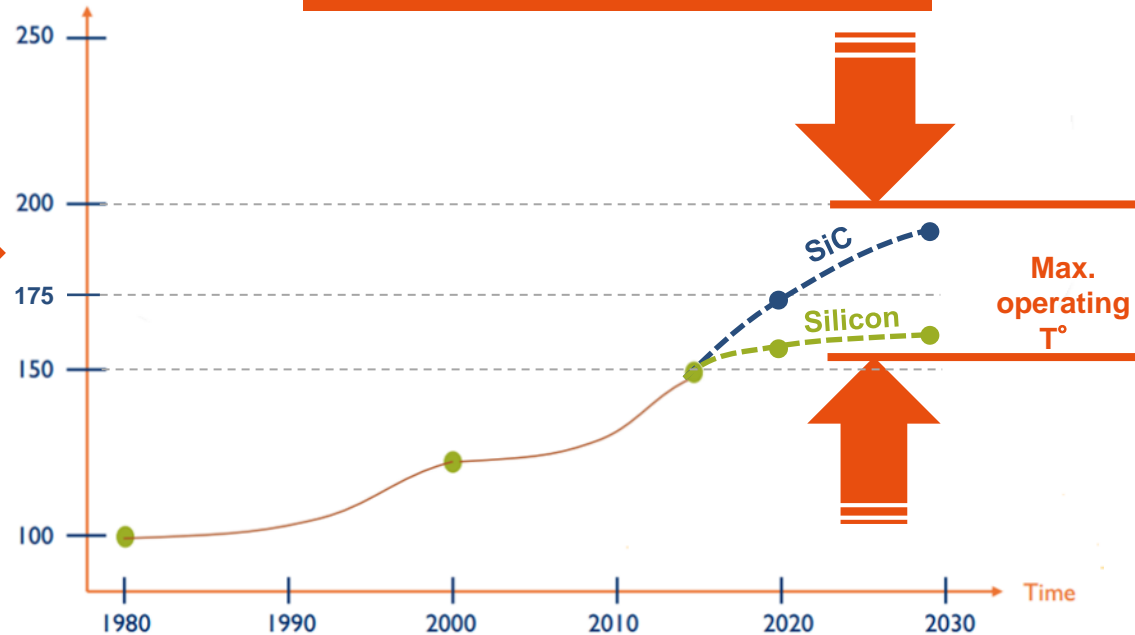
Junction temperature (°C)

What was expected so far:



Junction temperature (°C)

What will most-likely happen:



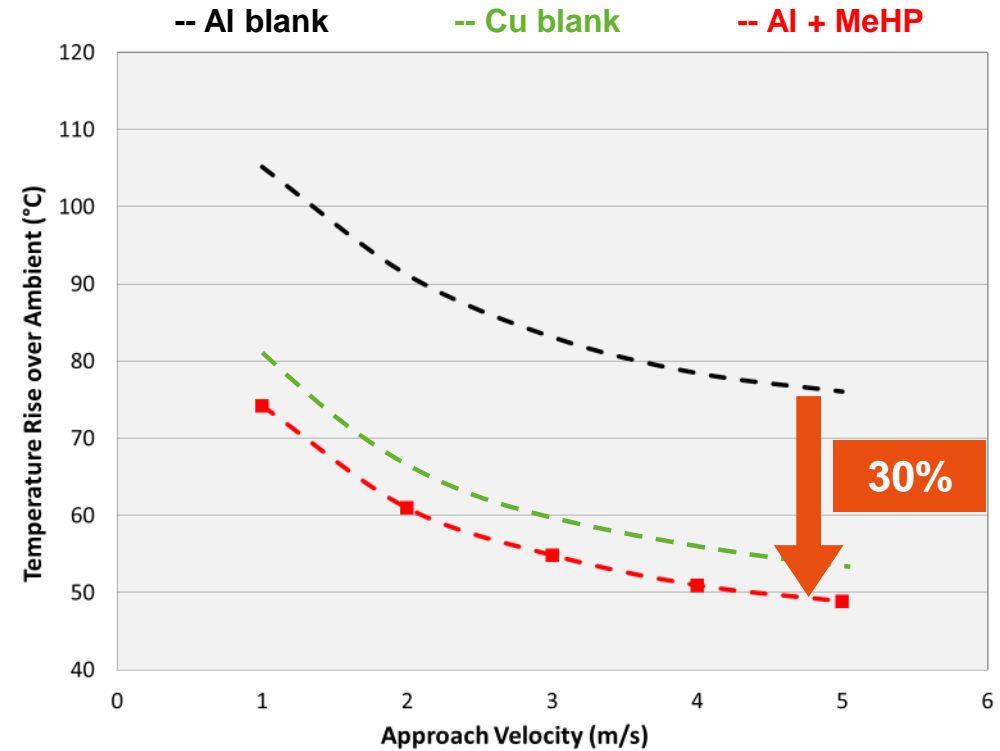
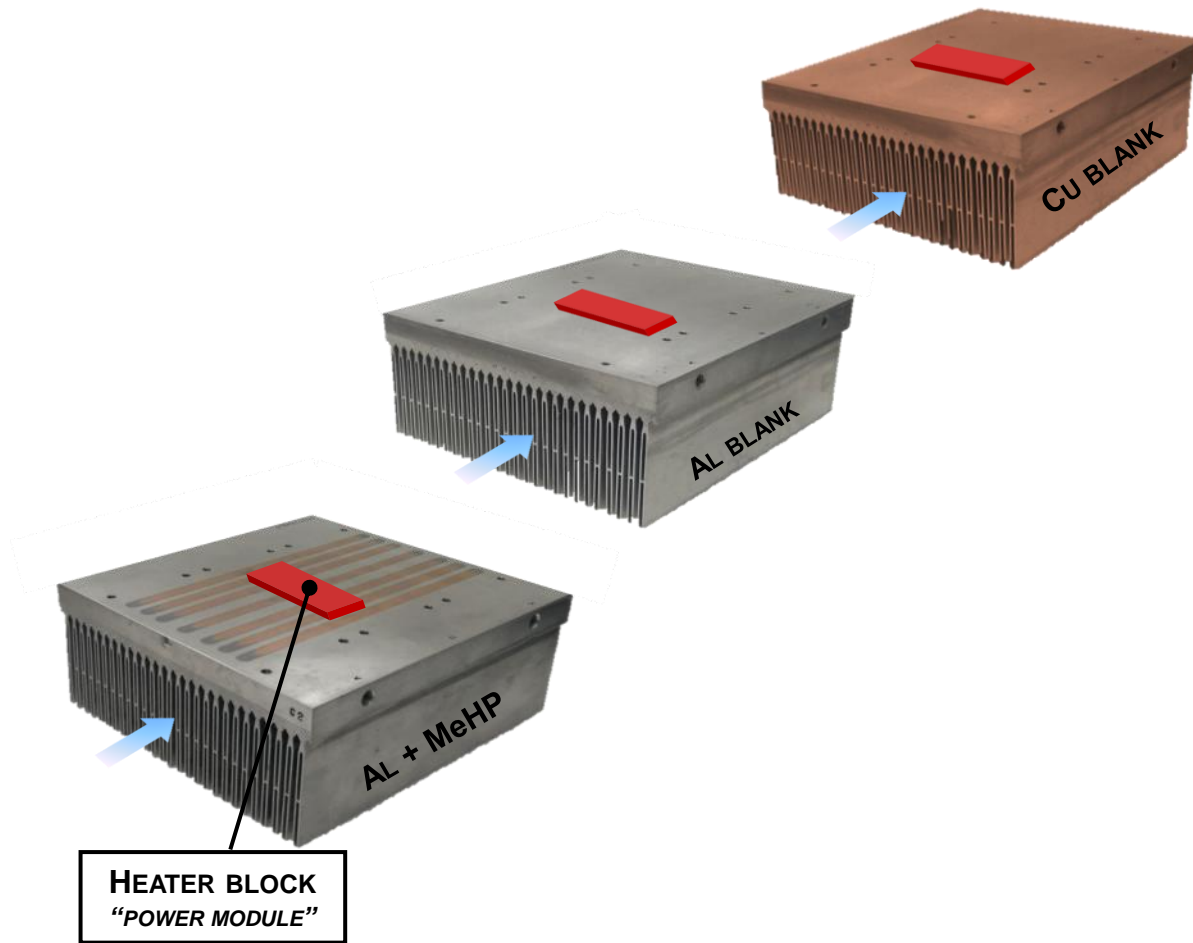
■ IT IS NOW CERTAIN THAT T_J MOST-LIKELY WON'T INCREASE AS INITIALLY FORECASTED, EXCEEDING 200°C FOR BOTH SILICON AND SiC OVER THE NEXT DECADE, FOR VARIOUS REASONS:

- Most of the power module packaging materials (Gel filling, housing polymer...) cannot handle such T° values
- Gate oxide layer in SiC MOSFET rapidly degrades beyond 200°C
- Chip-to-substrate soldering compounds are very unstable above 200°C
- Overall conversion efficiency decreases as T° increases
- We estimate T_j max will reach ~165°C for Silicon and < 200°C for SiC

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

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

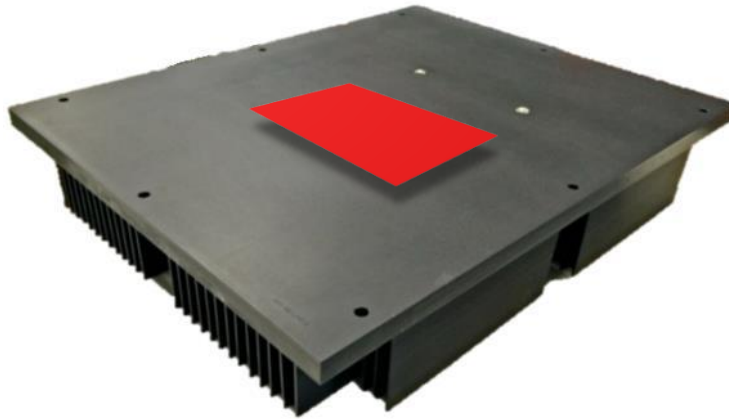
- A HEATER BLOCK, SIMULATING A POWER MODULE, HAS BEEN PLACED AT THE SAME LOCATION ON 3 DIFFERENT HEAT SINKS (AL+MEHP, AL AND CU) WITH SAME GEOMETRY. T° RISE IS MEASURED AT THE HEATER LOCATION AS A FUNCTION OF AIR VELOCITY



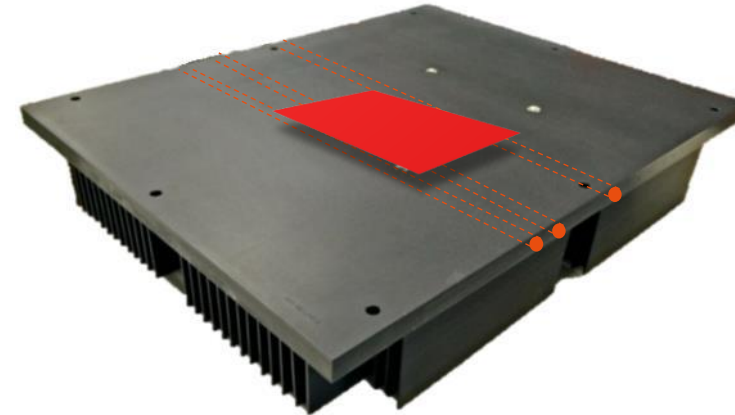
	Al blank	Cu blank	Al + MeHP
Average T° rise	Ref = 1	-23%	-30%
Cost comparison	Ref = 1	x 4	x 1.25
Weight	Ref = 1	x 3.5	1

IMPACT OF eHP ON SiC MODULE THERMAL SPREADING

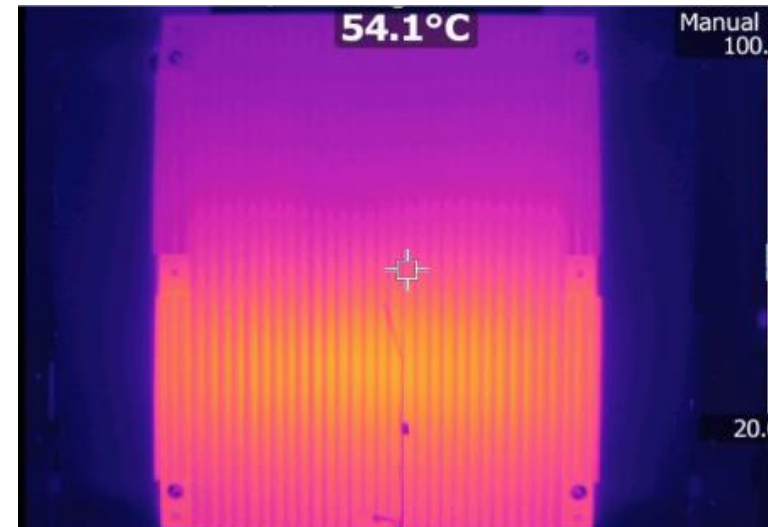
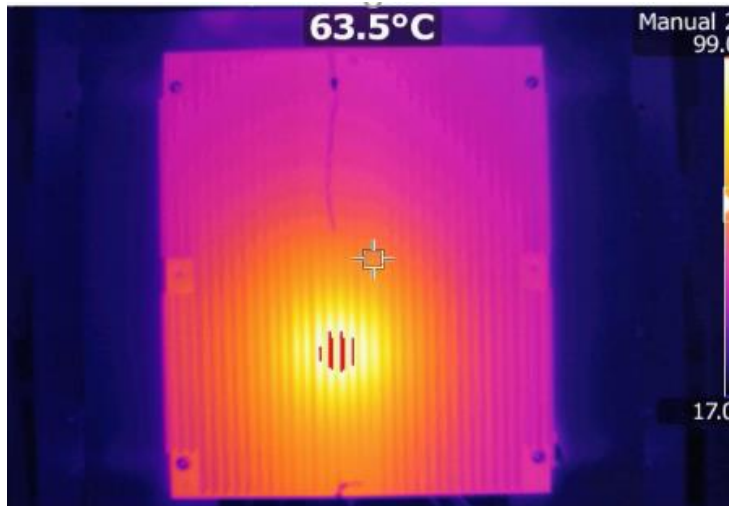
NO HOT-SPOT ANYMORE!



BLANK HEATSINK

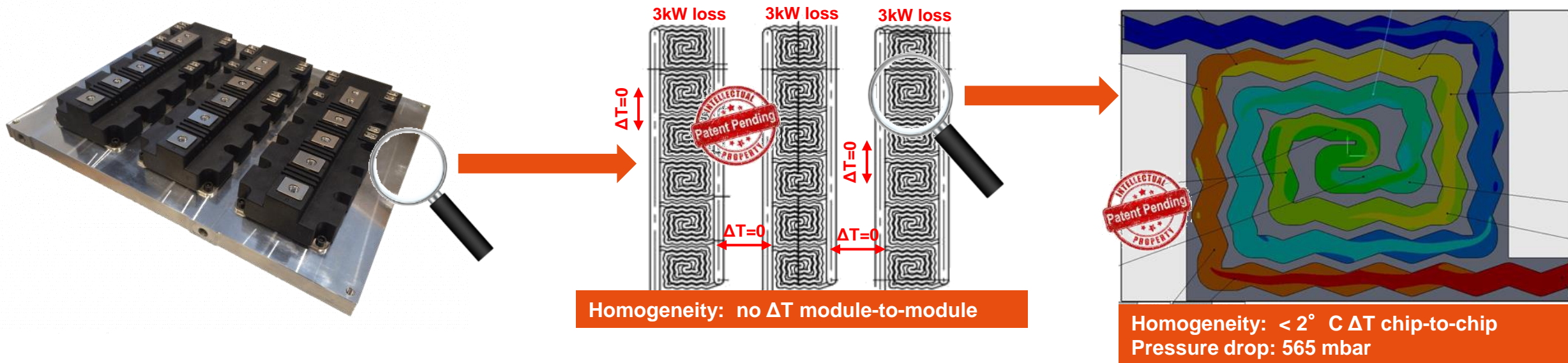


EMBEDDED HEAT PIPE MeHP
(INSERTED INSIDE THE BASEPLATE)



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:** $R_{th} \sim 6^\circ \text{C/kW}$
(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**



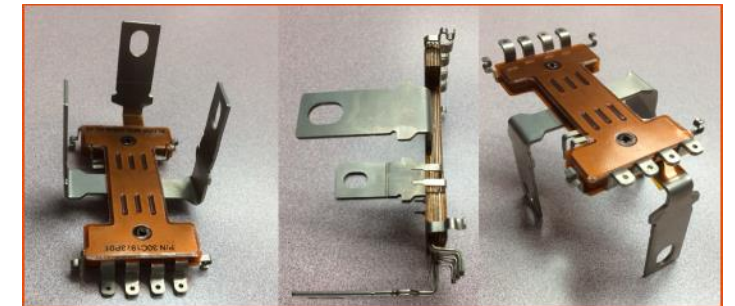
Use of external laminated busbar with low inductance connection

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



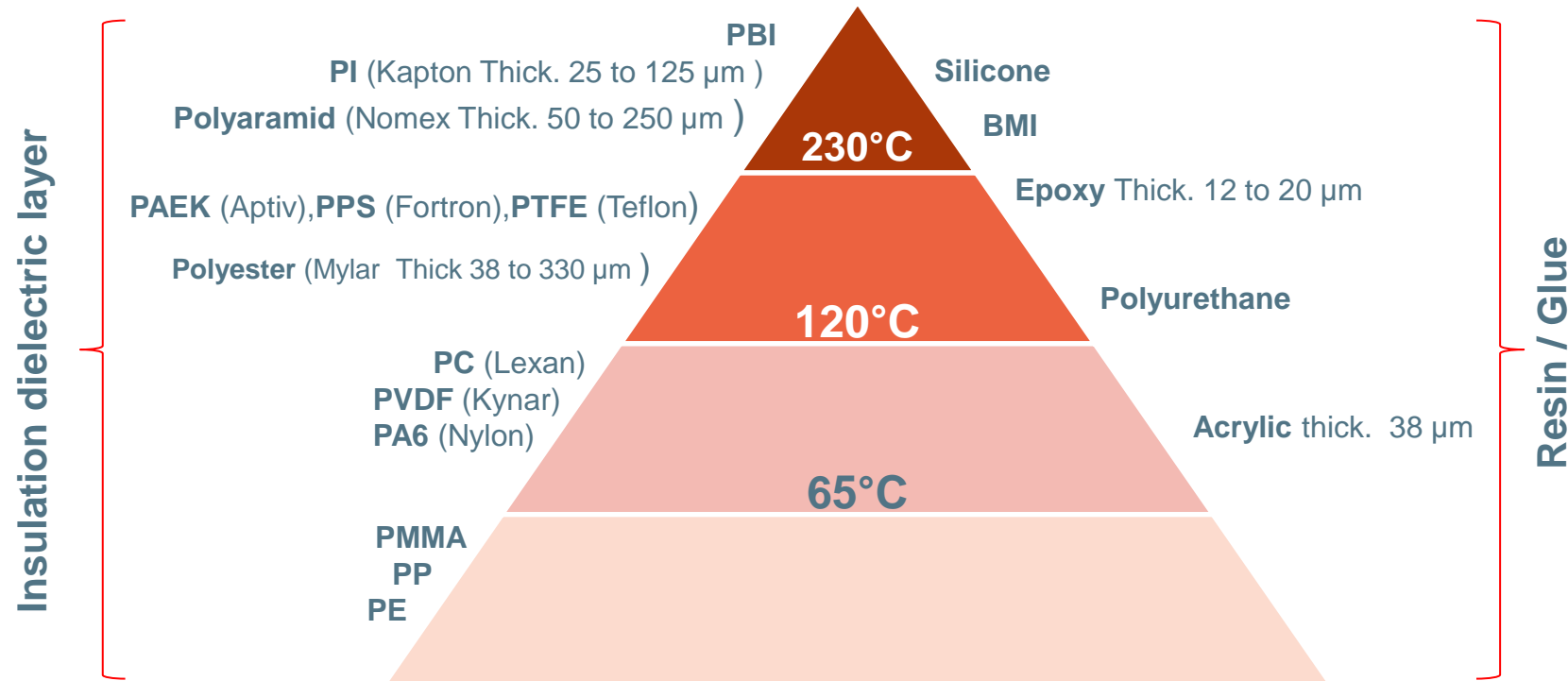
LAMINATED BUS BAR: HOW TO MATCH WBG MODULE HIGH T° REQUIREMENTS ?

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°:

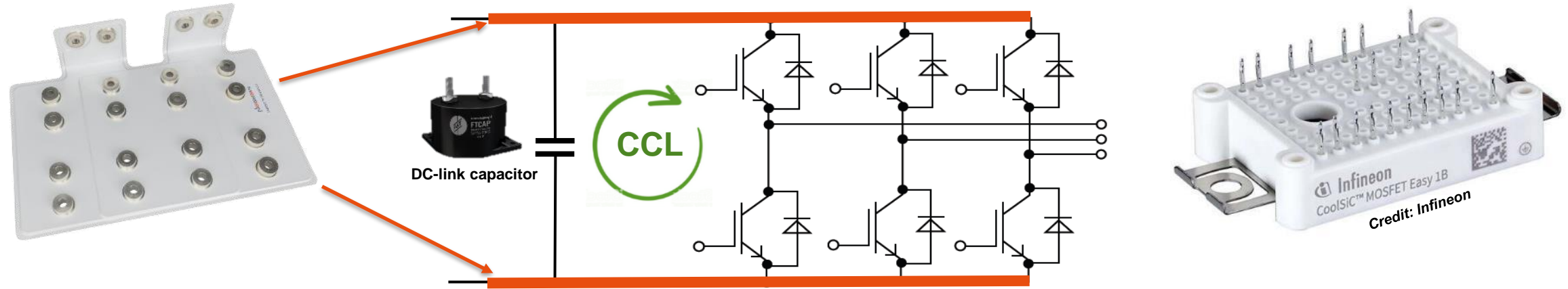


Now up to
180° C

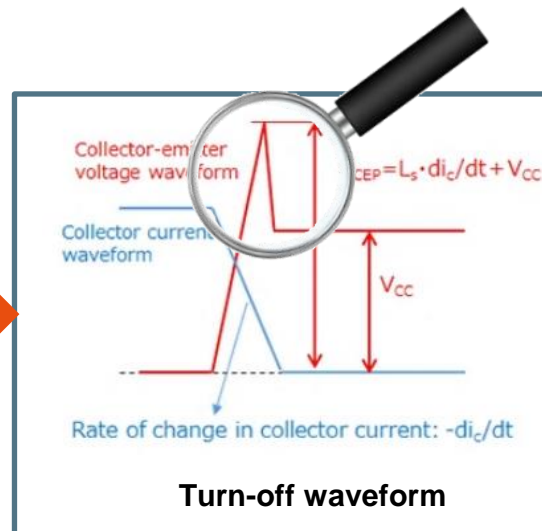
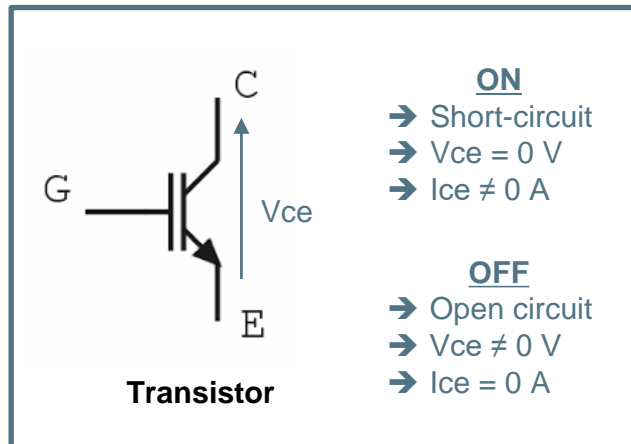


INDUCTANCE FUNDAMENTALS IN POWER CONVERTER DESIGN

HIGH INDUCTANCE CREATES VOLTAGE OVERTHOOT AND SURGE AT COMMUTATION



CCL: Commutation current loop

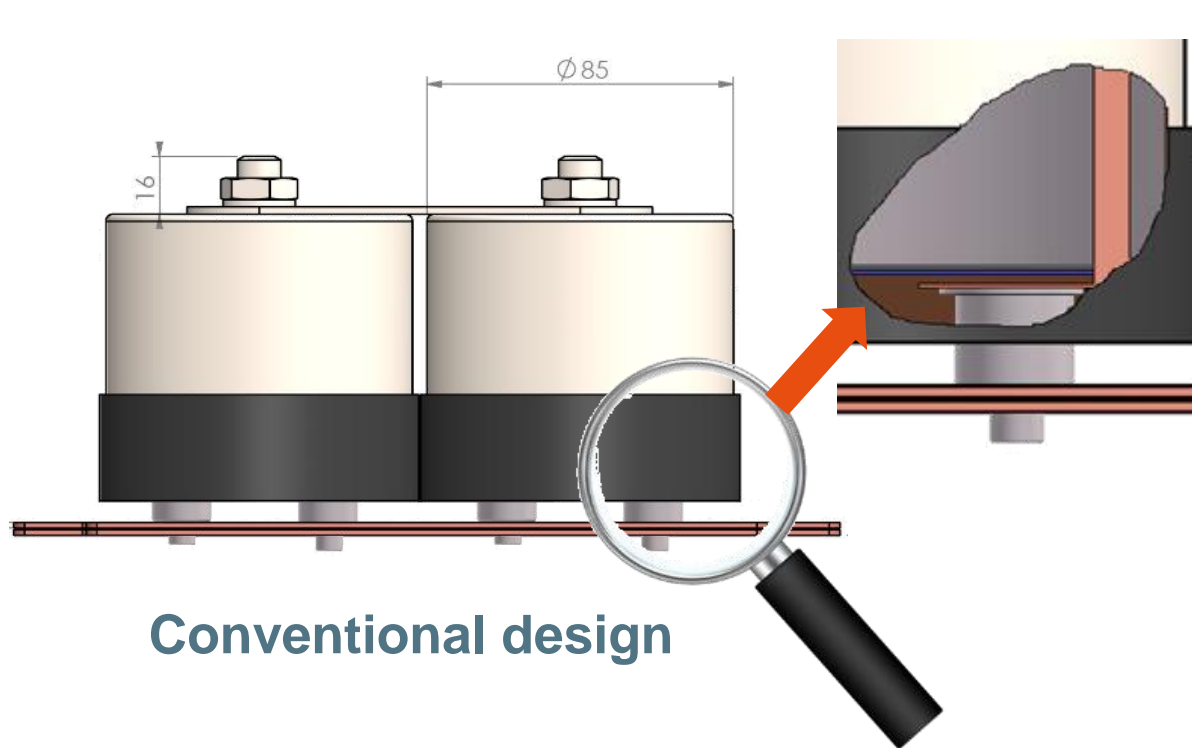


$$\text{Surge voltage} = L_s * \frac{di}{dt}$$

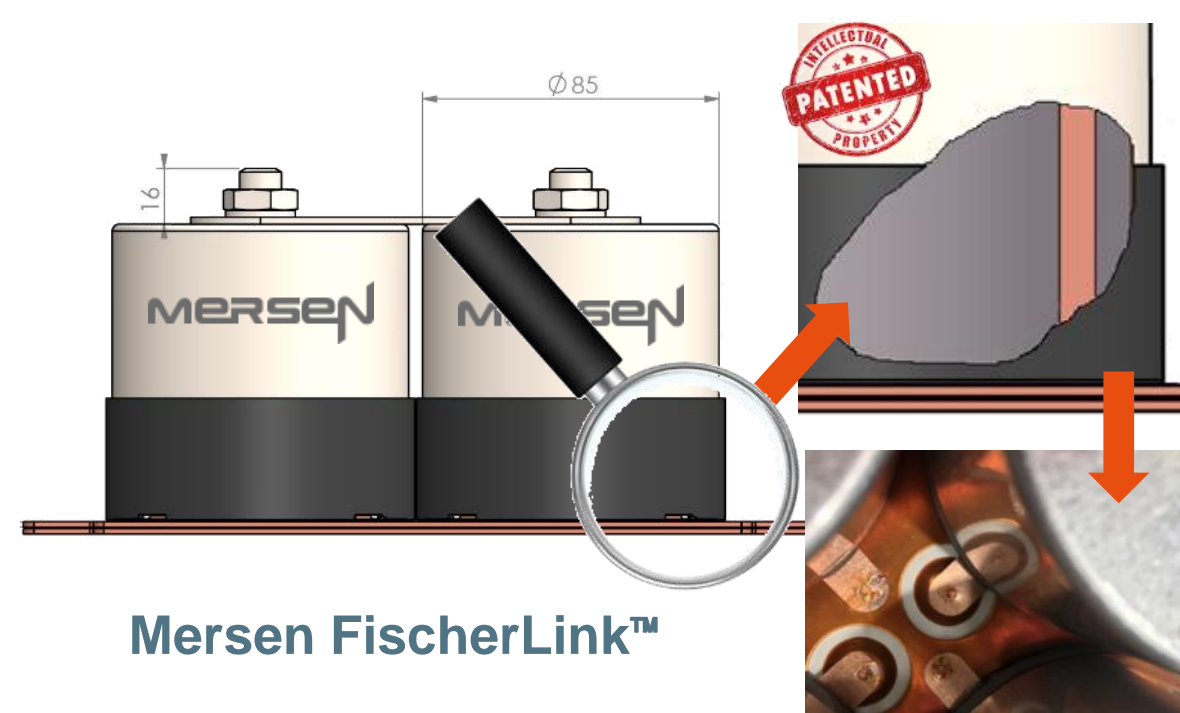
$$L_s = \text{inductance of CCL}^*$$

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

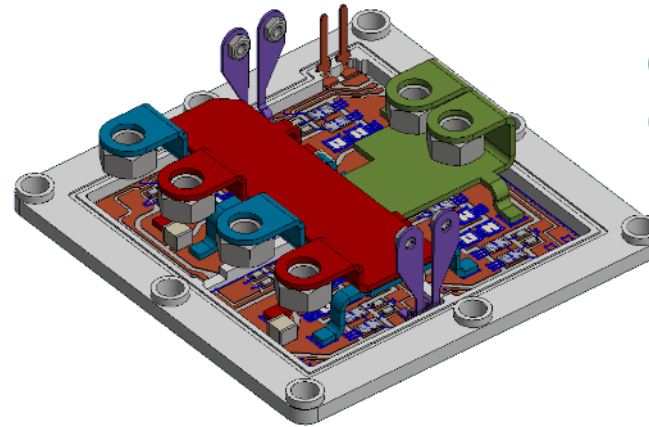
SOLUTIONS TO HANDLE 180° Tj @ 100 KHz Fsw... AND BEYOND !

■ 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

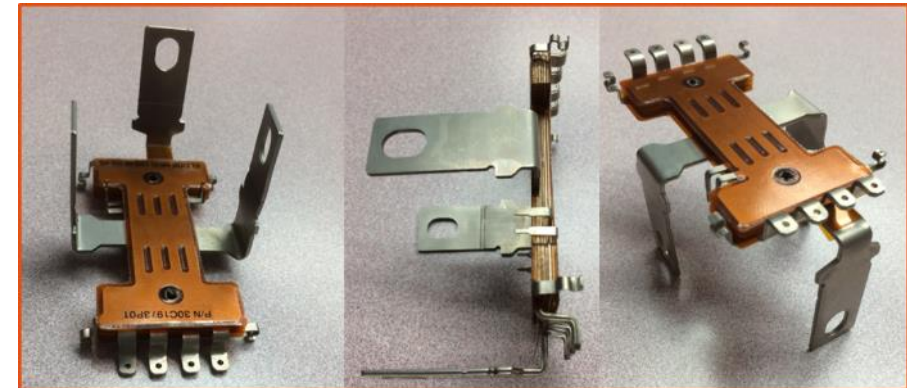
■ THE ACHIEVEMENT

- 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