THE FUTURE OF HIGH-POWERED EV CHARGING

The Technical Considerations for
Ensuring Efficient, Reliable Vehicle Charging

Vehicle electrification is gathering steam, as automakers and governments world-wide drive industry innovation forward.

The benefits of electrification are profound and numerous, creating a sustainable mode of transportation that reduces the use of non-renewable energy and carbon emissions, among other advantages. Obviously, there are hurdles that have yet to be overcome, including building out a widely available charging infrastructure, developing next-generation vehicle architectures and solutions, and financing this extensive industry innovation. Figure 1 summarizes the key benefits, as well as the industry concerns, regarding the adoption of electric vehicles.

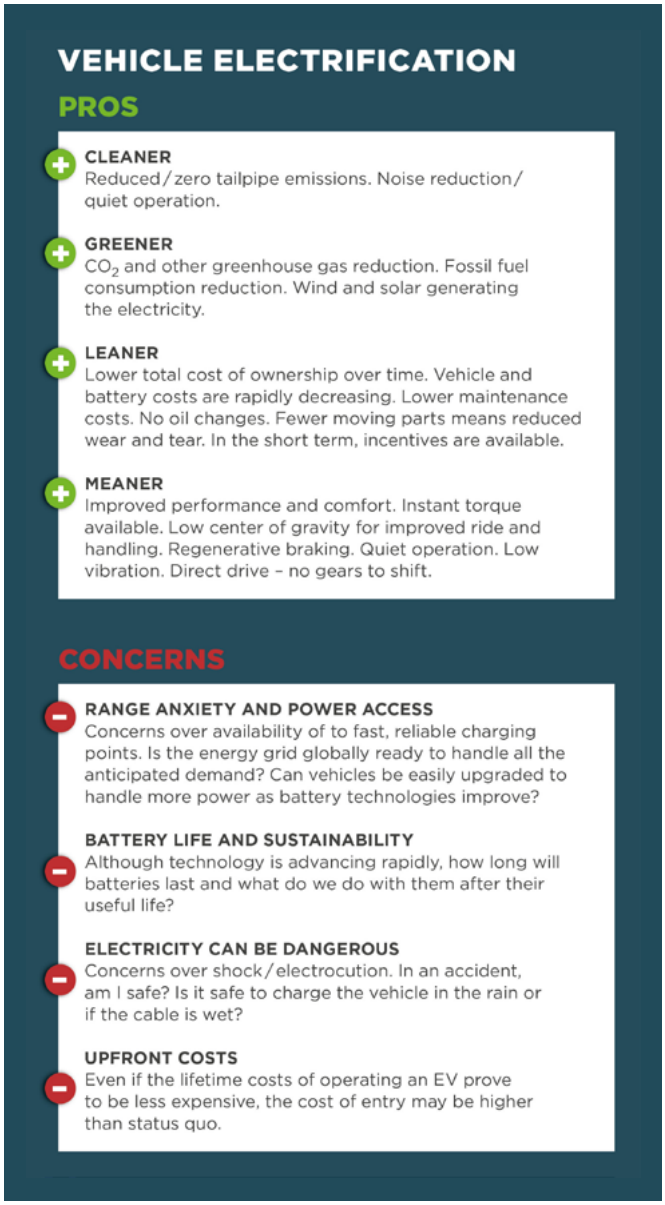


Figure 1: Benefits and concerns of vehicle electrification

The Automotive Industry Is Focusing on Providing a Faster Charging Infrastructure

Electric vehicle charging stations seem to be popping up everywhere. But in reality, the ability to quickly and conveniently charge one's car pales in comparison to the availability and speed of refueling a car at a diesel or petrol station. Today's available DC fast chargers, providing between 50 to 200 kilowatts of power, typically can add just under 200 miles of driving range in one hour for a typical electric car. This may be sufficient for many typical use cases, but for long-distance travel, a one-hour charge simply isn't fast enough. Currently, the industry is developing DC high-power charging (HPC) to provide the same amount of charge (200 miles of range) in 10 minutes or less, producing an experience similar to filling up one's gas tank in an internal combustion engine (ICE) vehicle. The transportation and power utility industries are hard at work addressing this critical industry need, as summarized in Figure 2.

Several groups, including the Society of Automotive Engineers (SAE), the International Electrotechnical Commission (IEC), CharIN E.V., and the CHAdeMO association are working to develop charging standards for electric vehicles worldwide. Multiple protocols and physical interfaces have been developed along the way by these industry-wide bodies. Work is underway to establish and accelerate megawatt DC charging, enabling even faster "refueling" of electric vehicles, especially for larger commercial vehicles like buses and trucks. While the exact implementation of a standard is still under discussion, it is certain that at some point in the not-too-distant future an ultrafast DC charging capability, with power transfer beyond 500 kilowatts, will exist.

Ensuring that vehicles are ready to take advantage of megawatt DC charging cannot wait until the standard interface is defined. Advanced connectivity technology investments need to be made, and solutions need to be developed now in order to be ready to meet the market needs of the future.

Vehicles Face Technical Challenges Related to Megawatt DC Charging Connectivity

Will vehicles be ready to handle 500 kilowatt charging? One megawatt and beyond charging? Although the need to be able to charge a vehicle in minutes rather than hours is apparent, the way to address this requirement safely and effectively is not as obvious. These demands are driving the industry to focus on a broad range of solutions to solve never-before-seen challenges. Charging inlets must be able to handle 10 to 20 times the power that today's generation of electric cars can accept.

Trying to push up to megawatts or even gigawatts of power through an inlet sized to handle 50 kilowatts is like drinking from a firehose. Connections, cables, switches, and contactors will all be subjected to increased electric stresses and must be able to intelligently manage this power transfer while also mitigating heat, arcing, and safety issues. New contact platings need to be developed to reduce heat and mitigate wear and tear from a high number of connection mating cycles and from public charging plugs that can transfer damage and abrasives to the vehicle's charging inlet.

New thermal management and simulation techniques need to be developed, allowing for optimized design of components and subsystems that can be stressed by the high charging voltage and current needs. Accurate sensing, both contacting and non-contacting, needs to provide real-time information for intelligent power management.

As a connectivity supplier to the EV market, TE Connectivity (TE) works closely with customers by providing robust components and solutions tailored to their specific needs and vehicle architectures. For both fast and high-power DC charging, TE breaks down application requirements by answering a series of smaller, more focused questions:

How do vehicles best address varying global standards? Referencing Figure 2, there are many competing worldwide standards for the charging plug interface, each with their own advantages and disadvantages. TE Connectivity participates in various standards committees and industry

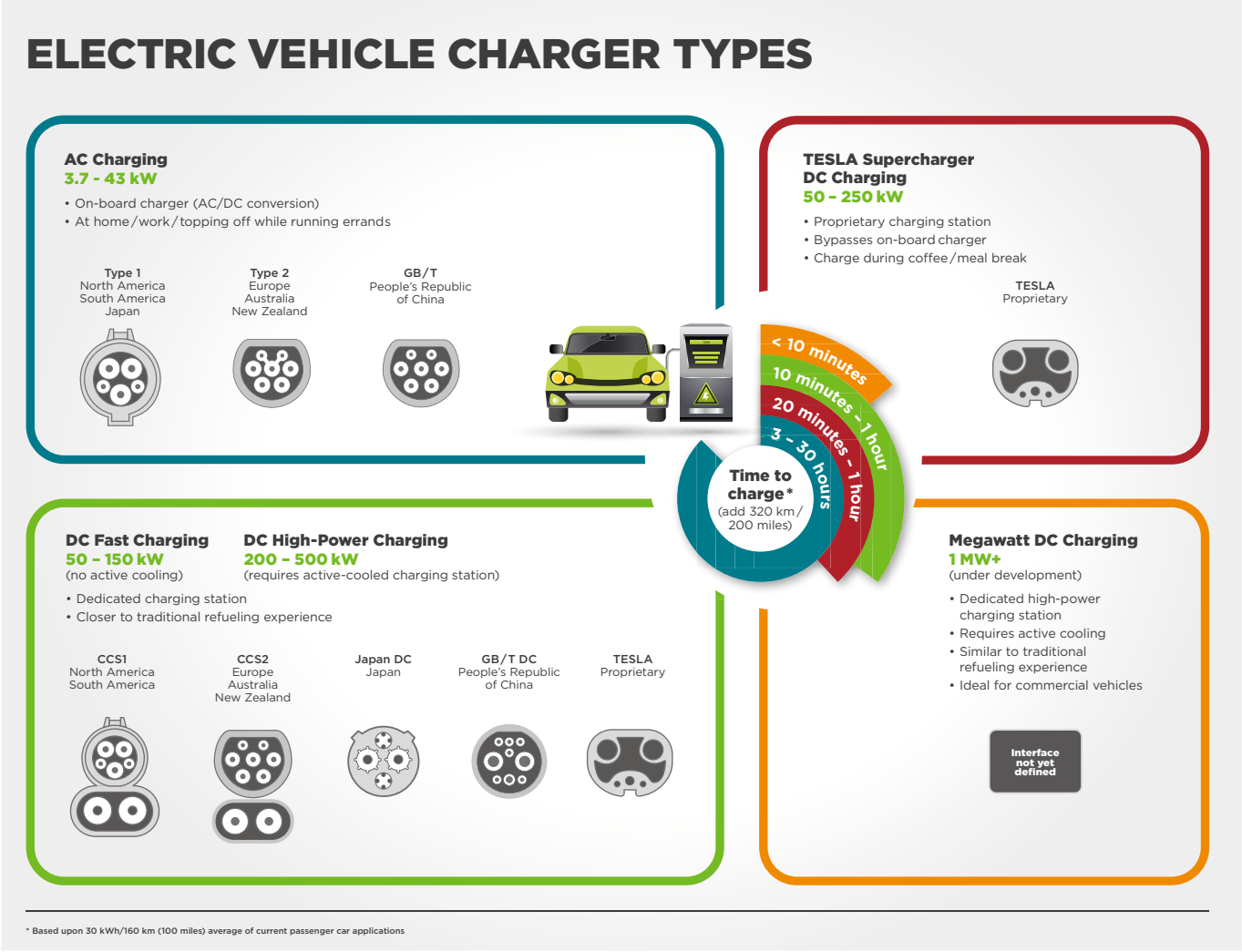


Figure 2: Electric vehicle charger types

consortia, enabling the identification of problems and the development of solutions early in the design process. TE, working with global customers and across multiple transportation segments, has tailored solutions to match the market's needs. This is achieved via a modular, platform building-block approach that enables TE to deliver the right solutions quickly and cost-effectively.

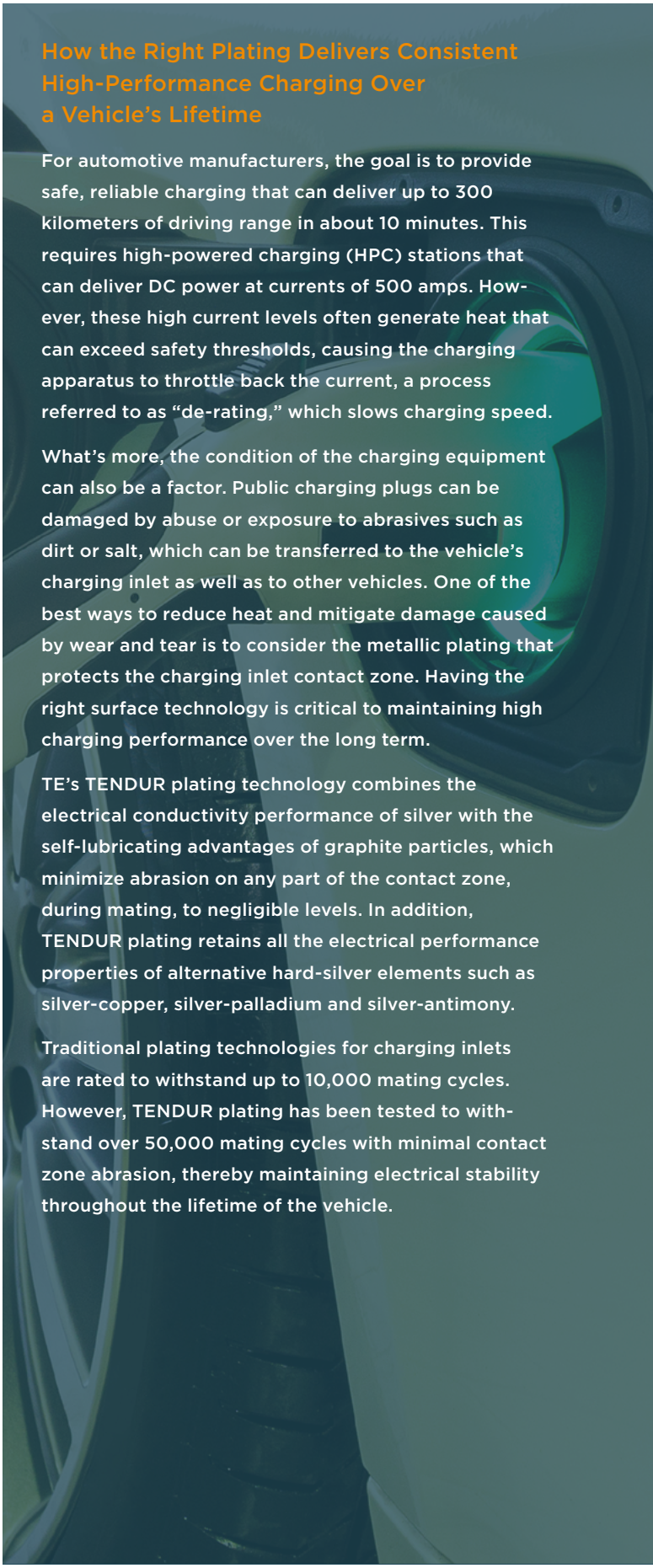
Does more power mean more heat?
Thermal management for charging is the biggest challenge for the inlet, plug, and cable. Simple physics dictates that P=V*I; Heat = I^2R (where P = Power; V = Voltage; I = Current; R = Resistance). Typical battery packs are currently at 480V. Moving from 50kW (480V x 100A) to 240kW (480V x 500A) is ~5x increase in power and 25x increase in heat. TE has an in-house electro-thermal modeling and simulation capability, allowing for the optimized design of components and subsystems that can be stressed by the high charging voltages and currents.

Does the higher power required to do DC fast and high-power charging drive technology advances in the vehicle charging inlet?
TE has developed charging inlets with integrated sensing and actuation capability, to allow for intelligent charging control while providing touch-safe operation and reliable charging state feedback. These inlets can be scaled to accommodate varying customer electrical/electronic architectures inside the vehicle, from discrete point-to-point operation or via distributed intelligent control. TE's architecture and electronics teams deliver solutions to fit varying charging station approaches and protocols.

Does higher power mean bigger wires and bigger connections?
Currents exceeding 200 amps require cooling to keep cable and connector sizes manageable from the charging station to the vehicle. Simply using larger cables and connectors will eventually make them unusable and cost prohibitive. Similar challenges exist inside the vehicle. While the connection from the inlet need not be physically handled like a charging cable, it still needs to be as small, light, and cost-efficient as possible.

TE Connectivity works with customers to proactively address these complex problems, leveraging our material science and contact physics expertise as well as employing active cooling and advanced power management techniques in creating innovative new solutions. Figure 3 illustrates some of the cooling opportunities along the high-power connectivity path.

What is the safety impact of the higher power requirement for fast charging?
Electricity has inherent safety risks. In addition to electric shock that can be caused by higher voltages, the heat generated by resistance can cause burns, so temperature management becomes a key consideration.



How the Right Plating Delivers Consistent High-Performance Charging Over a Vehicle's Lifetime

For automotive manufacturers, the goal is to provide safe, reliable charging that can deliver up to 300 kilometers of driving range in about 10 minutes. This requires high-powered charging (HPC) stations that can deliver DC power at currents of 500 amps. However, these high current levels often generate heat that can exceed safety thresholds, causing the charging apparatus to throttle back the current, a process referred to as "de-rating," which slows charging speed.

What's more, the condition of the charging equipment can also be a factor. Public charging plugs can be damaged by abuse or exposure to abrasives such as dirt or salt, which can be transferred to the vehicle's charging inlet as well as to other vehicles. One of the best ways to reduce heat and mitigate damage caused by wear and tear is to consider the metallic plating that protects the charging inlet contact zone. Having the right surface technology is critical to maintaining high charging performance over the long term.

TE's TENDUR plating technology combines the electrical conductivity performance of silver with the self-lubricating advantages of graphite particles, which minimize abrasion on any part of the contact zone, during mating, to negligible levels. In addition, TENDUR plating retains all the electrical performance properties of alternative hard-silver elements such as silver-copper, silver-palladium and silver-antimony.

Traditional plating technologies for charging inlets are rated to withstand up to 10,000 mating cycles. However, TENDUR plating has been tested to withstand over 50,000 mating cycles with minimal contact zone abrasion, thereby maintaining electrical stability throughout the lifetime of the vehicle.

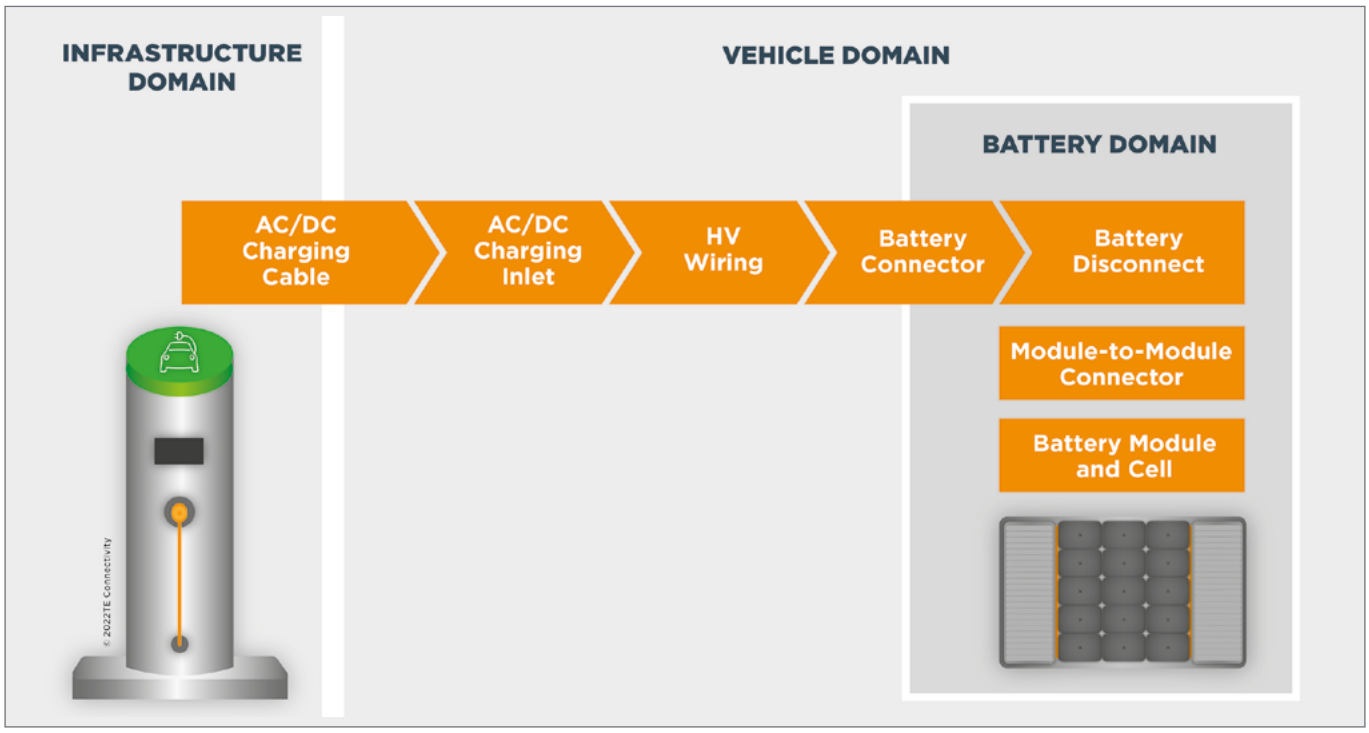


Figure 3: Thermal modeling can be measured across the entire power distribution chain

TE Connectivity provides safe, rigorously tested connectivity solutions that adhere to accepted electrical design standards. By integrating sensing (temperature, voltage, current) all along the current path, as well as providing controllable elements (contactors, relays, smart inlets, smart actuators), TE's customers have different levers they can use to intelligently manage and safely control the power path from beginning to end.

Can in-vehicle battery connections handle the increased power?
Battery technology development is a prime area of industry investment. Increasing the driving distance on a single charge means batteries with greater power density are needed. The challenge is how to maximize power per cubic centimeter while minimizing the package size and keeping costs under control.

TE has developed high-voltage, physically compliant, battery module contacts and connection interfaces that enable battery pack scalability. They are robust, harsh environment interconnects with integrated voltage and temperature sensing, enabling smart control of battery management (state-of-charge and state-of-health). This enables customers to balance the active chemical mass versus the mechanical overhead of the battery system.

Is fast, high-power or megawatt charging a panacea for all drivers?
Not necessarily. High-power charging is great for long-distance travelers and "street lamp" parkers who might not have access to overnight AC charging at their homes. Higher currents can stress vehicle components, including the battery's chemistry. There will always be a need for both slower AC and DC charging and fast, high-powered, and megawatt DC charging to address drivers' needs for comfortable long-distance travel and to keep their electrical systems efficient, well-maintained and affordable.

Answering the Fast-Charging Questions

To address these challenges, from charging to storage to propulsion, TE works closely with our customers to provide a broad range of solutions that address their needs today and well into the future.

Charging a Battery Electric Vehicle (BEV)
It all starts at delivering the needed power from the grid to the vehicle. TE's areas of focus include:

- Charging inlets, with integrated sensing and actuation capability, to safely and reliably allow for intelligent charging control while providing touch-safe operation and charging state feedback. These inlets are scalable to fit varying customer electrical/electronic architectures inside the vehicle, from discrete point-to-point operation, or via distributed intelligent control. TE's architecture and electronics teams deliver solutions to fit all regional charging station standards.

- TENDUR abrasion-resistant contact plating for charging inlets. Lifetime high-performance EV charging providing up to 50,000 mating cycles with virtually no wear-

through. It delivers highly stable, low electrical resistance with outstanding mechanical durability.

- High voltage contactors (electronically controllable switches) and connectors enabling safe and efficient power switching and distribution for intelligent and optimized charging.

- Thermal modeling and simulation capabilities, allowing for optimized design of components and subsystems that can be stressed by the high charging voltage and current needs.

- Application tooling expertise, ensuring manufacturability focus for TE's customers. We turn theory into practice by working directly with our customers' manufacturing methods and practices.

Storing power in a BEV
We support our customers as they develop battery storage and management systems. TE's areas of focus include:

- High-voltage, physically compliant, battery module contacts and cell-to-cell connection interfaces, enabling battery pack scalability.

- Robust interconnection systems designed for harsh environments, with integrated voltage and temperature sensing that enables smart control of battery management (measuring both state-of-charge and state-of-health).

- Design, manufacturing, and application tooling expertise in miniaturized and compliant interconnect technology enabling small, robust packaging for high-capacity battery packs.

Electrified and controlled propulsion
TE is proud to be working with our customers to help develop optimized solutions. Areas of focus include:

- A suite of sensors that enable intelligent control of EVs. These include: position sensors, wheel speed sensors, motor speed and position sensors, current sensors, temperature sensors, voltage sensors.

- Integrated electronics solutions that minimize size and weight while maximizing design flexibility. The ability to supply a single component that combines sensing, intelligent data processing and communication, and connection all in one robust package.

- High-speed data connectivity, enabling vehicle-to-vehicle and vehicle-to-cloud communications and intelligent vehicle control. TE leverages its expertise across multiple industries when it comes to high-speed data connectivity, both wired and wireless.

TE Connectivity as the Supplier of Choice

In summary, there is a strong industry need to deliver more power to the battery in a shorter amount of time (from hours to minutes) to refuel/recharge electric vehicles. More power means more heat and more component stress within the vehicle from the charging inlet to the battery. This phenomenon must be intelligently managed. Contacting and non-contacting sensing techniques are needed to provide accurate, real-time temperature, voltage, and current information.

To address these challenges, TE Connectivity's team of engineers and scientists engages closely with our customers and helps support their success by developing robust solutions tailored to their specific vehicle architectures for the harshest of environments. We are a system-knowledgeable connectivity solutions supplier with electronics architecture and physical integration expertise, which enables us to speak our customers' technical language. We bring to the table a comprehensive product portfolio, technical design know-how, manufacturing and application tooling prowess, and our depth and breadth of industries and geographies served.

TE Connectivity EV Charging Solutions

AMP+ CHARGING INLET 32 SERIES

- 32-amp AC inlets
- LED charge status indicators
- Variations for all standards and geographies

AMP+ CHARGING INLET 200 SERIES

- 32/200-amp AC/DC combined inlets
- Transfers up to 200 amps of continuous DC current
- Modular, customizable designs

AMP+ CHARGING INLET 500 SERIES

- 32/500-amp AC/DC combined inlets
- Transfers up to 500 amps of continuous DC for high-powered charging
- Reduces charging times for added convenience

AMP+ CHARGING INLET LOCKING ACTUATORS

- Prevents accidental removal for increased safety
- Robust design is durable for 50,000-80,000 charging cycles
- Variations available for all standards

TENDUR ANTI-ABRASION CONTACT PLATING

- Maintains lifetime high-performance charging
- Up to 50,000 mating cycles with no wear-through
- Outstanding electrical resistance stability

About TE Connectivity

TE Connectivity is a global industrial technology leader creating a safer, sustainable, productive, and connected future. Our broad range of connectivity and sensor solutions, proven in the harshest environments, enable advancements in transportation, industrial applications, medical technology, energy, data communications, and the home. With more than 85,000 employees, including over 8,000 engineers, working alongside customers in approximately 140 countries, TE ensures that EVERY CONNECTION COUNTS. Learn more at **www.te.com** and on **LinkedIn**, **Facebook**, **WeChat** and **Twitter**.

Connect with us

We make it easy to connect with our experts and are ready to provide all the support you need. Visit **www.te.com/support** to chat with a Product Information Specialist.

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TE Connectivity Germany GmbH
Ampèrestrasse 12–14
64625 Bensheim
Germany