SUPPORTING VEHICLE ARCHITECTURE DIVERSITY IN INDUSTRIAL & COMMERCIAL TRANSPORTATION APPLICATIONS

The Future of E-mobility, Expertly Engineered

Is this the end of the ice age? Will Internal Combustion Engines (ICE) be a relic of the past, or do they still have a place in the transportation of the future? Will Battery Electric Vehicles (BEV) be the new norm, or are they simply a part of the broader story?

In this white paper we explore the transportation industry's move towards electrification, which includes various (and competing) architectural approaches, each offering application-specific advantages. We will discuss societal and technical challenges driven by the speed of change in the marketplace, focusing on the industrial and commercial transportation (ICT) industry which has similar, yet distinct applications challenges and technical solutions needs as compared to passenger cars. Finally, we will address specific connectivity technical challenges and their solutions.

The Move to Electrification is now

Once seen as a slow and sluggish industry, transportation technology is now developing rapidly to become a leading driver of global technology investment. Original equipment manufacturers (OEMs) and automakers are driving technology development of electric transportation architectures, connected cars, and self-driving vehicles rather than waiting to bolt on other industry's solutions.

Vehicle propulsion methods have been evolving for some time. Internal combustion engines are no longer the only game in town when it comes to vehicle propulsion. While this propulsion method has served society well, new vehicle architectures have been, and are continuing to be, developed which are better suited to meet governments', business', and consumers' increasing demand for greener (clean, quiet, sustainable), efficient (tailored to specific tasks rather than one-size-fits-all), and less costly (total operating costs) solutions.

Today's trucks and industrial machinery are typically powered by internal combustion engines driving two or more wheels through a transmission. They primarily use gasoline, diesel fuel, or in some cases compressed natural gas. While industry manufacturers have taken steps to improve fuel consumption and reduce emission, including introducing 48 V mild hybrid approaches, more improvements are needed. Regional, national, and state legislation and widening diesel bans around the world are providing the business case for the industry's drive to reduce emissions.

As a result, vehicle manufacturers are accelerating development away from internal combustion engines and focusing more on architectures incorporating electric motors. The four primary architectures, of course, are conventional hybrids, plug-in hybrids, battery electric vehicles, and hydrogen fuel cell electric vehicles.

Conventional Hybrids

Conventional hybrid architectures have internal combustion engines, along with electric motors and batteries, but cannot be plugged into a power source. They derive their power from gasoline and diesel and thus are not categorized as electric vehicles. A mild hybrid typically uses a small electric motor and 48 V battery combined with an ICE, allowing for assisted acceleration and regenerative braking (capturing energy from braking). A strong, or parallel hybrid, will generally consist of a larger electric motor and battery combined with a downsized ICE using regenerative braking and electric motor drive.

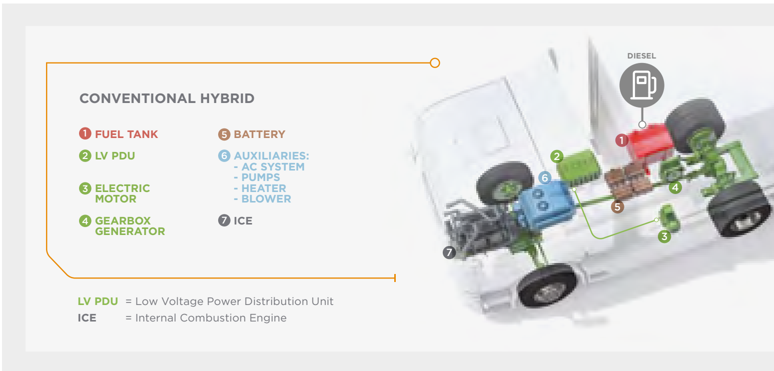

Figure 1: Typical Conventional Hybrid Architecture

Mild hybrid architectures are making their way into the light duty commercial truck segment, and even into some larger vehicles. Truck manufacturers are primarily electrifying accessory functions, while focusing the internal combustion engine's output on its primary purpose of propulsion. Engine cooling, in-cabin comfort, steering assist, and brake assist, along with energy capture via regenerative braking, are leading to substantial fuel savings due to enhanced energy efficiency. Additionally, these architectures enable engine-off climate control, reducing wasted fuel and unnecessary emissions.

While improving fuel efficiency is critical, greater fuel economy and lower emissions are not the only driving forces in ICT. For example, 48 V mild hybrids deliver 4X the power without larger wires versus 12 V systems. The e-motor / generator replaces the alternator. Power-consuming features and systems for advanced driver assistance (ADAS) can be more efficiently powered by the 48 V battery. An on-board DC/DC converter enables the co-existence of 12 V and 48 V systems, and so forth.

Conventional hybrid architectures offer relatively low-cost opportunities to reduce fuel consumption and emissions. They do not offer zero emission solution. Widely used in passenger car application, hybrids have also been deployed in city buses throughout Europe as well as some Class 8 hybrid sleeper trucks in North America.

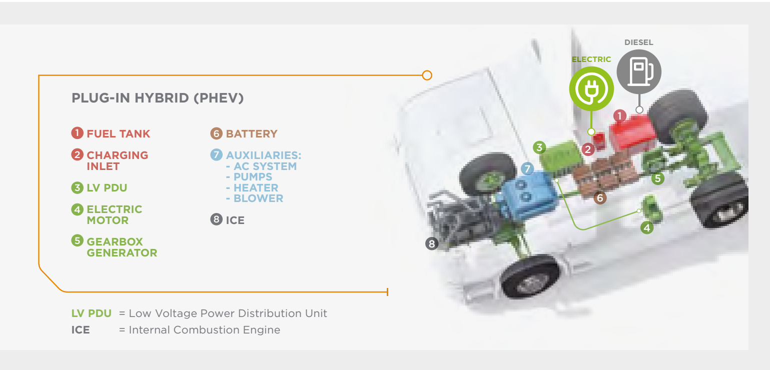

Figure 2: Typical Plug-In Hybrid (PHEV) Architecture

Plug-in Hybrids

Plug-in hybrid electric vehicles (PHEVs) are like battery electric vehicles, typically with a smaller battery, but also have a conventional gasoline or diesel engine. Although not as clean as battery electric or fuel cell vehicles, plug-in hybrids produce significantly less pollution than their conventional counterparts. Series PHEVs are typically referred to as range extenders, with the ICE's primary purpose to charge the battery on the go.

PHEVs take a step towards full battery electric vehicles. They are a popular option for passenger cars as they provide electric-only propulsion and a range-extending internal combustion engine for flexibility and backup power. However, they have not been a strong contributor in the long-haul transportation segment. In China, PHEV commercial vehicles are not being subsidized by the government, while BEVs are being strongly encouraged due the country's focus on eliminating oil consumption and tailpipe emissions. PHEVs do not offer zero emission solutions.

Battery Electric Vehicles

Battery electric vehicles (BEV) use stored energy in abattery to drive electric motors. The operating voltage can be as low as 48 V and as high as 1000 V, depending upon the application's requirements. Stored energy increases BEV efficiency and, like fuel cell vehicles, allows them to drive emissions-free when the electricity comes from renewable sources. Electric powertrains require large cables to dissipate the heat from higher currents; but specifying a cable that is too large for the application may add unnecessary cost and weight. Active and passive cooling techniques can ensure cables remain sized appropriately.

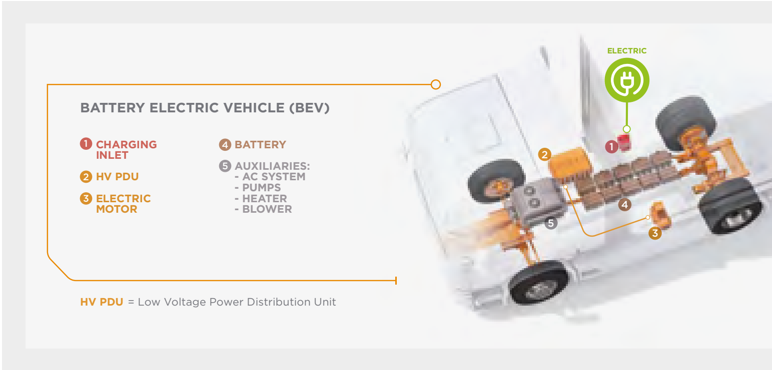

Figure 3: Typical Battery Electric Vehicle (BEV) Architecture

BEVs use existing infrastructure to recharge and are placing increased demand on the energy grid. One of the biggest challenges implementing BEV architectures for commercial vehicles is the lack of a pervasive charging network to support fleets. Ready availability of charging stations, and fast-charging capability, remain as the most significant hurdles to broader BEV implementation across industrial and commercial transportation applications.

There are, however, many commercial applications where neither charging station availability nor time to charge are the biggest concerns. City buses, for instance, can adopt full electric propulsion architectures very quickly. Buses in Shenzhen, China are essentially 100 percent battery electric vehicles (BEV). Cities, airports, and universities across North America are working to introduce zero-emission battery electric buses. They all run well-defined routes and have dedicated recharging stations at their disposal. School buses are another candidate for quick adoption of BEVs. They are used a small percentage of the day and travel well-defined routes. Several school districts within the US and Canada are deploying electric school buses. Local (last mile) deliveries from postal services or package services are also able to quickly adopt BEVs.

Hydrogen Fuel Cell Electric Vehicles

Hydrogen fuel cell electric vehicles (FCEVs) derive their power from on-board fuel cells that generate electricity from hydrogen, either to charge batteries or to drive electric motors. FCEVs require a hydrogen fueling infrastructure

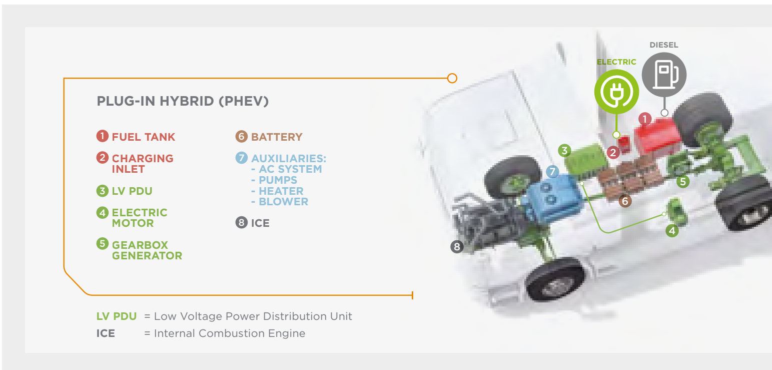

Figure 4: Typical Hydrogen Fuel Cell Electric Vehicle (FCEV) Architecture.

which is not always emissions-free and is not universally available today. Fuel cells, with their large power density, enable long driving distances between refuels. Most FCEVs today use the battery for regenerative braking, providing extra short-term acceleration power and normalizing and steadying the demand of the fuel cell output.

In the US, the state of California is working on a plan that will put more electric trucks on the streets, dramatically reducing emissions. Under this plan, manufacturers of medium- and heavy-duty trucks will be required to sell additional electric and fuel-cell options in California, starting in 2024. Shuttle buses for the winter Olympics in Beijing, China will be FCEVs. Long-time truck manufacturers, as well as relative newcomers, are developing heavy duty solutions for FCEVs for global markets.

In-Vehicle Power Connectivity Solutions to meet the Evolving Architecture Challenges

In the years to come we will witness a vehicle electrification architecture evolution, perhaps revolution, for ICT applications. While on the surface it appears that there are diverging architectures being developed, what we are witnessing are focused approaches to creating specific functional applications to meet the needs of customers and market demands in different regions. The move towards vehicle electrification in China far outpaces the rest of the world, and architectural solutions reflect that. Much of the pace is due to the government's investment in and regulations of zero emission technologies. Recently conducted polls have shown that in the US, a relatively small number of the respondent population say their next car will be electric.

Europeans, however, show a slightly higher "leaning" towards EVs. In China, however, over most of the respondents expect to be driving EVs soon. Figures 5, 6, and 7 depict slightly varying architectural approaches to the same ICT application, with the implementation differences based upon regional preferences as well as technology and infrastructure investment in the automotive and commercial transportation industries.Figures 5 – 7 on the next page show examples of bus and heavy/medium duty electrification architectures in China, Europe, and North America.

To meet the connectivity needs and challenges that this diverse customer base requires, TE Connectivity (TE) works closely with customers to develop modular platform solutions that can be quickly and effectively tailored for specific customer requirements. Diversity is mainly driven by three parameters: current, vibration levels, and shielded or unshielded design. By providing platform-based solutions, tailored designs can be achieved while still taking advantage of economies of scale as well as existing manufacturing processes.

From vehicle charging, to energy storage, to e-motor propulsion, TE Connectivity's team of scientists and engineers are proactively working on developing the connectivity solutions to meet customer needs. Increasing wire sizes (>70mm2) are driving new termination technologies. Power line shielding techniques are being developed to address induced magnetic fields.

Diverse architectures and applications have highly variable power connectivity requirements. Across the broad range of architecture approaches, direct current (DC) voltages can be anywhere from 48 volts to as high as 1000 volts. Currents can potentially be as high as 1000 amps. One megawatt of electric power in a vehicle, once the subject of science fiction movies, is now an agenda item at transportation society committee meetings. The one megawatt milestone is also the subject of TE Connectivity's advanced engineering investment. Figure 8 illustrates many of the architectural building blocks needed, and being developed, to address the many connectivity challenges.

These challenges include:

- Addressing voltages ranging from 12VDC all the way to 1000 VDC
- Safely switching high-voltage lines
- Delivering solutions for ever-increasing electric current needs
- Providing appropriate power line shields to address induced magnetic fields (for EMI/EMC).
- Ensuring touch-safe operation throughout the architectural implementation
- Designing package-efficient connectivity solutions which enable higher density battery packages
- Ensuring safe connectivity operation during all phases of usage, including scheduled maintenance, unscheduled maintenance, and collisions
- Providing modular, scalable connectivity solutions that can be used across the varying architectures that customers choose to implement. This help OEMs adapt their architecture to a variety of commercial needs without a significant investment for new development.

TE Connectivity as the Supplier of Choice

However ICT vehicle architectures evolve, TE is deeply committed to providing optimized solutions that meet customers' connectivity needs. We are a system-knowledgeable connectivity solutions supplier with electrical architecture and physical integration expertise, enabling us to speak our customers' technical language. We recognize that over time there is an increased need to deliver more power to the battery in a shorter amount of time – decreasing from hours to minutes - to refuel vehicles for long-haul commercial applications. Growing power demands are creating more heat and more component stress within the vehicle from the charging inlet to the battery and to the assorted e-motors. These functions must be intelligently managed by OEMs and suppliers.

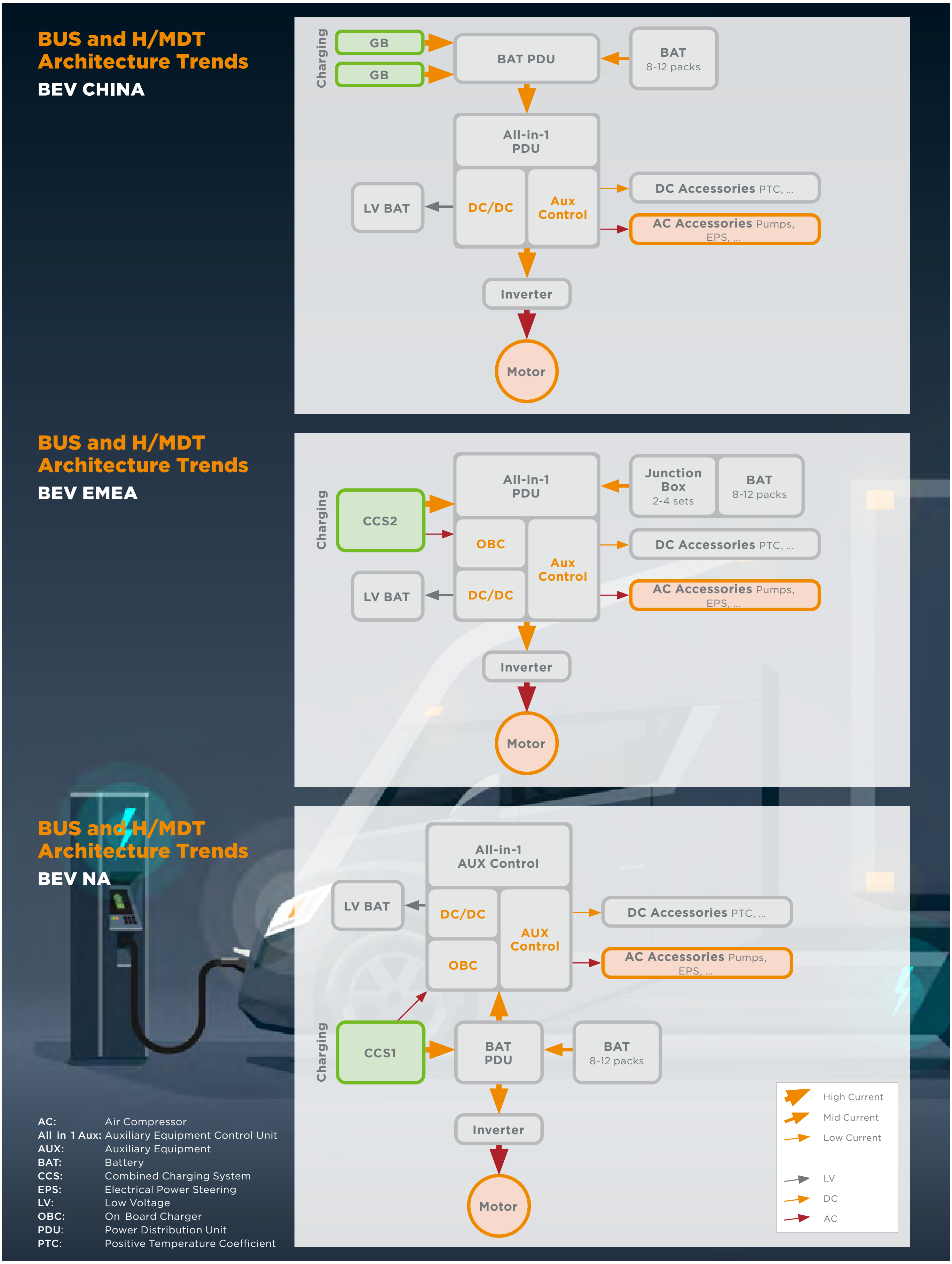

Figure 5 – 7: BUS and H/MDT Architecture Trends

To address these challenges, TE's team of engineers and scientists engage closely with customers to ensure their success by providing robust solutions tailored to their specific needs and vehicle architectures for the harshest of environments today and well into the future.

We support our customers with a comprehensive product portfolio, technical design expertise and know-how, manufacturing and application tooling prowess, and leveraging the power of TE - our depth and breadth of industries and markets served by our engineers, scientists, and global presence.

Product Portfolio

As a global leader in connectivity solutions, we collaboratewith our customers and other industry technology leaders to create engineered solutions that address the diverse architectural needs for high power connectivity solutions in ICT vehicles. We have a strong portfolio of terminals and connectors tailored to meet increasing power and vibration requirements. Our HIVONEX portfolio is specifically designed for the rigorous demands of industrial and commercial transportation and offer modular, scalable, and immensely powerful solutions for every high voltage application. We are able to provide complete inlet assemblies that allow for intelligent charging control while providing touch-safe operation and charging state feedback safely and reliably. These solutions include high-power connectors for charging, integrated actuators to lock cable nozzles to the vehicles, sensors to provide temperature and current information to battery modules, and LEDs to provide information to the vehicle operator. We can provide robust, harsh environment interconnects with integrated current, voltage, and temperature sensing enabling smart control of battery management (state-of-charge and state-of-health). To round out the HIVONEX portfolio, we offer high-voltage contactors (electronically controllable switches) and connectors enabling safe and efficient power switching and distribution for intelligent and optimized charging. Some of these solutions are illustrated in figure 9.

Technical design expertise and know-how. Drawing uponmore than 75 years of physical connection systems expertise, TE Connectivity's team of engineers, contact physicists, and material scientists work closely with customers to develop optimized solutions to ever-increasing connectivity demands and challenges. With design centers around the world, all the simulation, modeling, prototyping, and testing can be done close to where our customers are located. This includes thermal and EMC/EMI testing to cover full product validation across multiple industry standards.

Additional technical capability includes: RF design and EMC expertise; design, manufacturing, and application

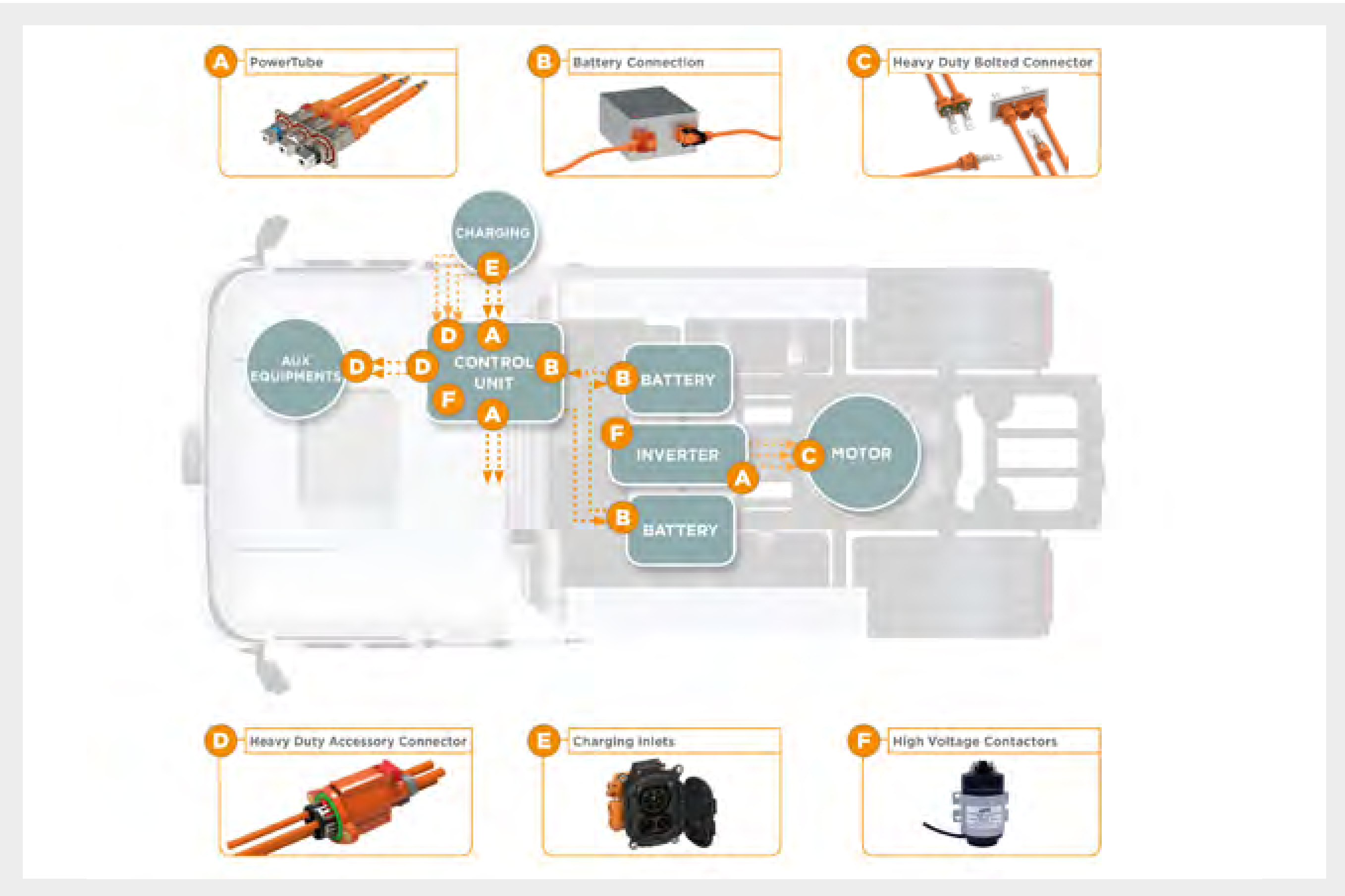

Figure 8: Solutions for Industrial and Commercial Transportation Electrification Architectures

tooling expertise in miniaturized and compliant interconnect technology enabling small, robust packaging; seamless electronics integration; environmental test and development laboratories at design locations to support both ends of the product development cycle; tools and equipment to optimize designs to customers' ever-evolving operating environment needs.

Depth and breadth of industries served and global presence. TE Connectivity serves a vast array of customers representing diverse industries and markets including consumer electronics, aerospace and defense, industrial, appliances, transportation, to name a few. By linking and leveraging across our company, our industrial and commercial transportation- focused engineers can draw upon the knowledge and experience of colleagues across the globe to solve ICT industry challenges. We participate in various standards committees and industry consortia, enabling us to addressproblem solutions early in the process. We invest extensively in upfront R&D, seeking to collaborate on solving tough industry challenges before they become problems for our customers. As a global manufacturer of connectivity solutions with an in-house application tooling business unit, we not only practice world-class manufacturing process for our products, but also confirm that our product designs align with specific customers' manufacturing methods and practices.

We have the tools and equipment to optimize designs to customers' ever-evolving operating environment needs. We work with the complete supply chain, from harness makers to module makers to system suppliers, to provide optimized system-level performance for high power connectivity. We provide the right power connectivity solution for the specifiapplication and need.

To connect with us click here

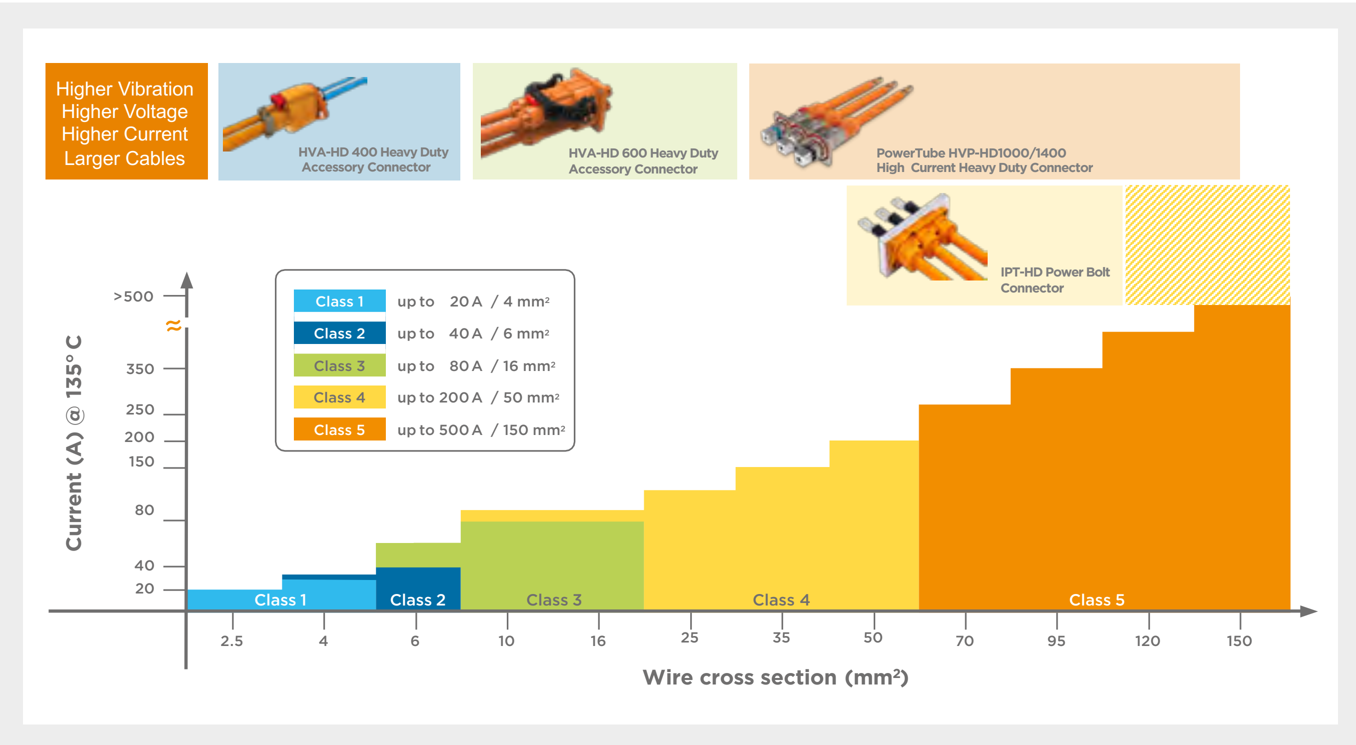

Figure 9. Terminal and Connector Solutions to Meet Application Needs

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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.

LET'S CONNECT

We make it easy to connect with our experts and are ready to provide all the support you need. For additional information or product assistance, please contact your field representative or our customer service department. Additional information is also available on the website te.com/ict.

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