TE CONNECTIVITY TREND PAPER

ELECTRIFYING A MOVEMENT

ACCELERATING HYBRID & ELECTRIC MOBILITY IN COMMERCIAL TRANSPORTATION

INTRODUCTION:
THE ROAD TO ELECTRIFICATION

Society is demanding cleaner and quieter alternatives to gasoline and diesel-powered engines, and the transportation industry is responding. For years, scientists and engineers have been developing cleaner ways to run cars and trucks. Alternative fuels such as ethanol, biodiesel, natural gas, hydrogen, and propane have been developed and used to move people and goods from place to place. And although it will not be the sole form of clean fuel, the future of transportation will undoubtedly include electric propulsion. From a curiosity, to a rarity, to a reality, electric vehicles (EVs) are clearly on a path to becoming a necessity.

VEHICLE ELECTRICATION

PROS

CLEANER.
Reduced/zero tailpipe emissions. Noise reduction/quiet operation.

GREENER.
CO_2 methane, and other greenhouse gas reduction. Fossil fuel consumption reduction. Wind and solar generating the electricity.

LEANER.
Total cost reduction (over time). Vehicle and battery costs are rapidly decreasing. Lower maintenance costs. No oil changes. Fewer moving parts means reduced wear and tear. In the short-term, incentives are available.

MEANER.
Improved performance and comfort. Instant torque available. Low center of gravity for improved ride and handling. Regenerative braking. Quiet operation. Low vibration. Direct drive – no gears to shift.

CONCERNS

RANGE ANXIETY AND POWER ACCESS.
Concern over access to fast, reliable and available charging points. Is the energy grid globally ready to handle all the anticipated demand? Can vehicles be easily upgraded to handle more power as battery technology improves?

BATTERY LIFE AND SUSTAINABILITY.
Although technology is advancing rapidly, how long will batteries last and what do we do with them after their useful life?

ELECTRICITY CAN BE DANGEROUS.
Concerns over shock/electrocution. In an accident, am I safe? Is it safe to charge the vehicle in the rain or if the cable is wet?

UPFRONT COSTS.
Even if the lifetime cost of electrification proves to be less expensive to operate, the cost of entry may prove to be higher than status quo.

In most city/urban environments, one cannot run a simple errand without seeing an electric car plugged into a public charging station. Whether at the mall, near a hotel, or in a public parking garage, it's easy to see that charging stations are proliferating. But what we are seeing today is clearly just the beginning. Only two percent of cars today are plug-in electric, and that is true of even fewer trucks and buses. Just a short 20 or so years ago, the new EV industry had a fast start and a seemingly faster stop. But a lot has changed since then, and it is safe to say that electric propulsion is here to stay.

But what about vehicles meant for industrial and commercial transportation (ICT) applications? Trucks? Buses? Construction, farm, and mining equipment? These industries are on a fast track to reduce fuel consumption and emissions through electrification while enhancing efficiency and productivity. Experts predict that by 2040, most forms of transportation will leverage electric motors and/or cleaner sources of fuel to meet heightened standards.

The reason for the 20-year runway is complicated. The landscape consists of diverse applications and use cases that may or may not be conducive to vehicle electrification given today's landscape. Dotting that landscape are regulations; legislations; and social, economic, and technical obstacles that seemingly undermine feasibility at every turn. Electric grid infrastructures aligned to transportation needs are just starting to emerge. Globally, city centers are proposing complete bans on fossil fuel vehicles, yet still expect goods and services to be delivered and provided. Noise pollution, especially around schools and hospitals, has become an increasingly growing concern. These factors, along with decreasing battery technology costs and improved battery technology, are also helping electric emerge as a choice beyond the city center for off-highway industries like mining, construction, and agriculture.

For more information, visit te.com/ictHEMS

WIDELY VARIABLE USE CASES MEAN DIVERSE ELECTRIFICATION PATHS FOR INDUSTRIAL AND COMMERCIAL TRANSPORTATION

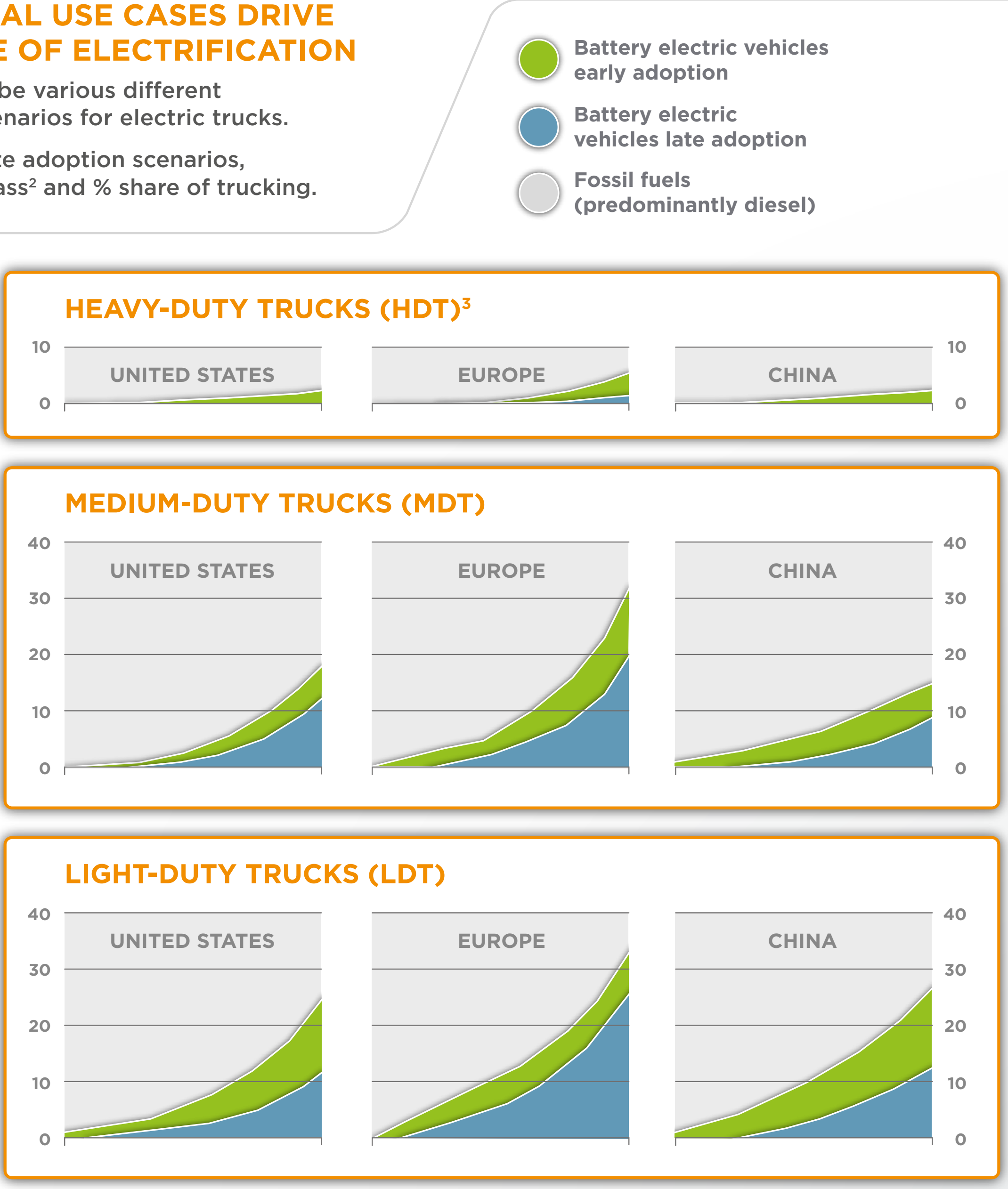
The ICT landscape is quite complex. Transitioning from "dirty" internal combustion engines (ICE) to cleaner propulsion methods is not as straightforward as it is for passenger cars, and the passenger car story itself is far from straightforward. There are many different applications and use cases, with each of these cases providing various opportunities with differing (optimized) solutions. The transition to electrified powertrains will look different depending on the job for the vehicle.

Trucks can be long haul, delivering goods across country or short haul, delivering goods and services locally and within short distances. They can be heavy duty, moving large and massive cargo, or medium/light duty, transporting smaller goods. Buses can be motor coaches, moving people long distances. They can also be city or school buses, moving people on shorter, well-prescribed routes during defined hours of operation. Other applications include industrial equipment used for construction, mining, farming, and forestry. This wide variety of use cases contributes to the complexity of transitioning from ICE to electric.

INDIVIDUAL USE CASES DRIVE THE PACE OF ELECTRIFICATION

There could be various different adoption scenarios for electric trucks.

Early[1] and late adoption scenarios, by weight class[2] and % share of trucking.



1 Based on set of more optimistic assumptions (for example, higher impact of regulation).
2 Weight-class definitions: United States: HDT: class 8 (>15 tons), MDT: class 4-7 (6.4-15 tons); LDT: class 2-3 (3.5-6.4 tons); Europe: HDT > 16 tons, MDT: 7.5-16 tons, LDT: 3.5-7.5 tons; China: HDT > 14 tons, MDT: 6-14 tons, LDT: 1.8-6 tons.
3 City buses not included.

Figure 1: Source: McKinsey Center for Future Mobility [ii]

INDIVIDUAL USE CASES DRIVE THE PACE OF ELECTRIFICATION

Different applications and weight classes will see varying breakeven points for total cost of ownership (TCO).

Timing of TCO breakeven point for Battery Electric Vehicles (BEVs) when compared with diesel vehicles, showing 'year achieved' range.

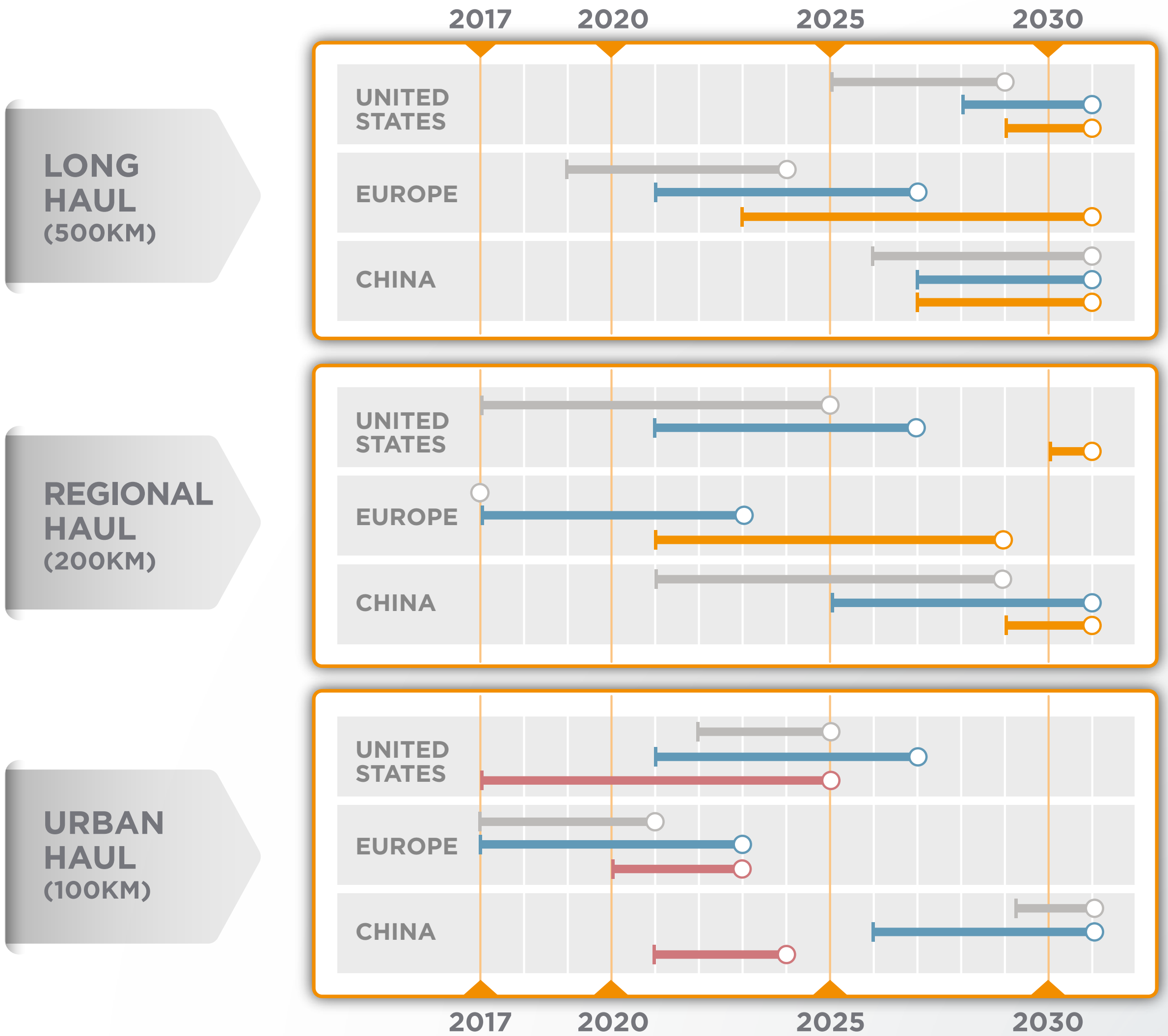


Figure 2: Source: McKinsey Center for Future Mobility ii

THERE ARE MULTIPLE PATHS ON THE ROAD TO ELECTRIFICATION

Not only are the use cases for heavy duty vehicles and equipment complex and varied, so too are the possible vehicle architectures being developed to enable cleaner transportation for these applications. Today's trucks and 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 (CNG). While industry manufacturers have taken steps to improve fuel consumption and reduce emission, including the introduction of 48V mild hybrid approaches, more needs to be done. Legislation and widening diesel bans are magnifying the need for reduced emissions. As a result, vehicle manufacturers are accelerating development away from internal combustion engines and focusing more on architectures incorporating electric motors. The approaches they are actively pursuing may be summarized in four categories:

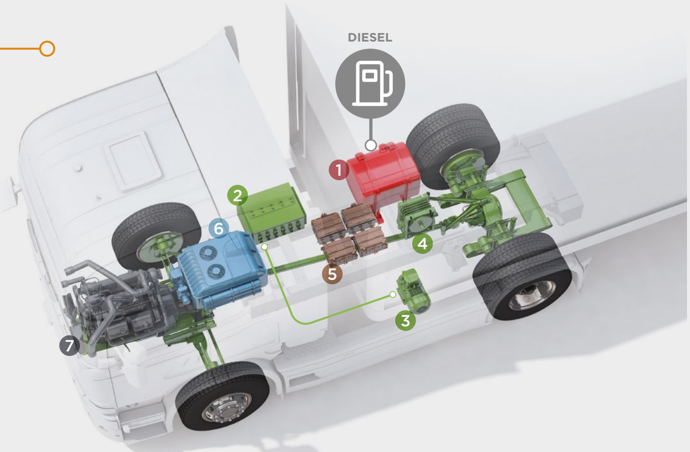
VARIOUS ARCHITECTURES

LV – Low Voltage. HV – High Voltage. PDU – Power Distribution Unit.

CONVENTIONAL HYBRIDS These hybrid architectures have conventional engines and electric motors and batteries, but cannot be plugged in. They derive their power from gasoline and diesel and thus are not categorized as electric vehicles. A mild hybrid typically utilizes a small electric motor and 48V battery combined with an ICE, allowing for assisted acceleration and regenerative braking. A strong, or parallel hybrid, will generally consist of a larger electric motor and battery combined with a downsized ICE utilizing regenerative braking and electric motor drive.

CONVENTIONAL HYBRID

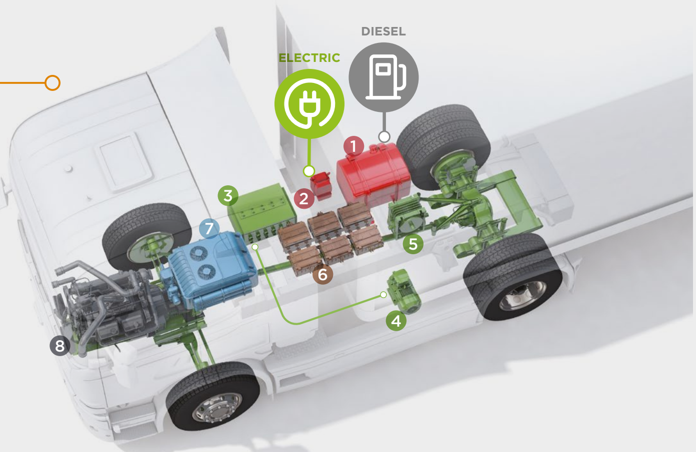
1. FUEL TANK
2. LV PDU
3. ELECTRIC MOTOR
4. GEARBOX GENERATOR
5. BATTERY
6. AUXILIARIES:
   - AC SYSTEM
   - PUMPS
   - HEATER
   - BLOWER
7. ICE



PLUG-IN HYBRIDS Plug-in hybrid electric vehicles (PHEVs) are similar to 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.

PLUG-IN HYBRID (PHEV)

1. FUEL TANK
2. CHARGING INLET
3. LV PDU
4. ELECTRIC MOTOR
5. GEARBOX GENERATOR
6. BATTERY
7. AUXILIARIES:
   - AC SYSTEM
   - PUMPS
   - HEATER
   - BLOWER
8. ICE



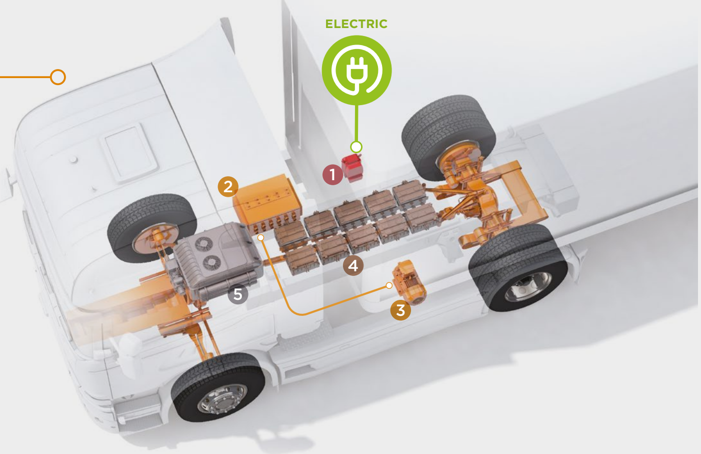
VARIOUS ARCHITECTURES continued

LV – Low Voltage. HV – High Voltage. PDU – Power Distribution Unit.

BATTERY ELECTRIC VEHICLE (BEV) BEVs use stored energy in a battery to drive electric motors. The operating voltage can be as low as 48V and as high as 850V, depending upon the application. This offers them increased efficiency and, like fuel cell vehicles, allows them to drive emissions-free when the electricity comes from renewable sources. BEVs use existing infrastructure to recharge and are increasing the demand on the energy grid.

BATTERY ELECTRIC VEHICLE (BEV)

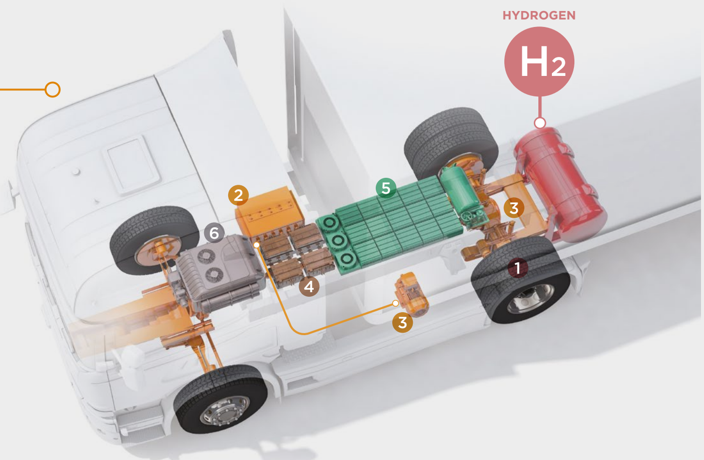
1. CHARGING INLET
2. HV PDU
3. ELECTRIC MOTOR
4. BATTERY
5. AUXILIARIES:
   - AC SYSTEM
   - PUMPS
   - HEATER
   - BLOWER



HYDROGEN FUEL CELL ELECTRIC VEHICLE (FCEV) The source of power is an on-board fuel cell that generates electricity from hydrogen, either to charge a battery or to drive the electric motors. FCEVs require a hydrogen fueling infrastructure which is not always emissions-free and not broadly available today.

HYDROGEN FUEL CELL ELECTRIC VEHICLES (FCEV)

1. HYDROGEN TANK
2. HV PDU
3. ELECTRIC MOTOR
4. BATTERY
5. FUEL CELL
   - CELL STACK
   - BLOWER
   - GAS INJECTOR
   - AIR COMPRESSOR
   - SENSORS
6. AUXILIARIES:
   - AC SYSTEM
   - PUMPS
   - HEATER
   - BLOWER



So which applications will most likely be near-term adopters of one of the EV architectures?
Depending upon the application and use case, the timing of the rollout will vary. Buses in Shenzhen China, for example, are essentially 100 percent BEV today. These vehicles were able to make the change very quickly.

CHINA'S LASTING DOMINATION

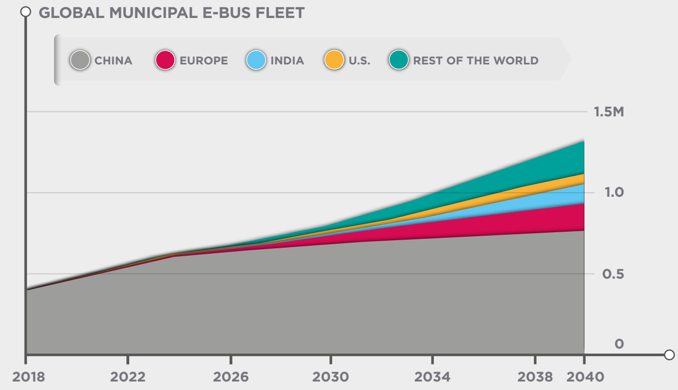


Figure 3: Source: BloombergNEF's 'Electric Vehicle Outlook 2019' [1]

It may be 10 or even 20 years until a large percentage of heavy-duty transport trucks carrying goods across continents and countries can transition to becoming fully electric due to the lack of a capable charging infrastructure. There are numerous original equipment manufacturers (OEMs) that have demonstration electric trucks and some also have announced production dates for these vehicles within the next few years. Before broad adoption can be realized, however, the infrastructure for charging or hydrogen re-fueling will need to be more broadly available.

School buses, on the other hand, are used a small percentage of the day and travel well-defined routes. This type of use case facilitates implementation of a charging infrastructure, whether plug-in, wireless, or pantograph, making them great candidates to rapidly move from diesel to electric. Similarly, construction equipment may be moved to the jobsite, then left there for days while the job is completed. It may be used for half the day, then recharged at night if a suitable charging point is made available. Or in the case of mining with around-the-clock operation, an all-electric approach can continuously operate without the need to regularly clean the air.

While enabling a quieter operation and a safer work environment are desirable, mine operators are achieving substantial cost savings on diesel, propane, and electricity. They also are realizing productivity gains, with the increased uptime of electric vs. traditional ICE solutions which have more components and higher maintenance costs. Whether a truck, bus, or industrial piece of equipment, the use case can dictate the pace of electric adoption. But whenever the electrification happens, and whether it be fully electric or as a hybrid, vehicle electrification for the ICT industry is here to stay.

CONNECTIVITY FOR POWERTRAIN ELECTRIFICATION IN INDUSTRIAL AND COMMERCIAL TRANSPORTATION DEMANDS RELIABLE, ROBUST, AND INNOVATIVE SOLUTIONS

Industrial and commercial transportation vehicles and machinery are making the move towards becoming fully electric. Many factors are leading society on a path from stand-alone internal combustion engines for propulsion, to mild and full hybrid solutions, to intelligent fully electrified powertrain architectures. And while societal challenges exist and are being addressed, technical challenges must also be overcome. ICT applications demand extremely high power AND flawless operation in very harsh environments where failure is not an option. Ensuring robust connectivity solutions for this mission-critical industry to meet worldwide demand is a must.

ICT applications demand extremely high power AND flawless operation in very harsh environments where failure is not an option.

The exact rollout and precise evolution of various powertrain architecture approaches for heavy duty vehicles is unclear.

Varying applications, regulations, and industry challenges (societal, economic, and technical) all contribute to the industry's lack of clarity. And although the timing is uncertain, what we do know with a high degree of certainty is that whether vehicles utilize hybrid architectures or full electric powertrains, these three things will be necessary:

1. **A source of electric power.** The source may be from an external plug, a wireless charger, or from an on-board fuel cell;
2. **A way to store the electric power.** The storage could be in a large array of batteries, in the case of full electric, or it could be a smaller battery approach;
3. **An intelligent application and control of the electric power.** The electric power can drive e-motors for propulsion, performing work via a loader bucket, or providing climate control for the cabin.

DIVERSE ICT USE CASES PRESENT VARYING CHALLENGES

TRUCK

Function	Use Case Description
Long-Haul / Cross-Country Delivery	Heavy-duty trucks. Long distance between refuels. Refuels must be fast. 24/7 continuous vehicle operation expected.
Regional Distribution	Medium-duty trucks. Move between regional distribution centers.
City Distribution, Delivery	Fairly small geographic boundary.
Drayage, Port Freight Logistics	Large loads, heavy-duty vehicles, controlled standardized routes.

BUS

Function	Use Case Description
Long-Trip / Motor Coach	Long distance between refuels. Refuels must be fast.
City Bus	Prescribed routes. Fairly short distances.
School Bus	Prescribed routes. Fairly short distances.

INDUSTRIAL WORK MACHINES

Function	Use Case Description
Construction, Mining, Earth Moving – Loaders, Excavators	Remote locations. Heavy-duty / high power operation.
Agriculture and Forestry – Tractors, Harvesters, Tree Cutting	Remote locations. Medium-duty operation.
Material Handlers – Forklifts, Small Loaders	Typically smaller jobs. Controlled location.
Municipal Machines and Vehicles - Gardening, Cleaning, Trash Collection	Operated by municipalities that can control routes, local usage and refueling.
Small Machines - Golf Carts, Lawnmowers, Leaf Blowers	Light-duty applications. Lower power consumption. Typically unused 1/3 of the day.

Figure 4. Varying Industrial & Commercial Transportation (ICT) use cases present diverse challenges.

CONNECTIVITY SOLUTIONS FOR MANAGING HIGH POWER

In the case of plug-in electric, the industry is currently developing High-Power Charging (HPC) stations — targeting 500 kilowatts of power with development goals for commercial transportation applications up to one megawatt. These demands are driving the industry to focus on a broad range of solutions to address unprecedented challenges in the transportation industry. Charging inlets that can handle 10 to 50 times the power of the current generation of electric cars are needed. Connections, cables, switches, and contactors are all part of power distribution and are more complex than low voltage connections. We must be able to intelligently manage this power transfer, dealing with heat, arcing, and safety issues. New thermal modeling 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.

With tremendous power comes tremendous heat. Passive, convection cooling may not be enough to mitigate the heat, driving the need for active cooling approaches at the connections and in the cables. This enables reduced cable sizes, resulting in less weight, space, and cost. New sensing techniques are needed to provide real-time data to manage the safe and smart charging aspects. Advanced materials, for both insulated housings and conductive terminals, need to be developed.

We must be able to intelligently manage power transfer, dealing with heat, arcing, and safety issues

One of the industry's most pressing challenges is how best to properly address customer Electromagnetic Compatibility (EMC) requirements. These include immunity to radio frequency (RFI) and electromagnetic interference (EMI) and minimizing radiated emissions. This is especially important for AC high power systems due to the sinusoidal power characteristics. But it is also true for DC systems where an electric cable's shielding may see induced currents up to 35 percent of the main power line's current level. For an electrified propulsion system, for example, this can rise to several hundred amperes depending on the system power demand. Vehicle and system manufacturers will need cost-effective, package-efficient innovative termination technologies to ensure low resistance with minimized corrosion between the shield mesh and the power line.

CONNECTIVITY SOLUTIONS FOR STORING POWER

It is all about range for a truck or bus, and the operating time and load requirements for a piece of heavy-duty equipment. These are all functions of the amount of energy that can be stored in the batteries or generated by fuel cells. EV batteries are quite complex given their operating voltages and current. To complicate matters, battery packs must fit within the dimensions of the vehicle and safely operate in an extremely harsh environment. Thanks to the demand for more and more battery-powered devices and green energy technology, there is a tremendous amount of investment taking place to dramatically improve battery technology in order to efficiently store the energy that is needed to operate vehicles and equipment cost effectively. The challenges are to do so safely, reliably, and in small packages. Battery disconnect and service disconnect systems are a large part of the safety equation. All these factors drive the need for highly reliable, flexible terminal and connection systems in cell-to-cell and module-to-module connectivity solutions that enable battery pack scalability. To limit size, sub-assemblies with integrated sensing capabilities are under development to enable smart control for battery management (state-of-charge and state-of-health). ICT vehicle and equipment manufacturers and system suppliers require miniaturized and compliant interconnect technology solutions. This will enable the production of small, robust packaging for high capacity battery packs.

CONNECTIVITY SOLUTIONS FOR ELECTRIFIED AND CONTROLLED PROPULSION/DRIVING E-MOTORS

Maximizing driving range on a single charge is critical. We have already discussed one half of the challenge — battery capacity. The second and equally critical part of the story is efficient operation of the vehicle or machinery. Intelligent control of the electric motor (not over-driving nor under-driving the e-motor), and regenerative braking (recovering and storing energy during a vehicle slowing event) are key approaches for energy-efficient operation.

With this high degree of control comes a high degree of integrated electronics solutions

Additionally, vehicle manufacturers are looking at ways to bring more and more outside data into the vehicle to help with efficiency. This drives the need for a new suite of sensors to enable control of EVs to ensure optimized power management and control. With this high degree of control comes a high degree of integrated electronics solutions — minimizing size (and weight) while maximizing design flexibility for our customers. New EV architectures need a single component that combines sensing, intelligent data processing and communication, and robust connection all in a single package. These architectures need robust actuators and power distribution modules that can be used to switch various loads, controlling and minimizing energy waste. They also need high speed data connectivity, both wired and wireless, enabling vehicle-to-vehicle and vehicle-to-infrastructure communications and intelligent vehicle control.

HIGH VOLTAGE CONNECTIVITY SOLUTIONS FOR HARSH ENVIRONMENTS WHERE FAILURE IS NOT AN OPTION

An electric truck, bus, or earth mover will experience much more severe operating conditions than electric cars will encounter. Rain, snow, dust, desert sun, arctic cold, rough roads, and other punishing conditions must not stop the mission at hand. High voltage switching can cause electromagnetic interference (EMI), disrupting communications and signals on low voltage circuits. For a phone or laptop computer, failure is a terrible inconvenience. Failure of a vehicle or a piece of heavy-duty equipment can mean a loss of productivity — resulting in an impact to one's business, or in a worst-case scenario, can cause serious injury or death. Safe operation is critical. Charging, maintenance, and crash mitigation must all be done in a safe manner. The complexity of electric vehicle architectures and basic operating principles is closer to airplanes, energy grids, and consumer electronic devices than it is to ICE vehicle approaches. It is critical that the ICT industries work with companies in other verticals to bring new, application-specific solutions for their customers. Material scientists and contact physicists need to collaborate to innovate viable, robust solutions for the fast-growing EV market, where a plug-in charging connection will experience thousands of mating cycles over its lifetime. Testing and validation techniques will be pushed to physical and safety-critical limits usually reserved for aerospace and industrial applications. Added complexities for both manufacturing and field service drive the need for innovative tools and methodologies to be developed.

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ABOUT TE CONNECTIVITY

TE Connectivity is a $13 billion 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 nearly 80,000 employees, including more than 8,000 engineers, working alongside customers in approximately 150 countries, TE ensures that EVERY CONNECTION COUNTS. Learn more at www.te.com and on LinkedIn, Facebook, WeChat and Twitter.

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