The Future of Fleets

The road to electrified power for commercial vehicles

Introduction

Over the last one hundred years, Cummins Inc. has grown from humble beginnings to become the world's largest independent manufacturer of diesel engines with a broad portfolio of power solutions including natural gas and electrified power. Since being founded in 1919, the company has been consistent in its ambition to develop market-leading power technologies, and its approach to innovation has created advances which keep the world moving.

Today, the world's needs are changing. Across industries and nations, enormous amounts of investment and work are going into transitioning our way of life into a sustainable model preserving the planet's resources for future generations. As part of this global effort, Cummins has worked on the means to manufacture diesel engines with the lowest possible particulate matter and nitrogen oxide emissions, minimizing the impact its engines have on the planet. However, we know by the end of the 21st century we will need to be less reliant on fossil fuels, and now is the time to diversify how we power mobility and heavy industry. Cummins will invest more than $500 million into Electrified Power, primarily on research and development, while continuing to invest in diesel and other technologies. As electric solutions join our portfolio of products and enter a phase where they are viable for consumers, the potential to transform commercial fleets is clear. What's less well understood is how we can accelerate adoption of these technologies, bringing them into widespread use in the commercial automotive sector, while maintaining productivity and prosperity.

Today, technological progress on battery electric vehicles (EVs) is growing more rapidly by the day. Cummins is taking a leading role in that progress to ensure we have the right power solutions for our customers' fast and effective adoption. Our electric buses and trucks are already on the road, however technology is just one part of the story. The same four keys which made the internal combustion engine one of history's most successful inventions – technological maturity, infrastructural capacity, economic reality, and regulatory surety – must also be considered as we endeavor to diversify.

In 1919, Clessie Cummins had a vision for how the diesel engine could change the world. Today, the company he founded has a vision for the next thirty years, setting challenging goals to achieve net carbon neutrality by 2050. In 'The Future of Fleets', we discuss how, with collaboration across the industry and with policy makers, commercial vehicles can be at the forefront of emissions reduction.

Julie Furber
Vice President, Cummins Electrified Power

The four keys of adoption

Technological maturity

The first hurdle a technology must overcome in order to be adopted for any given purpose is its ability to perform the task at hand. Assessing this for EVs is difficult, as the technology will be used in a broad variety of applications – from bikes, to buses, to heavy construction equipment – each with a unique set of needs and challenges.

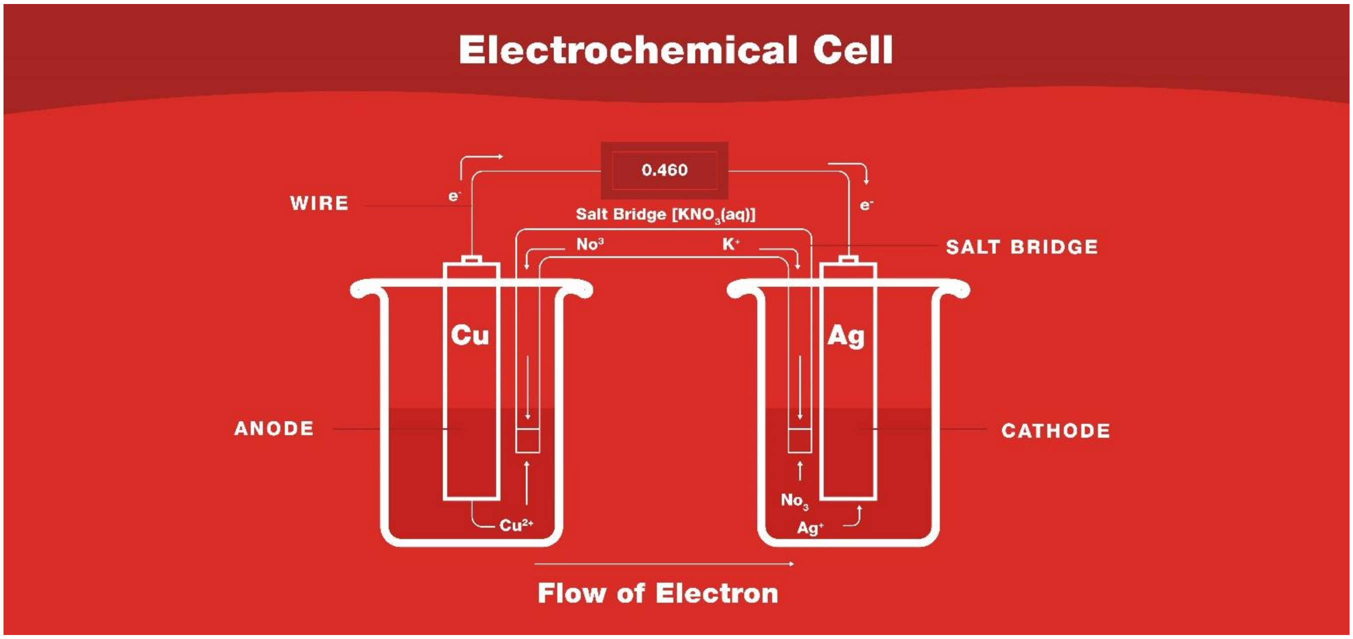
While much of what goes into an electric vehicle is familiar, some components, such as the motors, are substantially different to their conventional vehicle equivalents. One technology, however, has been the critical innovation which above all else has made modern EVs possible: the lithium-ion battery.

How Lithium-ion batteries work

While everyone is familiar with an AA battery, the lithium-ion (Li-ion) battery represents, as its inventors' winning of the 2019 Nobel Prize in Chemistry would suggest, a significant step forward from those everyday household items.

The goal of a Li-ion battery, like any electrical power source, is to move electrons through a circuit. As the electrons pass through the circuit, energy which they are carrying is converted into other forms of energy such as light, heat, and motion by machines attached to it. The more energy those machines require, the harder the power source works in order to keep the electrons flowing. Li-ion batteries are made using Li-ion cells, these building blocks allow the desired voltage and energy of the battery to be achieved through series and parallel connections.

A Li-ion cell achieves this by transferring lithium ions from one side of the cell, the anode, to the other, the



cathode. As lithium ions hold a positive electrical charge, while electrons hold a negative electrical charge, electrons are attracted to join the lithium ions from one side of the cell, the anode, to the other, the cathode. As lithium ions hold a positive electrical charge, while electrons hold a negative electrical charge, electrons are attracted to join the lithium ions at the cathode, but are prevented from doing so by a separating layer which will transmit ions but not electrons. Instead, electrons must travel through an externally completed circuit to join the ions at their destination – this flow of electrons is what provides power.

Energy density

Using batteries to provide power to a vehicle involves a key trade-off: movement over a large distance requires a lot of energy, but adding additional cells or batteries also adds weight and volume, increasing the vehicle's energy requirements even further. Therefore, one of the key scientific challenges in creating batteries for vehicles, is maximizing the amount of energy they can hold in a given volume and weight; this is precisely what Li-ion batteries achieve. As a point of comparison, older lead-acid battery technology holds 35-40 watt hours per kilogram (Wh/kg) and 80-90 watt hours per liter (Wh/L) – which means that a lead-acid battery weighing one kilogram can supply one Watt of power for 35-40 hours, and a lead-acid battery which takes up one liter of volume can supply one watt of power for 80-90 hours. Current state of the art Li-ion cells can have high energy densities of 250 to 300+ Wh/kg and 500 to 650+ Wh/L, depending on the specific chemistry being used, making it almost six times more efficient than previously used lead-acid technology. Just as this makes thin, powerful mobile phones with full-day battery life possible, it makes it possible to store enough energy in a familiar vehicle form, such as a bus, to power for long distances between recharges.

Since becoming commercially viable, the per-kilogram energy density of Li-ion batteries has more than doubled, while their per-liter density has more than tripled. As this progress continues, it will become possible to electrify more varied types of vehicles. Long-haul freight, for instance, demands a huge amount of stored energy, but adding additional battery units eats into the available storage space, making each journey less economically useful. Here, storing more power in a smaller volume will enable new possibilities for electrification. Seeing this potential, cell vendors developing the next generation of Li-ion technology are diversifying their portfolios by developing cells meeting the specific industrial requirements of commercial and off-highway vehicles.

"At Cummins, we're working on optimizing our battery design. Innovative materials for anode and cathode manufacturing can affect not just the battery's capacity, but also its cost per kilowatt-hour, maximizing battery life, optimizing charge rates, managing the range of temperatures it can endure without damage, and above all else, ensuring its safety. In our Milton Keynes (U.K.) facility, our team of experts research, design and build battery solutions for highly demanding on- and off-highway applications."

Andrew Penca
Executive Director, Electrified Power, Cummins

Infrastructural capacity

As with the technology that goes into an EV, much of the technology that we require in order to practically use one is already in place.

One infrastructural element, however, which enabled the widespread adoption of the internal combustion engine is not compatible with EVs. Oil-derived fuels are plentiful, energy-dense, easily transportable, and their liquid state means they can rapidly be pumped from their point of storage, in a petrol station or tanker in a commercial vehicle depot, to their point of use inside the vehicle. For widespread commercial adoption of EVs to take place, a solution which is competitive with these factors must be established.

Li-ion battery recharging

The key variable for Li-ion battery recharging from an infrastructure perspective is time. For a typical electric passenger car, fully recharging from a standard UK power outlet will take over ten hours; for commercial vehicles, it is likely this amount of downtime introduces significant costs. This situation is exacerbated by the fact that commercial vehicles are often larger and heavier, and therefore require larger batteries which take longer to recharge.

A bus, for example, may be shared between multiple drivers on multiple routes and therefore only have an expected downtime of a few hours per day. Here, rapid charging is vital. This is why, alongside improving energy density, a lot of research is being applied to make battery recharging faster.

"Decarbonising the transport network is a clear priority and we want to make a shift to PHEV and EV as soon as possible. However, the EV infrastructure charging network has yet to reach a level of maturity to enable this shift at scale. Many PHEV drivers do not have off-street parking and will therefore need rapid and ultra-rapid charging points close to their homes so that their earnings are not impacted by lost time charging. It is also important that passengers have confidence in the service.

Solving the recharging hurdle is really important for electrification more broadly: if we had an electric fleet of private hire vehicles, we would actually be helping to bring EVs more into the mainstream, as our vehicles are replaced every three years which provides a significant boost for the UK's second-hand EV market.

To boost rapid and ultra-rapid charging points across the UK, significant investment from government is needed along with incentives for private sector charging providers. In fact, independent research shows that London alone requires over 8,500 rapid charging points to ensure zero emission technologies are economically viable for taxi and private hire fleets, so current plans to install 300 rapid chargers in the city by 2020 is a good start, but we need a dramatic increase in the next two years."

Catherine Hutt
Mobility Innovation Lead, mVentures, Addison Lee

In principle, this is achieved by increasing the amount of power that can be put into the battery by the recharging system. While a household power outlet in the U.K. might supply 3kW of power, the DC fast chargers are rapidly increasing to ratings of 350kW and higher. By being able to provide more power, charging time can be significantly reduced.

In the context of commercial vehicles, this downtime factor has a range of consequences for infrastructure design. If the vehicles are being charged at a centralized hub, each vehicle needs a parking space for the period of charging. Here, halving the charging time of a vehicle means halving the physical space needed by the recharging infrastructure, as well as halving the number of charge points which need to be purchased and installed. For situations where a certain number of vehicle-hours is mandated by the operation, reducing the charging downtime also means reducing the number of vehicles which need to be purchased in the first place, further reducing physical space requirements.

The power grid and EVs

The energy which powers EV recharging also comes from somewhere. While internal combustion engines get their energy from a dedicated fossil fuel distribution network, EVs get their energy either from on-site power generation, such as solar and wind power, or else from the national grid. For energy companies, this will potentially represent a challenge as the overall peak energy demand upon power stations may be significantly higher when a significant percentage of vehicles are running on battery-powered motors. One solution to this will be to use smart charging solutions which, where possible, supply energy to the vehicle overnight when the electricity demand from households and industry is lower.

For commercial vehicles, however, this situation presents a more immediate problem. To take a bus depot as an example: whereas today they might have similar electricity requirements to an office building – principally running lighting, heating, and computers – charging a fleet of thirty buses at 120kW would add 3.6MW to the site's peak power demand. For context, 3.6MW of electricity generated by a power station would be enough to supply the energy needs of over a thousand homes.[1]

[1] https://www.solar-trade.org.uk/solar-farms/#:~:targetText=Some%20facts%20about%20solar%20farms&targetText=%E2%80%93%20For%20every%205MW%20installed%2C%20a,megawatts%20(MW)%20of%20installation.

Supporting this level of power draw may require constructing high-energy power-lines from the grid to the site. To prevent emissions being pushed upstream, decarbonizing the grid is also an important consideration.

"Vehicle-to-grid technology is going to be a major benefit of electrification – especially with commercial fleet applications such as school buses, which provide large energy storage capacity and where usage is limited to very specific times of day. Feeding that stored power back into the grid can benefit the power network at large by load-balancing against changing demand and picking up periods when production from renewable sources fluctuates. Beyond that, there is an opportunity to defray the costs of electrification as vehicle to grid financial benefits will lower the total cost of ownership of an electric vehicle.

Making this win-win possible, however, requires further collaboration between commercial vehicle operators, utilities, legislators and technology vendors. As an example of how effective this can be, the state of Virginia recently amended its policy so that electric school buses can be declared grid assets. This simple change means that utility companies in the state can purchase electric school buses and lease them to schools, radically lowering the up-front financial barrier to entry while improving sustainability and grid stability. Smart policy approaches and energy market design can help open the door to significant commercial EV uptake."

Marc Trahand
E-VP Marketing, Nuvve

Economic reality

Today, the economic decision-making involved in purchasing a commercial vehicle, whether as a replacement or an expansion of existing capacity, is familiar to anyone involved in fleet management. It can be broadly divided into capital expenditure – the up-front cost of the vehicle and infrastructure – and operating expenses – the day to day costs of running the vehicle such as fuel and maintenance requirements.

It is difficult to calculate in fiscal terms the social benefits and, for profit-making enterprises, the customer appeal of sustainability. The direct costs, however, are more readily apparent, and may be thought of in terms of the initial and ongoing expenses as they relate to the previous two keys for adoption.

The cost of electrification

Battery EVs are currently more expensive than their like-for-like internal combustion engine alternatives. One reason for this is inherent material costs: while battery manufacturing requires large quantities of lithium, there is no equivalent source of cost for internal combustion engines. As processes are refined, efficiencies are found, and scalability is increased, the manufacturing costs of Li-ion batteries are expected to decrease.

Even as battery prices fall, innovative strategies are being found to defray and reduce batteries' total cost of ownership. As batteries are a major factor in overall vehicle cost, leasing schemes can play a useful role here, effectively converting capital expense into operating expense and lowering the hurdle of upfront expenditure. When leasing periods conclude and ownership is returned to the manufacturer, or when batteries owned by commercial vehicle operators reach their end of life – there is also space for secondary battery usage. While a battery pack which has degraded to 80% of its original capacity may no longer be suitable for use in a vehicle, it will still be viable as an energy store for applications such as on-site backup power or to balance fluctuating output from renewable sources. This second life use approach has advantages for the economics of batteries and the environmental cost of initial manufacturing.

"At present, battery manufacture represents a significant part of the overall cost of an electric vehicle, and the reduction of this cost for a given level of performance will be a major enabler for early EV adoption. However, history shows that technologies which are initially seen as like-for-like replacements for existing solutions often turn out to provide unforeseen competitive advantages when fully implemented. Finding this advantage requires a holistic view of the value chain; in this case, considering how both overall vehicle design and the industrial context it fits into can be adapted to the nature of electric vehicles. Nonetheless, even while working towards a future in which electric vehicles can do more and better than today's options, the industry must be wary of the Osborne Effect, in which the promise of better technology tomorrow delays valuable adoption today. While some use cases for electric vehicles are currently challenging, there are also many where sustainable options are already, or soon will be, competitive with conventional vehicles."

Doug Morton
Head of Technology Strategy, Arrival

In terms of infrastructure, EV adoption can involve significant outlay which varies widely on the basis of application. For some commercial vehicle fleets, such as last-mile delivery vans, the growing availability of on-street EV charging points might be leveraged much as petrol stations supply the infrastructural needs for both passenger and commercial vehicles today. For other applications, such as buses, owned infrastructure is necessary, which will necessitate construction work – and new electric fleets may demand entirely new configurations of buildings.

Charging points can, however, be shared, meaning the upfront cost can be amortized over many vehicles. In this way, large electrification projects can deliver a better return on investment than smaller projects. The overall picture for operating expenses is simpler than that for capital expenditure. There are two main cost areas for operation: energy and maintenance. Energy costs for EVs are dependent on national electricity prices, much as fuel costs today are ultimately dependent on oil prices, while maintenance costs may be minimized through the use of advanced telematics which are more easily integrated with EVs than with conventional vehicles.

When vehicles are designed with data-sharing in mind, using components that can communicate every aspect of their performance and condition, different approaches to routing and vehicle management also become possible. In this way, data can also be used to minimize overall vehicle travel, thereby reducing wear and tear and energy costs.

Return on investment

Despite the expense involved in electrifying commercial vehicle fleets, parity in the total cost of ownership compared to diesel solutions may for many applications be close at hand.

In a recent white paper, the International Council on Clean Transportation (ICCT) studied how much infrastructure EVs will need and how this effects vehicle ownership cost versus diesel. Examining a range of variables, including vehicle class (for delivery, drayage, and long-haul applications), number of trucks required (100, 1,000, or 10,000), and predicted future trends in costs (forecasting prices for 2020, 2025, and 2030), the ICCT suggests that over the next decade battery electric heavy-duty fleets will involve a total lifetime cost of ownership of between 25% more and 25% less than the diesel equivalent.

Take delivery vehicles as an example, the ICCT calculates a fleet of 100 delivery trucks, working across a set geographic spread of fulfilment centers, will require 130 charging outlets, costing £6.1 million ($8 million) at current prices. A fleet of 10,000 delivery trucks working across a similar geographical area, meanwhile, is estimated to require 6,300 charging outlets at a cost of £206 million ($270 million) at 2030 prices. While major capital expenditure is clearly involved at either level of adoption, the infrastructure cost per truck for the former case is £63,000 ($82,000), but falls to £21,000 ($27,000) for the latter case. This pattern is repeated across the three vehicle classes: through a combination of falling prices over time and efficiency savings from vehicles sharing charging points. Therefore EVs can be, and in the case of delivery trucks already are, economically competitive with diesel options.[2]

> **"It is evident that zero-emission trucks, and the many air quality and climate benefits they will bring, are on the way."**
>
> *- International Council on Clean Transportation*

[2] https://theicct.org/sites/default/files/publications/ICCT_EV_HDVs_Infrastructure_20190809.pdf

Regulatory surety

In the previous three keys to adoption there is much in terms of promising progress. The energy density of Li-ion batteries is steadily rising, while their cost per amount of energy stored is falling. Increasingly rapid EV chargers are being rolled out, and there is a growing convergence around EV charge point standards. There is positive forecasting around trends in return on investment.

They also, however, represent a multitude of options for professionals considering diversifying their fleets. Often in technology we speak of a first-mover advantage: businesses which are quick to adopt new technologies are the first to leverage the benefits of those technologies and can therefore out-compete the market – whether through efficiency gains or more commercially attractive products. Early adoption does not always function in this way: Moving too soon can pose the risk of being left behind when an alternative solution becomes more favorable.

It is important when encouraging the electrification of commercial vehicles that policy is designed with the three previous keys to adoption in mind. The range of routes here is broad: long-term zero-pollution targets will set the overall direction of travel for the industry; cross-industry working groups will establish proven technological standards; policies which fund, and remove barriers to, infrastructure rollout will create progress on usability; sustainability stipulations in contracts put out to tender will demonstrate economic viability and create a market for sustainable vehicles; collaborative work on data sharing will improve monitoring and efficiency; and linking tax rates with emissions will improve return-on-investment.

Finding the right focus will require ongoing conversation, consultation, and collaboration with stakeholders from across the mobility space – but, there are currently examples of best practice emerging across the world.

"Policy and regulations regarding EVs must, even as it works to encourage adoption amongst industries and institutions, be carefully developed in collaboration with those industries and institutions. Sustainability, after all, is not an issue limited to any one sector, and only by drawing on the insight of experts in the technology, infrastructure, and economics of EVs, as well as end-users and other policymakers, will successful incentives to adoption be designed."

Laura Gilmore
Director of Government Relations, Cummins Europe

Zero-emission construction

The focus so far has been on commercial road vehicles. While less a topic of public discourse than the emergence of EVs in the private car market, commercial vehicles like buses are nonetheless a very visible source of emissions – especially, in major cities.

The environmental impact of construction is easier to overlook, and yet – according to a recent report from the NGO Bellona – 23% of global CO_2 emissions come about as a result of construction, with 5.5% of that emitted as a direct result of activity on the construction site, mostly due to the burning of fossil fuels. The off-highway vehicles which constitute a lot of heavy construction equipment (such as excavators, dump trucks, and steamrollers) are therefore an important area for progress on sustainability. Cummins zero emission electric mini-excavator prototype demonstrates feasibility, operating a full work shift and charging in under three hours.

> **"Collaboration between local policy-makers, industrial actors, and civil society, is helping to develop innovative technologies to comply with Oslo's procurement standards."**
>
> *- Bellona Report*

Bellona's report details the nature of some policy initiatives which are already seeing positive outcomes in this area. In the Norwegian capital Oslo, emissions from construction vehicles constitute 7% of all municipal emissions. One of the city's municipal developers, Omsorgsbygg, has operated a series of initiatives involving setting minimum standards for bidders on contracts it puts out to tender. After successfully making it a requirement that partners switch from diesel to biodiesel, the developer adopted the policy that 'what can be run on electric, shall be run on electric'.

In 2016, when this policy was adopted, there was very little electrified construction machinery available, meaning that it had little to no impact.
What it did do, however, was create the potential for a market for electrified construction equipment. The city's first zero emission construction site began operation in September 2019.

In October 2019, the city council agreed that by 2025 all public construction sites will operate emission-free machinery and transport.

Part of the success of Oslo's initiative, besides the determination of stakeholders to make it work, may be in the phrasing of its policy. By using the phrasing 'what can be run on electric', the city avoids forcing construction firms into inappropriate adoption, electrifying what is not yet suitable to be electrified, and opens a dialogue with them about what can and cannot be electrified, while working cooperatively on progress towards sustainability.[3]

> **"There are major opportunities for decarbonisation in the public sector. Refuse collection vehicles, for instance, might not be the most glamorous face of new technology, but electrifying these heavy, diesel-powered and frequently idling vehicles which visit every road in the country on a regular basis offers significant benefits for sustainability and air quality. That's why we've collaborated on electric refuse collection vehicle projects to retrofit existing vehicles with electric powertrains, bringing the benefits of EVs to bear while saving on whole-lifecycle emissions and establishing the case for retrofitting in a range of heavy applications.**
>
> **Proving that this approach works requires collaboration between many partners – including councils, operators, and technology suppliers – and there is still work to be done in terms of showing that there is long-term reliability and trustworthy infrastructure in place. As the viability of electric vehicle technology for this kind of purpose is demonstrated, however, councils will begin to make a real difference by writing sustainability requirements into their tendering processes."**
>
> **Kim Smith**
> *Head of Smart Mobility, dg:cities*

[3] https://bellona.org/news/transport/electric-vehicles/2019-10-bellona-launches-report-on-zero-emissions-construction-sites-at-c40-cities-summit

Bringing it all together

There is a broad, valuable, and under-considered case to be made for the electrification of commercial vehicles. All over the world, progress is being made to bring the technological capabilities of EVs up to the level where they meet the requirements of commercial applications. This requires us to understand their infrastructural requirements and make them clearly actionable, to bring their total cost of ownership down to a level where they compete with and exceed conventional vehicles, and to produce policy which incentivizes their adoption.

EVs are a familiar topic of discussion, and are now emerging in the consumer space as a viable product. However, achieving buy-in from consumers happens person-by-person, piece-by-piece, and the infrastructure to support these vehicles is caught in a chicken and egg situation; where it doesn't become a broad, profitable enterprise without a critical mass of passenger EVs on the roads and many will not purchase an EV until blanket infrastructure is in place. This impedes the cost reduction, as companies struggle to find economies of scale, and public policy to encourage adoption is slow to show positive outcomes.

These four keys to adoption are at play in the consumer vehicle space, as they are in the commercial vehicle space – but for commercial vehicles, finding the right solution and starting that process of transformation means replacing large groups of internal combustion engines with zero-carbon alternatives at a time, bringing about the scale of usage which can lead to mass adoption.

For Cummins, this process of finding the right solution is always a collaborative effort. Getting it right means having conversations across stakeholders in industry, policy, and end-users to deeply understand the issues and ensure a successful roll-out. Therefore, the invitation is to talk more about how to make electrification happen. If you'd like to continue the conversation with us, visit *www.cummins.com/electrification*.

Cummins Inc.
Precedent House,
3 Precedent Drive, Rooksley
Milton Keynes, MK13 8HF
UK

www.cummins.com/electrification
ElectrifiedPower@cummins.com