PERSPECTIVES PAPER

BENDIX FOCUSED ON LEADERSHIP IN EMERGING EMOBILITY ENVIRONMENT

Company Committed to Advancing Industry Understanding and Optimizing Vehicle Technology Solutions

Like the view out of a trucker's window, change is a constant in the commercial vehicle industry. One of the most significant changes taking place in trucking today is the onset of the shift to electric vehicles. Every major original equipment manufacturer (OEM) is at work developing the architecture for their coming trucks and buses powered by electricity. Although electric commercial vehicles have been in production for many years in niche applications such as transit, by 2020-22, initial production of on-highway, goods-transport, heavy-duty electric commercial vehicles will begin in North America, and motor carriers will be able to order them in quantity.

Bendix (Bendix Commercial Vehicle Systems LLC and Bendix Spicer Foundation Brake LLC) is a vital technology partner to the truck makers as the industry pursues electrification. For nearly 90 years, Bendix has set the standard for commercial vehicle air brake charging and control systems, plus educating the industry about them.

Today, Bendix is applying that leadership in the emerging eMobility landscape in two key ways:

- Bendix is focused on optimizing its technology solutions for electric trucks and buses by adapting product strategies to meet the needs of the upcoming vehicles.
- The company is driven to help fleets and vehicle operators understand this new environment – the dynamics shaping it, and the changes it will bring to vehicle systems and maintenance operations – so they can determine if or when to enter it.

Emergence and Growth of Electric Commercial Vehicles

Developments around electric vehicles have been ongoing for many years, from continuing advances in battery technology to innovations in brake control. Now the industry is at a point where a shift to electric vehicles is not only possible, but increasingly inevitable.

Total cost of ownership (TCO) is an essential point in the electric vehicle conversation. Because a commercial vehicle is a rolling asset that generates profit, fleets are highly focused on cost per mile and lowest TCO for their application. This emphasis on TCO sets electric commercial vehicles apart from electric passenger cars, where buyers typically may follow a different set of buying criteria, such as environmental concerns. Commercial vehicle buyers think about the whole cost of ownership – how much the initial vehicle is going to cost, what is the cost per mile to run, what's the residual value, and what are the maintenance considerations. Fleets keep these factors top of mind.

In tandem with TCO considerations, a set of market drivers is affecting how much and how fast commercial vehicle electrification will take hold among fleets and vehicle operators.

- **Market Drivers**

  - ***Cost of batteries.*** Changes are taking place in batteries and battery technologies to make them denser, lighter, and most cost efficient. As electric automobiles gain in popularity, battery prices could start dropping. A significant reduction of prices within the next three to five years has the capability to increase commercial vehicle adoption quickly.
  - ***Cost of diesel.*** Fluctuating diesel costs are a fact of life in trucking. Fleets historically have been forced to take the ups with the downs. But electrification will present a possible alternative option. The math could reach a point where a fleet is at a competitive disadvantage by running diesel, while other fleets run electric. On the other hand, if electric vehicle growth reduces demand for diesel and causes lower prices, diesel's favorable cost per mile could make it more challenging for electric vehicle adoption to grow further.
  - ***Charging infrastructure.*** Primary fleet garages and depots are the likely starting points for the charging infrastructure, and will initially better support local pickup and delivery, transit, and hub-to-hub operations. As electric commercial vehicles become more popular, charging may start to appear at nationwide truck stops.
  - ***Environmental regulation.*** Prior emissions regulations have added $15,000+ to the cost of a vehicle. Future greenhouse gas regulations could add cost to diesel engines – also up to $15,000 per vehicle. For fleets calculating TCO of diesel vs. electric, whether or not environmental legislation is in play represents an important factor.
  - ***Pollution and noise restrictions.*** A number of cities are considering not allowing diesel vehicles to run within certain zones inside the city due to emissions and air quality concerns. And in many cases, diesel vehicles cannot run during certain times – for instance, anything before 7 a.m. and after 9 p.m. – because of the sound they emit.
  - ***Move to automated driving.*** As discussed later in this paper, automated vehicles are helping to prompt the transition to Electronic Braking Systems (EBS) and redundancy, both of which are central parts of the electric vehicle platform. Some OEMs are using the introduction of electric and automated vehicles to drive their next-generation brake control systems.

- **Timeline**

  - ***Market view.*** Estimates on how much of the commercial vehicle market will be electric within the next 10 years range widely, from 5 to 40 percent. Leading market research groups, as well as Bendix have done studies and created models, and most agree on this range. The majority of models show that by 2030, between 15 and 20 percent of the market will be electric. Battery prices are key: If they remain steady, the adoption number stays closer to 5 percent; as noted earlier, however, if there's a step-change decrease in the next three to five years, that could change the

scenario and push the adoption estimate closer to 40 percent. The models anticipate TCO parity within 2025-30, where it would cost as much to run an electric vehicle as it does one powered by diesel fuel. One analysis, from 2018, noted the likelihood of some fleets introducing electric vehicles and then waiting a year or two to verify reliability – to confirm they're getting the TCO they anticipated.

- ***OEM availability.*** The emergence into the commercial vehicle marketplace of new players have energized the major truck makers to launch electric vehicle programs. Since 2017, every OEM has announced a new program in which serial production will start between 2020 and 2022. A key question at this point is what price they will attach to these vehicles.
- ***Industry segments.*** Multiple studies indicate that some segments of the industry will enjoy strong TCO early on, with others coming later. Earlier segments include pickup and delivery, regional haul, hub-to-hub, and buses. For vehicles making many starts and stops, and returning to a home base daily, electrification is an advantage and makes sense quickly. Other areas, such as medium- and long-haul, present more challenges for electrification. Here it will take fleets time to understand how electrification fits. Carriers will need to closely consider the charging infrastructure, number of miles, and usage of the vehicles. That said, there may be scenarios in which medium- and long-haul make sense for electric adoption, when calculation of the various costs – including batteries and diesel fuel – points in the direction of electric.

How Electrification Is Changing Vehicle Systems

The electrified platform will trigger key changes to vehicle systems. OEM engineers – teaming with partners like Bendix – are working out details for the initial generations of vehicles, but enough primary pieces are in place to gain a big-picture understanding of what those changes will look like. This paper focuses on braking components and shares a high-level look at how electrification is affecting air management, brake control, and wheel-end systems.

- **Air Management**

  - ***Compressor.*** With the internal combustion diesel engine removed, components and accessories that rely on that engine for power – including the air compressor – will become electrically driven with a motor. Also, compressors will likely need to utilize different technologies to meet the desired lower noise and lower oil-passing levels needed for electric vehicles that the current reciprocating compressors cannot meet.
  - ***Air dryer.*** The air dryer is the next step in the system, and in an electric vehicle, the dryer will use a solenoid or electronic control unit (ECU) to control when it is purging. It is a smart component that will add a monitoring element to assess the health of the system, including communicating cartridge life and air system leakage.
  - ***Air governor.*** This component determines when a compressor builds air pressure. An intelligent air governor can be integrated into a conventional air dryer and

contributes added features and prognostic capabilities to the air brake system when functioning as part of an electric vehicle.

- **Brake Control**

  - ***Electronic Braking Systems (EBS).*** EBS is likely to emerge as the base brake control system in electric vehicles. If not EBS, then the addition of electronically controlled brake valves to the current antilock braking system (ABS). EBS has been in production for 20 years in Europe, but has yet to come to North America in significant numbers. Now, the combination of automated driving and electrification is causing the industry to reconsider ABS versus EBS. EBS controls the braking pressure electronically on every stop. It differs from ABS, which is designed as an intervention system that electronically activates only periodically to limit locking of the wheels when braking, limit wheel spin-up with traction control, and provide individual wheel braking for collision mitigation and to maintain vehicle stability.
  - ***Electric motors.*** Because they will no longer rely on a diesel engine and drive train, a vehicle will be driven by one or more electric motors, depending on the vehicle application. There could be one or two motors per driven axle. As with hybrid vehicles today, the motors can switch functions to become "generators," recovering energy during deceleration to recharge the batteries. As a result, there will likely need to be improved coordination between the motors and brakes during typical deceleration.
  - ***Traditional system remains.*** The electrified powertrain, however, will not replace the traditional air brake system, which will remain on electric vehicles. Legal requirements state that the vehicle must meet stopping performance without electrical systems. In addition, the electric drivetrain is unable to absorb enough energy adequately in an emergency stop. In light of this, the traditional air brake system will be in existence for many years to come. The pneumatic brake system may not be used as much on an electric vehicle, but when needed, it must be there, ready and able to meet stopping distance requirements. As a result, the brakes will not get smaller. Brakes will use air when applied, with the electronics in place to better control the pressure. If something goes wrong with the electronics, the pneumatic back-up brake control must be ready to operate like an air system today.
  - ***Redundancy.*** Some electric vehicle makers are also looking to use electrified vehicles as autonomous vehicles. Autonomous vehicles will also require redundancy, or complementary systems to ensure that multiple functions, including braking, will continue to function if the primary system has an issue. A redundant brake system provides a way for a vehicle without a driver to bring it to a safe condition – either off the side of the road or through a limp-home function, where it moves at reduced speed off highway within a designated number of miles to the nearest service garage.
  - ***Brake blending.*** As the electric vehicle slows down, this process allocates the deceleration energy back – initially through the motor system, where it is absorbed in the batteries so it can be utilized later – and then through the friction brakes when necessary.

- ***Full electric brake system.*** Looking further into the future, the industry is exploring concepts for a totally electrically driven brake system, focusing on vehicles less dependent on an air system, such as straight two-axle delivery trucks. Ten to 15 years from now, it's possible that a small group of vehicles will have brake systems that are fully electric.

➢ **Wheel-End**

- ***Optimized friction.*** At the wheel-ends, a key change is likely to be in the friction couple. The brakes are expected to be used less in electric vehicles, as the electric motors take on more of the typical brake work. Because of this, a different type of friction will be needed – a formulation that will clean itself more and, in the language of the industry, resist "going to sleep" from reduced usage, yet be able to maintain stopping distance during hard deceleration braking events.
- ***Optimized rotor.*** The rotor and friction are a system, and since the friction might be designed to take on less of the low-torque requirements for braking, the rotor design would be optimized to do the same. It also has the potential to be reduced in weight as the amount of work it needs to do continuously is reduced.

Effect of Electric Vehicles on Fleet Maintenance Operations

Electrified truck systems will cause changes to fleet maintenance operations. On electric vehicles, some vehicle parts will become easier to maintain, because electrification will give them the ability to diagnose themselves. But challenges will come with the addition of new technology.

Technicians will be required to understand issues with electrical systems. For example, driving the compressor electrically means adding a motor to the brake system. That motor may be 48-volt, but it will more likely be higher voltage, from 400-volt to 1,000-volt. High-voltage systems involve unique maintenance practices and typically require specialized training.

Service professionals will also need the appropriate diagnostic tools to determine what is wrong and how to repair it. In some cases, it will mean updating the vehicle or brake system software so the unit functions properly. The coming of electric vehicles will force diagnostic tools to get better and require technicians who know how to use them.

Some maintenance practices will not change. Since the traditional braking system isn't going away, the brakes must always be in top working condition. It will be the job of the maintenance team to ensure the constant readiness of the friction and rest of the wheel-end components.

The Place of Bendix Technologies

Bendix provides a complete system solution for electric vehicles, including electric compressors, intelligent air treatment, Electronic Braking Systems (EBS), electronic parking brakes, and optimized wheel ends, among other technologies. In addition, the company offers a flexible architecture that can adapt to varying vehicle and functional requirements, while optimizing energy efficiency. Bendix leverages its close collaboration with parent company Knorr-Bremse to further the hybrid

and electric application expertise it supplies to the industry. In the realm of electric vehicles, as in all other industry areas where it demonstrates leadership, Bendix is proud to work alongside its trucking partners to shape tomorrow's transportation, together.

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