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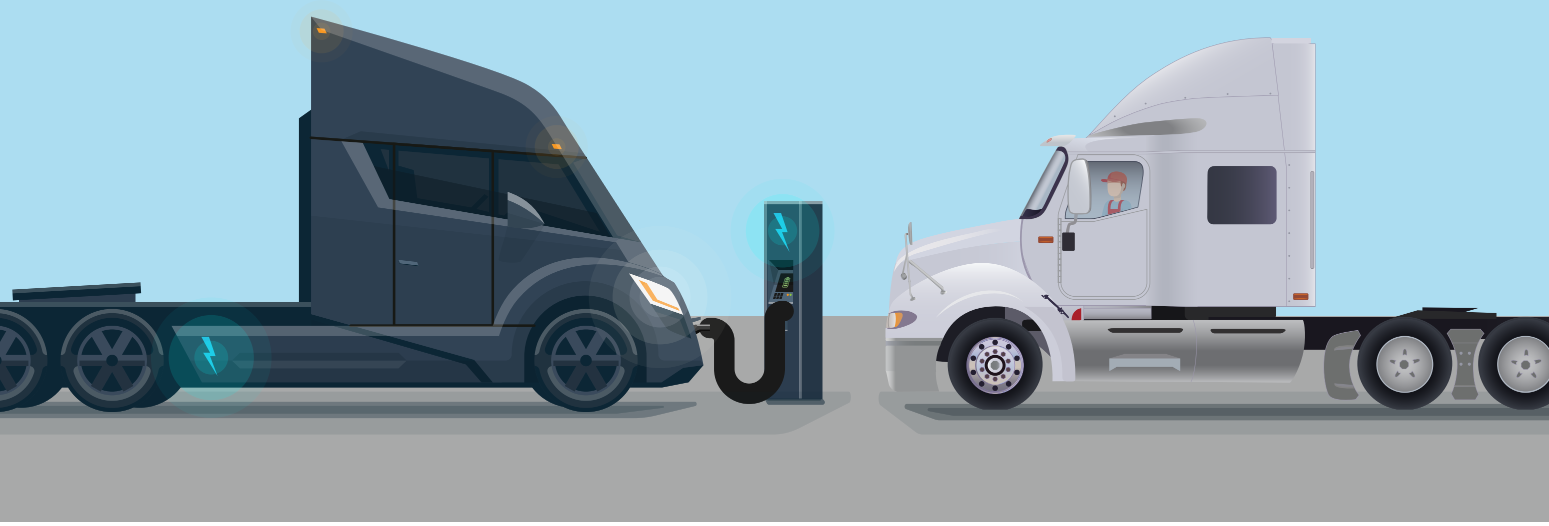


ELECTRIC TRUCKS—WHERE THEY MAKE SENSE

The North American Council for Freight Efficiency (NACFE) created this Guidance Report to provide perspective, insights, and resources on the complex topic of the viability of commercial battery electric vehicles (CBEVs), Classes 3 through 8. This report provides a foundation for understanding the key arguments for and against this rapidly evolving powertrain alternative. This report expands NACFE's role to include emerging new technologies that may not yet be available in production.

The fuel costs faced by the trucking industry are a significant part of the expense to operate a tractor-trailer in North America. Over the past decade fuel has been as high as \$0.65 per mile driven and then dropped to \$0.34 by 2016. At these two points, fuel costs accounted for 39% and 21% of the total cost of operating a commercial vehicle respectively. The price per gallon for diesel as of March 2018 has now risen to around \$3.00 per gallon (\$0.44 per mile) from the 2017 yearly average of \$2.65.

In addition, the United States Environmental Protection Agency (US EPA) and the National Highway Traffic Safety Administration (NHTSA) have enacted greenhouse gas emissions regulations on commercial vehicles extended to 2027 that require manufacturers to develop and sell technologies to improve efficiency. These factors have driven fleets, manufacturers, and others to improve the efficiency of over-the-road tractor-trailers.

Fortunately, myriad technologies that can cost-effectively improve the fuel efficiency of Class 8 trucks are readily available on the market today. While the industry continues to increase the adoption levels of these technologies, industry stalwarts and new startups are aggressively developing revolutionary new products such as electric powertrains for trucks and technologies that continue to increase automated operation. To assist the industry in these efforts, the North American Council for Freight Efficiency (NACFE) is expanding its role with Guidance Reports—providing information on emerging new technologies that may not yet be available in production.

Widespread innovation and technological advances are producing technologies and practices that could affect decisive, revolutionary, and potentially disruptive opportunities across the transportation industry. As novel concepts, new applications, and original modes of behavior reach the market, fleets and manufacturers need information on the benefits, challenges, and risks so that everyone can profit in this evolving landscape. NACFE hopes that by fleet managers using its Guidance Reports in the months and years leading to launch, the first generation of production technologies will perform much better and offer better return on investments. This Guidance Report on electric trucks represents the first in a subset of reports being published on emerging technologies. Subsequent reports will focus on specific product offerings for market segments, duty cycles, and relevant technologies.

The goals of this Guidance Report are: (a) to present the viability of Class 3 through 8 commercial electric trucks, (b) to discuss the pros and cons of this evolving alternative to diesel powertrains, and (c) to provide industry with the quality information needed to make sound business decisions on this rapidly emerging technology.

ELECTRIC TRUCK ARGUMENTS

Battery electric vehicles for commercial applications are here today and are a growing alternative to traditional gasoline, diesel, alternative fuel, and hybrid powertrains. Opinions vary on whether this technology is a viable alternative to traditional powertrains; they are considered a threat by some and a promise by others. While considerable capital is being invested as a result of CBEVs, information is rife with biases and vested interests.

In research for this Guidance Report, NACFE identified some common arguments both for and against electric Class 3 through 8 commercial vehicles. The findings fall into several broad categories: weight, technology, cost, and charging/electric grid issues.

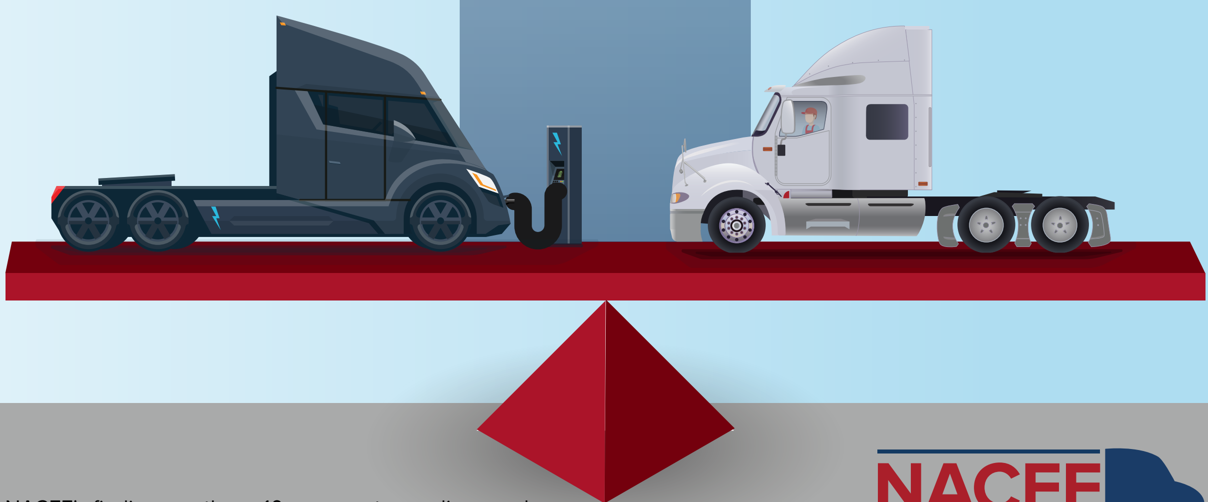
METHODOLOGIES

This report's conclusions were generated through interviews with fleets, manufacturers, and subject matter experts with first-hand experience with battery electric vehicles and grid infrastructure. Fourteen fleets responded to a survey that was used to better understand their needs and plans with respect to electric truck adoption. An extensive list of references was researched with the same diligence and thoughtful processes NACFE uses with its Technology Confidence Reports. The references and links are provided at the end of the full report for those interested in more detail.

FIGURE ES1

10 ARGUMENTS FOR AND AGAINST ELECTRIC TRUCKS

Argument FOR Electric Trucks	VS.	Argument AGAINST Electric Trucks
1 Commercial battery electric vehicle (CBEV) weight is not an issue	WEIGHT	1 Vehicle tare weight is too high to support my freight needs
2 CBEV technology is proven and here now	TECHNOLOGY	2 Technology is not ready
3 Maintenance will be less costly		3 Maintenance may not be less costly
4 CBEVs will last beyond 10 years		4 Vehicle life is too short
5 CBEVs will be competitively priced	COST	5 Vehicle purchase price is too high for a positive ROI
6 CBEVs will be less expensive to operate		6 Vehicle operating costs are too great for positive ROI
7 CBEVs will command a premium at resale		7 Vehicle residual value is questionable
8 Trust the market to provide CBEV charging solutions	CHARGING	8 Charging infrastructure is not ready
9 Trust the market to provide CBEV charging solutions		9 Charging Infrastructure is not fast enough
10 The grid and market will evolve with CBEVs		10 The electric grid cannot support growth in electric vehicles



NACFE's findings on these 10 arguments are discussed in detail in its Electric Truck Guidance Report

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Image courtesy of Ryder System Inc.

This Guidance Report evaluates these positions and assesses the viability for North American Class 3 to 8 commercial battery electric vehicles to help the industry understand the many claims and rebuttals.

FINDINGS

NACFE's findings on these major positions on the extreme end of each argument are summarized below.

WEIGHT

Weight affects fuel economy. And the tare weight—the unladen weight—of the truck is important in determining the amount of freight it can legally carry. Many people worry that adding batteries to gain range in an electric truck will unacceptably reduce allowable freight, increasing the net vehicle operating costs so much that the comparison to a diesel is not attractive. Yet competitive vehicle tare weights are possible in all classes for many duty cycles. Diesel powertrains include fluids, emissions systems, exhaust systems, cooling systems, and mountings—all things that aren't included in CBEVs and that increase weight. Also, typical payloads in many applications are well below maximum GVWR. The combination of both of these factors allows for CBEV solutions with equivalent freight carrying capacity in many applications, but not all.

TECHNOLOGY

The rapid pace of improvements in battery technologies—increased capacity and decreased cost and weight—could spur increases in CBEV efficiency that likely cannot be matched by evolutionary changes to internal combustion engines. These competing technologies are at different points in maturing on their innovation S-curves, with the greater potential going to the newer CBEVs.

Reliability of the new CBEV technologies will improve through OEM experience with increasing numbers of vehicles on the road. The large OEMs will enter the market with production CBEVs providing long-term stability for fleets considering electric trucks.

Maintenance and service cost reduction is an open question at this time. The industry is still at the early stages of development where designs have not yet matured through significant field experience. Preliminary findings indicate that these costs are average or slightly better than typical internal combustion alternatives but could prove to be significantly better given the much simpler overall design of the CBEV. Feedback from medium-duty electric truck operators is that after separating out early failures, these vehicles over the long run do have lower maintenance costs versus diesel.

In regards to vehicle life, fleets, OEMs, and suppliers expect a Class 3 through 8 vehicle life of seven to 10 years before major refurbishing or salvage. The most common concern is the battery packs as charging of CBEV battery packs tends to reduce their capacity. The manufacturers expect the battery packs to be replaced when they reach 80% of their initial capacity. NACFE projects that batteries will likely exceed the seven to 10-year vehicle life.

COST

Cost is of course a critical factor in fleet technology decisions. The determination of net costs/benefits of CBEVs requires more effort than traditionally limited ROI calculations. Multiple factors need to be included, from straightforward costs such as grants, incentives, and taxes, to hard-to-quantify costs such as emissions credits, brand image, liability costs, disposal costs, indirect costs, driver/technician retention or attraction, potential customers, and other opportunity costs/benefits buried in overhead or ignored in traditional ROI calculations. Residual value and salvage value are also significant questions as there is no history at present. New business model innovations related to costing the delivery of energy to the vehicle also need to be included. Charging these trucks is not currently as available as gasoline or diesel refueling.

The industry is also developing alternatives to traditional purchasing or leasing which will factor into attaining positive ROI for CBEV investment. The battery system is the most expensive cost item. The trend over the last decade is expected to continue, with large reductions in cost and significant gains in performance. Diesel performance, in contrast, is unlikely to yield large gains in performance with reduced costs. Diesel powertrains, after a century of commercial vehicle development, are at a different point in maturation where gains are small and expensive, and complicated further by increased demand for emissions reduction.

Operating costs can be less for CBEVs because electric drives are more energy efficient than diesels and the reduction in diesel-based friction-sensitive mechanical systems such as pumps, valves, transmissions, and belts should reduce maintenance and servicing. However, vehicle residual value is still undetermined. Electric vehicles (cars and trucks) are still mostly within their first owner's use. The used electric vehicle is in its infancy. And Class 3 through 6 vehicles may not typically have a second life as the first owner may run them until they are scrapped. However, the value of electric motors and batteries in salvage may prove an advantage as they can be repurposed for non-vehicle uses and may have significant life left.

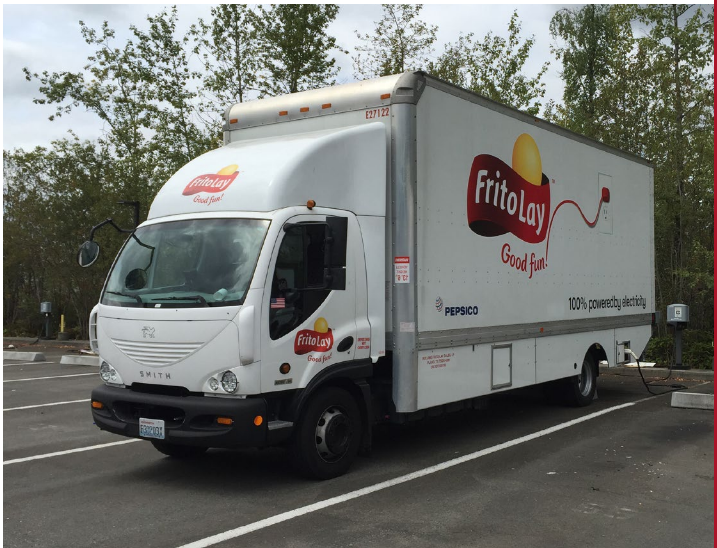
CHARGING/ELECTRIC GRID

CBEVs will increase demand on electricity and require improved demand management and storage and new electrical charging infrastructure. There are new business opportunities for charging infrastructure that may accelerate this, such as utilities or third parties providing the charging stations to factories and warehouses. Thus, the lack of current infrastructure is not a detriment to CBEV adoption, but rather an opportunity for market growth.

The speed needed for charging depends on each fleet's duty cycles and daily and weekly route scheduling. Many operations have defined cycles that permit off-cycle daily charging. While off-shift charging of vehicles is possible today with existing systems, the challenge is high-speed charging. CBEVs needing sub-30 minute charging speeds require high-capacity production charging systems that are currently only in the conceptual phase. Technically, these high-speed systems are thought to be feasible by a range of experts, but practicality is still a question for them. Fleets with well-defined one-driver shift A-B-A, or A-B-C-A type routes, for example, are well positioned to have base depot charging. Even fleets with routes between hubs, if range is sufficient, could have charging at both ends of the trip. Fleets with variable routes and no guaranteed return trips, will need growth in remote "public" charging capacity before considering replacing diesels with CBEVs. Hybrids may be needed where vehicles operate between and in zero-emissions zones.

The U.S. has energy production capacity for significant volumes of electric cars and trucks. Adding vehicle charging stations to a warehouse or factory is like adding a new line, a process utility companies regularly perform for commercial sites. High-rate charging expected for any sub-30 minute charging of commercial vehicles, does create a significant demand on the grid. Alternatives to mitigate this through leveling and storage systems are being considered.

Image courtesy of National Renewable Energy Laboratory

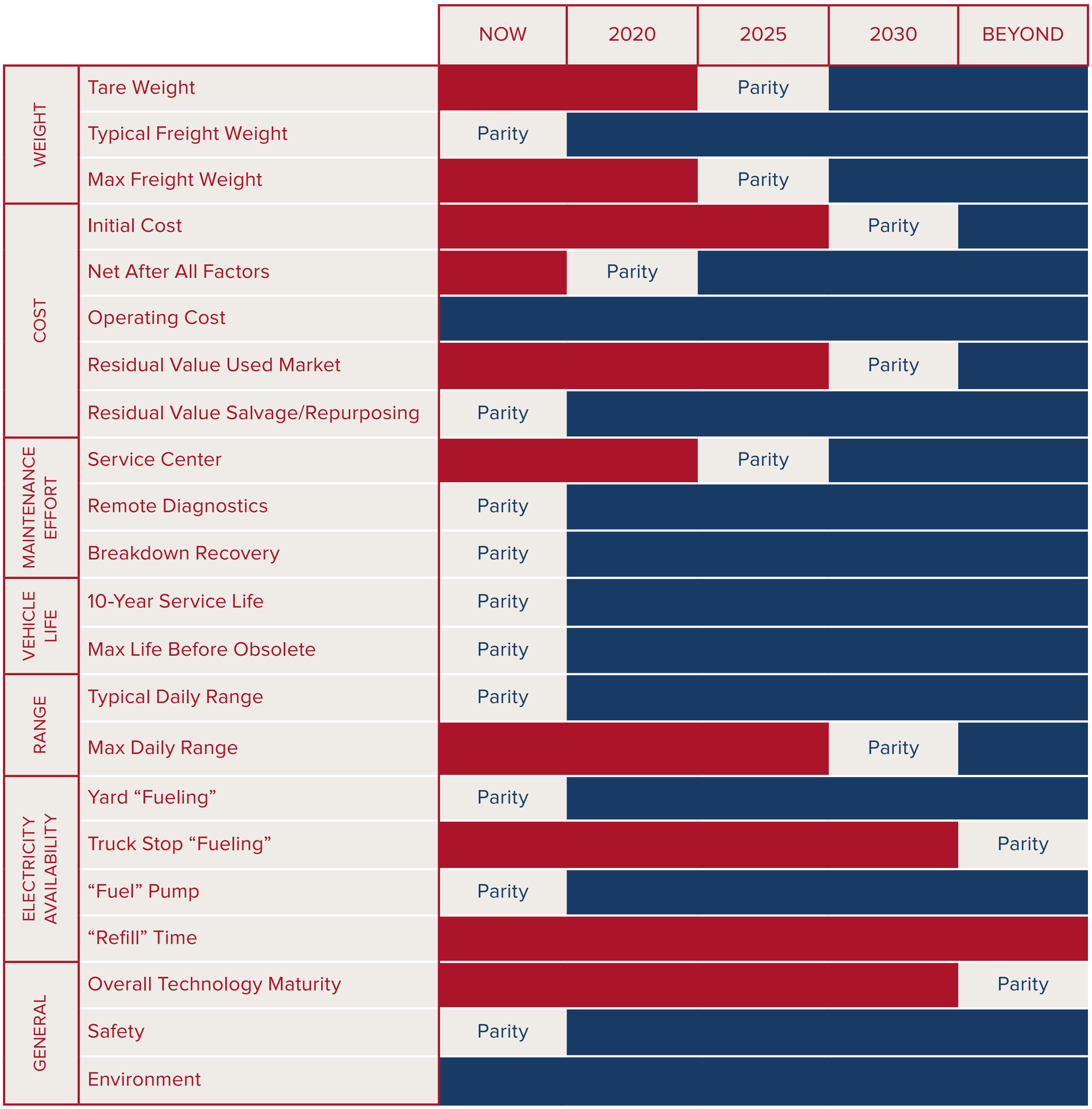


PARITY BETWEEN CBEVS AND DIESELS

CBEV comparison to diesel powertrains is not a simple yes/no choice. There are multiple factors, time frames, and cost/benefits to consider. NACFE summarizes these multiple factors using parity, the point at which a CBEV is roughly equivalent to a diesel powertrain. The two charts below summarize NACFE's estimated time frame where parity is reached between these two powertrains. The first is for Class 3 through 6 segments, generally referred to as medium duty. The second is for Class 7 and 8 segments, heavy duty.

FIGURE ES2

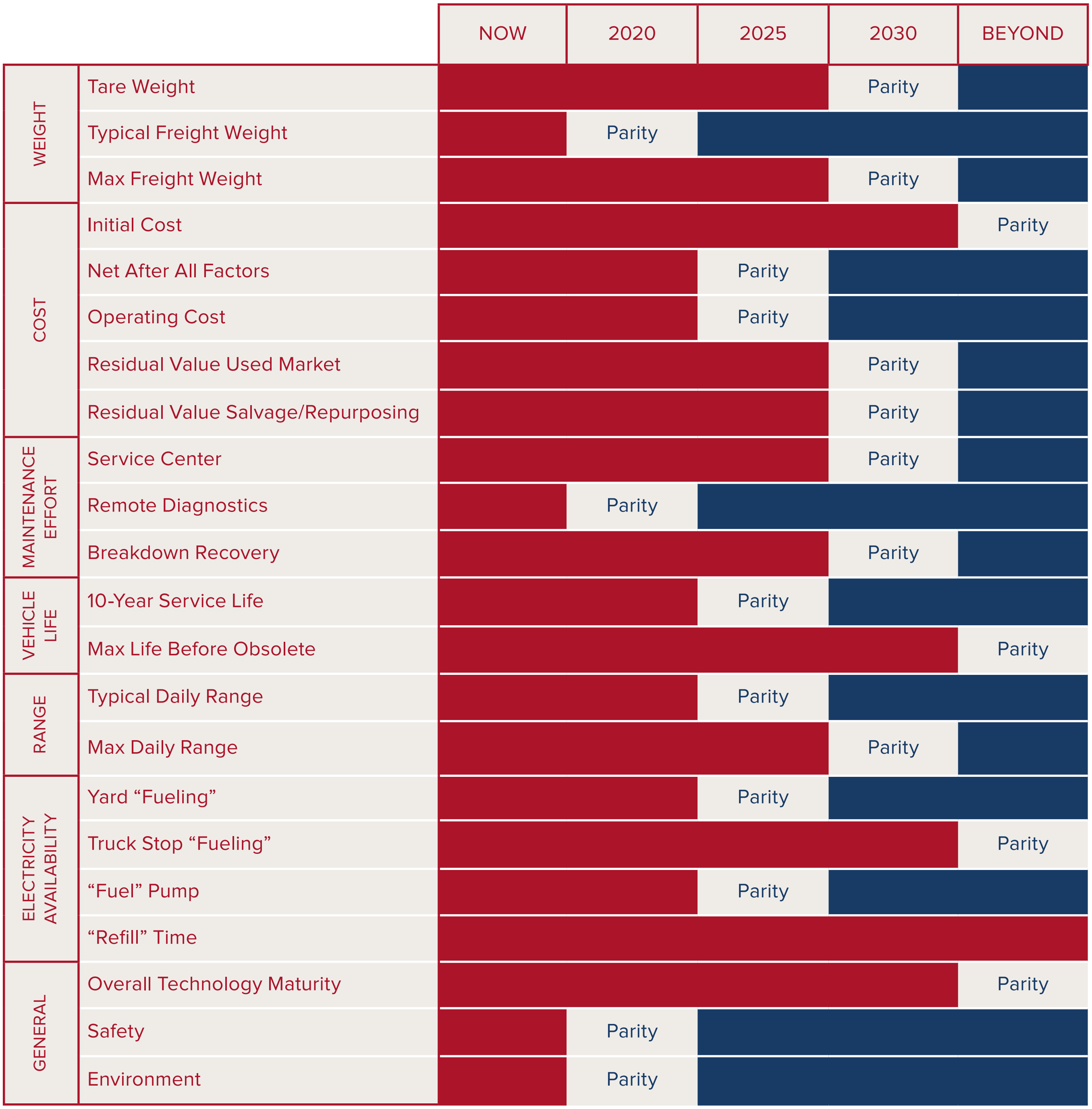
CLASS 3 THROUGH 6 CBEV PARITY VS. DIESEL SYSTEM (NACFE)



Key: Comparison to ‘Equivalent’ Diesel Baseline: Worse Parity Better

FIGURE ES3

CLASS 7 AND 8 CBEV PARITY VS. DIESEL SYSTEM (NACFE)



Key: Comparison to ‘Equivalent’ Diesel Baseline: Worse Parity Better

“Overall this is a very detailed report that will be valuable for the industry. It effectively discusses electric trucks in a way that is relevant to fleet managers and others who are interested in exploring the viability of this technology in the commercial vehicle market.”

–Mike O’Connell, VP Supply Chain, Fleet & Sustainability, PepsiCo.

"There are many predictions about electrification. The reality is for the foreseeable future we will need a range of power solutions to provide fleets with the best opportunity for meeting their needs. NACFE sheds light on many of the complexities that will impact the rate of electrified power adoption in commercial trucks."

–Julie Furber, Executive Director, Electrified Power, Cummins Inc.

An example in how to interpret these charts is to look at the Class 3 through 6 weight. As stated in the report, battery capabilities and weight have evolved to the point that production CBEVs are available and capable of many medium-duty urban delivery services. These are where daily routes are in the 25 to 100 mile range, where load density cubes out, and where traffic stop-and-go conditions accentuate use of regenerative braking systems to recover energy. Parity exists today for typical daily range achievement. However, a diesel-fueled truck may have 30, 60, or more gallons in its fuel tank, meaning a potential daily range of hundreds of miles. While that truck only drives 25–100 miles per day, it could go much farther. Parity here requires advances in battery technology (e.g., energy density improvement and weight reduction). The report outlines that this improvement is occurring and significant change is expected in the next decade. So parity when max daily range is equivalent between similar capacity medium-duty urban delivery trucks is predicted in 2030.

This example highlights that electric truck viability is a series of trade-off discussions, not one single thumbs up or thumbs down.

CONCLUSIONS AND RECOMMENDATIONS

While CBEVs will not be a solution for every application or market, NACFE's research finds that commercial CBEVs will have an increasing role in freight transportation in Classes 3 through 8. The transition in specific market segments will be drawn out over decades, sharing space with traditional gasoline, diesel, and other alternative-fuel powertrains and also competing with other emerging technologies like fuel cells and hybrids. Thus, mixed fleets (including diesel, natural gas, hybrid, and CBEV products) optimized for specific routes and duty cycles will likely be the norm through 2050.

Early adopters will be in the urban delivery Class 3 through 6 segments where operations are characterized by fairly stable route definitions between 50 and 100 miles per day, loads tend to cube out, and vehicles run one shift per day and return to the same base location. Longer ranges and heavier weights in Classes 7 and 8 are possible in specific operations, but will not be viable in all roles. Particularly challenging will be long haul segments which need distributed infrastructure and payload capacity.

Electric trucks will succeed or fail under the intense spotlight of the marketplace. The evaluations we read daily in media and technical reports span the spectrum from overly optimistic proponents to overly pessimistic opponents. NACFE hopes this report provides a middle ground, where judgments include fact-based decision-making, active testing, and fleet experience.

"The explanation of arguments for and against CBEVs is a great way to explain where the opportunities and issues exist. The question of weight and freight carrying capacity was really compelling and presented in a balanced, logical manner."

–Mel Kirk, Chief Technology Officer, Ryder System, Inc.

THE FULL REPORT

The full report is available at www.nacfe.org and includes 204 references; a robust, current, relevant bibliography of CBEV works; and 85 graphics, of which 31 are new. See the Table of Contents below for more information on the full report:

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NACFE

The North American Council for Freight Efficiency (NACFE) is a nonprofit organization dedicated to doubling the freight efficiency of North American goods movement. NACFE operates as a nonprofit in order to provide an independent, unbiased research organization for the transformation of the transportation industry. Data is critical and NACFE is proving to help the industry with real-world information that fleets can use to take action. In 2014, NACFE collaborated with Carbon War Room, founded by Sir Richard Branson and now a part of RMI, to deliver tools and reports to improve trucking efficiency. These reports include a series of Confidence Reports that detail the solutions that exist, highlight the benefits and consequences of each, and deliver decision-making tools for fleets, manufacturers, and others. As of early 2018, NACFE and RMI have completed 16 such reports covering nearly all the 85 technologies available.

www.nacfe.org

ROCKY MOUNTAIN INSTITUTE

Rocky Mountain Institute (RMI)—an independent nonprofit founded in 1982—transforms global energy use to create a clean, prosperous, and secure low-carbon future. It engages businesses, communities, institutions, and entrepreneurs to accelerate the adoption of market-based solutions that cost-effectively shift from fossil fuels to efficiency and renewables. RMI has offices in Basalt and Boulder, Colorado; New York City; Washington, D.C.; and Beijing.

www.rmi.org

GET INVOLVED

Trucking Efficiency is an exciting opportunity for fleets, manufacturers, and other trucking industry stakeholders.

Learn more at: www.nacfe.org

Or contact: Mike Roeth at mike.roeth@nacfe.org