TRUCK ZE

Transitioning to Zero-Emission (ZE) Technology

TECHNOLOGY TYPES

When most people think about zero-emission, they typically think of battery electric vehicles (BEV) but ZE can also include alternative fuels such as Compressed Natural Gas (CNG)/Renewable Natural Gas (RNG) and fuel cell (FC) technology.

Light-duty (defined as Class 1–4 in this paper) and medium-duty (defined as Class 5–7) are in the midst of transitioning to zero-emission (ZE) technology due to several motivating factors. The ZE technology types, motivating factors, and transition timing are discussed here.

BATTERY ELECTRIC VEHICLE (BEV)

BEVs have the potential to offer several benefits to operators such as lower fuel costs, reduced maintenance costs, and ultimately lower total cost of ownership (TCO). However, this has yet to be fully demonstrated and several barriers to full adoption currently exist such as limited range, higher upfront cost, limited charging infrastructure, unknown component reliability, increased vehicle weight, and expected battery life.

Arguably, out of the list of barriers, the two most critical are charging infrastructure and range. Both likely can and will be improved within the next decade but until then these limitations make it harder for fleets to adopt BEVs. Infrastructure can be solved via cooperation with state governments, utilities, equipment providers, and customers. Range anxiety, as it's become known, is the apprehension that comes from not knowing if a vehicle will make it to a charging station before running out of power. This will gradually be reduced as battery power density is improved which will increase a vehicle's range beyond daily needs. However, it can also be mitigated using advanced features such as real-time range prediction, advanced route planning, and accessory power consumption estimation.

BEV INTEGRATION CHALLENGES

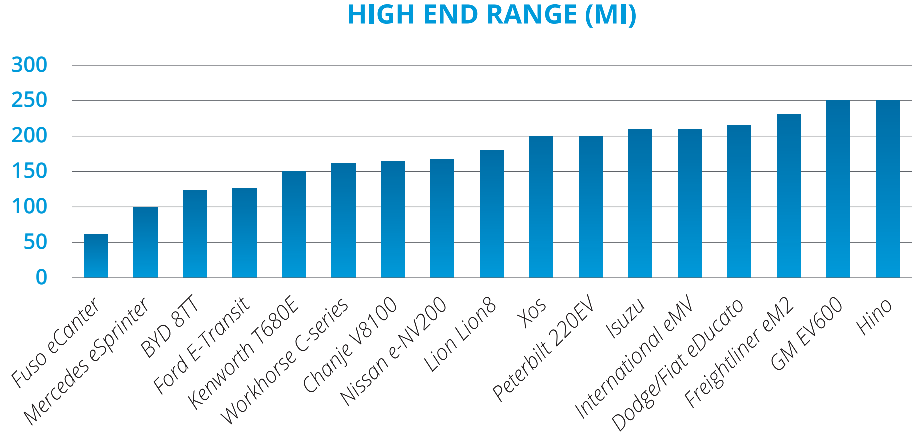
With traditional combustion engine technology, various component and vehicle companies rarely had to interact as the complexity with bolting a transport refrigeration unit (TRU) onto a box and chassis was relatively low. However, integration with accessories such as a TRU is becoming an industry concern. Many vehicle OEM's plan for inverter rated loads like worksite power tools and other accessories that can simply be plugged into a 120V outlet and only draw upwards of 2KW and therein lies the problem. Any TRU supporting a vehicle size from class 2b-4 will require upwards of 3-5KW steady-state power draw and class 5-7 up to 10KW. Therefore a TRU that will likely need to be powered directly off the vehicle's high voltage DC battery. While other arrangements are possible, pulling power directly from the high voltage batteries results in the most efficient power use, minimizes conversion loses, and ultimately results in a longer operating range. Many applications such as dump trucks, cement mixers, boom trucks, and city vehicles will require similar accommodations.

A secondary issue that requires deeper integration is the desire to have the TRU able to run while the vehicle is "off". Having the ability to run the TRU while the vehicle is making a stop is critical to maintaining proper temperature control. Naturally most electric vehicles (EV) don't have a traditional on/off key ignition but rather push-buttons or other actions that activate the vehicles main power. For the sake of safety, OEM's prefer to have the vehicle's power shut off all the way upstream to the high voltage battery which makes operating high power accessories like a TRU or pre-cooling/heating the cabin impossible without special accommodations.

These two main issues, among others, requires TRU manufacturers and vehicle chassis OEM's to communicate directly and constantly to ensure compatibility. Furthermore, the higher power consumption has the potential to greatly reduce vehicle range which must be accounted for during the selection process.

VEHICLE RANGE

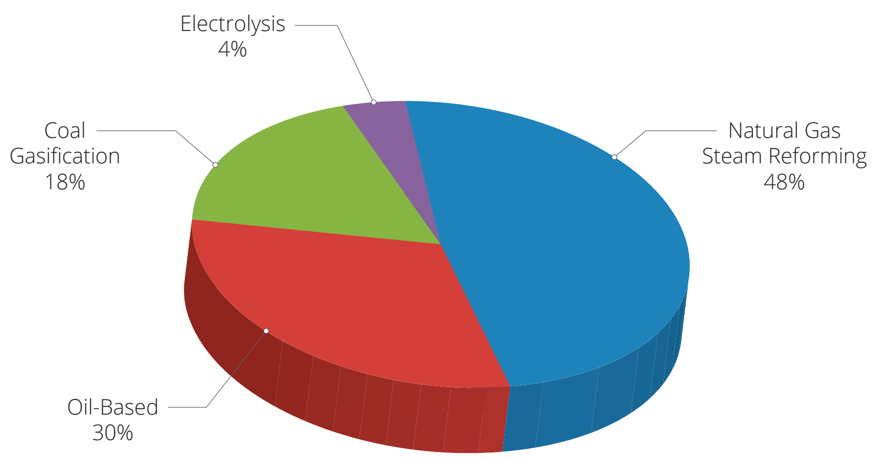
Vehicle range is initially expected to be in the range of 100-250 miles for most light and medium-duty vehicles with higher range typically accompanying higher Gross Vehicle Weight Rating (GVWR). The estimates in the chart below do not consider the decreased range that will be observed if a TRU is pulling power from the chassis which could impact the range up to 30% in some cases. To minimize range loss from TRU operation, operators should plan to pre-cool as much as possible during stationary operation.



FUEL CELLS

Fuel cell (FC) technology continues to make progress, but many variables and unknowns exist that are preventing the industry from having a clear picture as to the future of the technology. Among the obstacles are durability, system cost, fuel availability, and hydrogen fuel prices. Few in the industry doubt that fuel cell technology could be a viable replacement for diesel and act as a range extender for BEVs since a fuel cell exists to simply recharge a vehicle's battery. However, it's not simply a matter of plug and play as even if the technological issues are worked out, fleets will still have a sharp learning curve as it relates to the hydrogen supply chain.

Hydrogen is produced from a couple of key sources like natural gas production, electrolysis, and most commonly via steam-methane reforming which accounts for nearly half of hydrogen production currently. Hydrogen production cleanliness also varies heavily depending on the source and reforming method as large amounts of carbon dioxide can be produced along with the hydrogen. Unless the carbon dioxide is sequestered, the production process itself can negate the environmental benefits. In addition, the large amount of energy needed to reform hydrogen can also be a dirty process unless powered purely by renewables. Therefore, the argument over whether a hydrogen fuel cell economy truly has "net-zero" emissions will need to be tracked and defined.



[1]

Fuel cells will likely lend themselves most favorably to long-haul or regional trucking but that is where weight becomes a concern. As a comparison against diesel equivalents, a BEV might weigh upwards of 7K-10K lbs heavier while a fuel cell truck might weigh upwards of 5,000 lbs heavier. This is largely due to significantly heavier fuel tanks and the fact that batteries of some size will likely need to be involved.

Ultimately, it's the economics that will drive fuel cell usage in trucking. Fuel availability and pricing will power decision-making on technology investment and fleet adoption, but a hydrogen economy has yet to materialize despite years of prophesizing.

ZERO EMISSION TRANSITION MOTIVATING FACTORS

There are typically three major motivating factors for purchasing a zero-emission vehicle: Regulations, TCO, and environmental/green benefits.

REGULATION

ZE regulations are largely being led by the California Air Resource Board (CARB). Regulations have also been focused primarily on the medium-duty segment which is where most OEM's are focusing their ZE development efforts. Regulation also has the potential to be adopted by a consortium of 15 states plus the District of Columbia through a Memorandum of Understanding (MOU) signed in July 2020 *[2]*. The MOU has the goal of mimicking CARB's regulation scope and timing and if successful it would greatly increase the need for ZE vehicles across the US.

CARB

Regarding the truck market, CARB has been focused on transitioning all units operating in California to zero-emission technology and also regulating TRUs. Recently released language from CARB in January 2021 emphasized their commitment to begin ZE TRU phase-in starting Dec. 31, 2023.

12/31/2022

- Newly manufactured truck TRUs shall use refrigerant with a global warming potential less than or equal to 2,200.

12/31/2023

- Applicable facility owners shall register facility with CARB, pay fees every three years, and report all TRUs that operate at their facility to CARB quarterly or attest that only compliant TRUs operate at their facility.
- TRU owners shall register TRU (including out-of-state based) with CARB, pay fees (every three years), and affix CARB compliance label (every three years).
- Truck TRU fleets shall transition to zero-emission at 15 percent each year (for seven years). All truck TRUs operating in California shall be zero-emission by December 31, 2029 (compliance extension may be granted due to infrastructure delays).

NOTE: "Truck TRU" verbiage stated here only applies to class 4–8 truck applications.

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Unfortunately, one issue troubling TRU truck operators is matching up the timing of the truck ZE transition and the TRU transition timing. As you can see below, the timing of the truck ZE transition is very different from that of a truck-mounted TRU.

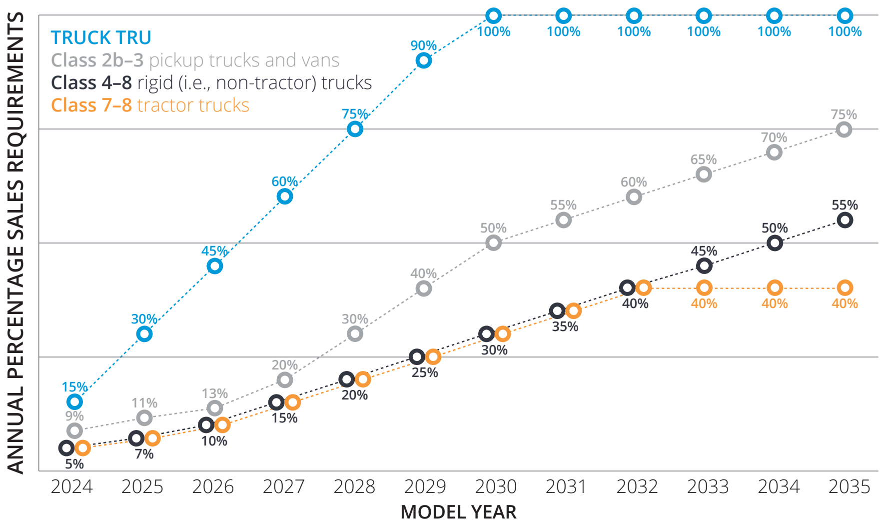


Figure 1: Zero-emission sales percentage schedule by vehicle group and model year. *[4]*

From the table above you can see that CARB starts to enforce ZE transition effectively starting in 2024 but with the vehicles themselves being based on model year, the actual enforcement date would be sooner. However, with TRU adoption required to be at 15% in year 1 and incrementally every year thereafter until at 100%, the transition timing is rapidly accelerated. For example, in 2027, it is more than 4x the ZE rate of the comparable chassis and still doubles by 2030. It isn't until 2040 that the chassis regulation transition rate catches up with the TRU side.

So, what are California fleets to do? Adopting a ZE chassis And TRU will require significant investment in both the vehicle and infrastructure but could ensure compliance. While there is no guarantee that enough chassis will be available to accommodate refrigerated applications, there is positive movement in that realm and fleets may have to be more selective in early years about who to use as their preferred chassis OEM based on vehicle characteristics and TRU compatibility.

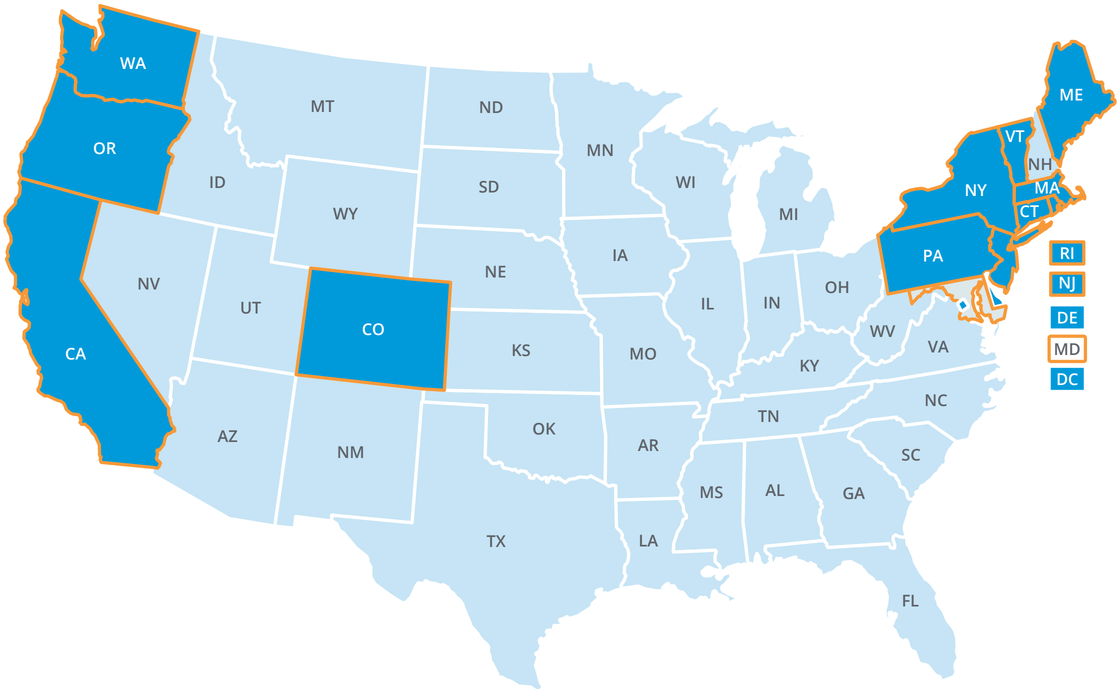
The alternative is pairing an electric TRU with an internal combustion engine ICE chassis but there are many issues with this. The main issues involve the fact that the CARB regulations state the TRU cannot derive its power from a combustion engine source. This means it is not allowable to recharge or power an electric TRU from the chassis engine and therefore the TRU must effectively carry its own power storage and be charged by the grid. The implications of this are a large increase in TRU cost because of the added batteries, added system weight, and the added operational complexity of having to charge the TRU separately from fueling the vehicle. To exacerbate this issue, while there are grant programs that subsidize adoption of EV and infrastructure, there currently no active programs that would subsidize a Battery Electric TRU BETRU on ICE chassis.

15 STATE MOU

What if you don't operate in California? Are there regulations that might affect your fleet? In July of 2020, a coalition of 15 states (plus D.C.) adopted a Memorandum of Understanding (MOU) that created a pact to have only ZE commercial vehicles sold by 2050 but with an interim goal of 30% by 2030 which would be reassessed in 2025 as new data comes available. Called the Multi-State Medium- and Heavy-Duty Zero-Emission Vehicle Memorandum of Understanding it has been signed by the governors of California, Colorado, Connecticut, Washington, D.C., Hawaii, Maine, Maryland, Massachusetts, New Jersey, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington. While per the MOU it is also not legally binding for any signatories this development has the far-reaching implication that regulation is coming to the rest of the United States and therefore fleets and the industry need to start preparing for the future.

Currently the coalition is studying the feasibility of implementation factors including incentives (both financial and non-financial) related to infrastructure and vehicles, education, partnerships with utilities, weight exemptions, and more.

STATES THAT HAVE ADOPTED CALIFORNIA'S STRONGER GREENHOUSE GAS STANDARDS, AND ZERO EMISSIONS VEHICLE STANDARDS



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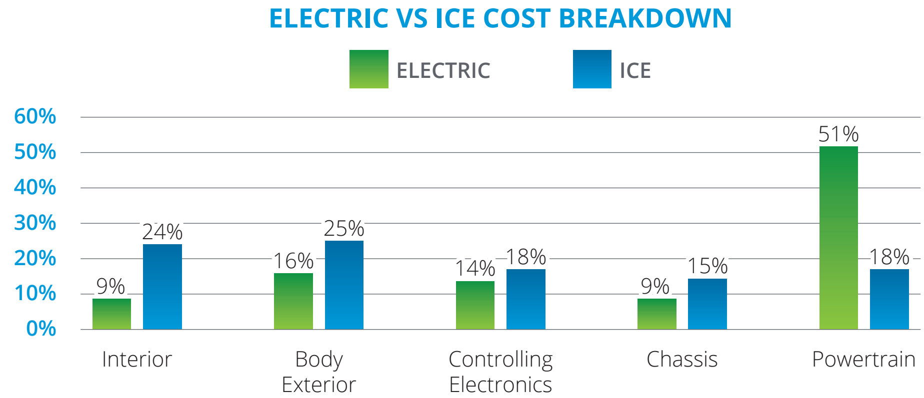
FEDERAL/EPA REGULATION

Lastly regulation also has the potential to be more potent with the Biden administration. Under the Trump administration, the EPA rolled back several emissions rules as well as effectively stopped additional efforts to regulate or incentivize ZE technology on a national level. With White House National Climate Adviser Gina McCarthy (former EPA chief under Obama) at the helm, the Biden administration is stepping up efforts with utilities and automakers over a process to curb greenhouse gas (GHG) emissions. President Biden has directed the EPA to suspend, revise, or rescind President Trump's rule that significantly eased vehicle emissions standards by July 2021. *[6]*

Additionally, McCarthy aims to announce renewed carbon-cutting commitments as part of rejoining the Paris Climate Accord. The Obama administration had previously committed to curbing GHG emissions by 26 to 28% (from 2005 levels) by 2025 and McCarthy has signaled that new commitments would be more aggressive. Lastly, President Biden has vowed to put the US on a path to carbon neutrality by 2050. How this will affect the commercial vehicle sector on a national level is yet to be seen, but what is clear is the EPA will very likely adopt more stringent guidelines.

TCO

Total cost of ownership is a critical motivating factor for adopting ZE vehicles but is a more complicated topic as OEM's strive to achieve TCO parity with traditional ICE vehicles. While multiple parts of an EV are more cost-effective than a combustion engine equivalent, the powertrain which mainly consists of the batteries, typically makes up ~50% of a vehicle's cost and therefore is the primary driver in upfront purchase cost. *[5]* The resale value of an EV is also a major concern as currently batteries are expected to have only an 8-year life expectancy with some gradual performance degradation over that time period. This creates the assumption that a vehicle's battery would have to be replaced and therefore removes most of a vehicle's trade-in value. Alternatively, older vehicles could be reassigned to shorter routes requiring a smaller duty cycle. Moreover, it's likely that battery technology will continue to advance at such a pace that after 8 years, adopting that vehicle would be akin to purchasing a used 8-year-old computer or cell phone. This is a similar situation for the Class 8 long-haul space which has a relatively short trade cycle of ~3-4 years for first owners. Those vehicles see such rapid improvements in advanced driver assistance systems (ADAS) and fuel economy showing that it pays to keep the latest technology on hand. A similar trend might emerge with EV's where rapid advances in power density, self-driving capability, route planning, and rapid charging might create a motivating case for shorter trade cycles.



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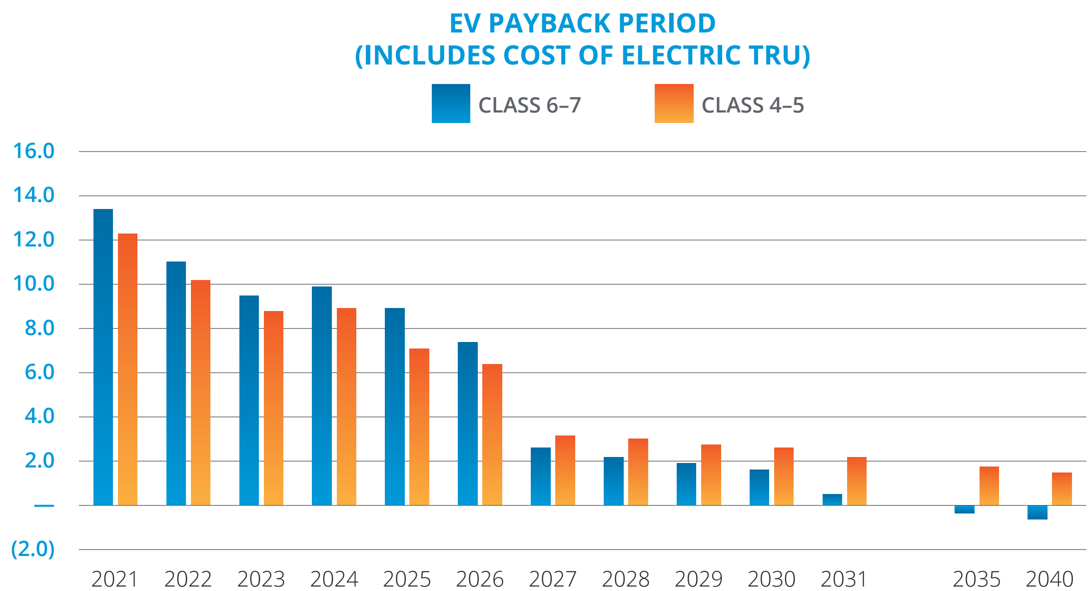
The chart below shows the payback period in years of light and medium-duty EVs versus a diesel equivalent truck. You'll notice that it is not forecast to improve year over year as the fuel efficiency and operating costs of diesel make periodic improvements which reduce the relative benefit of an EV. For example, the pullback of EV payback between 2023 and 2024 is largely due to efficiency gains from GHG-2 regulations in 2024 and subsequently the higher diesel emissions costs under the assumption that the EPA follows the CARB low-NOx regulations passed in summer 2020. Therefore, with current information and assumptions, 2027 appears to be the year that the payback could become very rapid. However, keep in mind that it's not because EVs suddenly get cheaper, but because the alternative got more expensive. Regardless, fleets must be aware of trade cycles, battery life, and lack of trade-in value when evaluating using EVs in place of diesel.



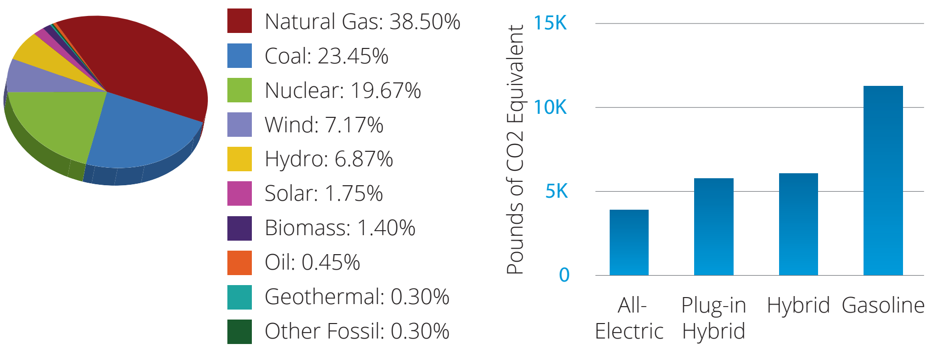
ENVIRONMENTAL/GOING GREEN

Many corporations are implementing greenhouse gas reduction targets corporate-wide with much of that burden falling on transportation. But is an EV much cleaner than an ICE vehicle? According to multiple studies, making the battery for the BEV incurs massive CO2 emissions; over 17.5 tons for a passenger car and multiple times greater for a commercial vehicle. That's not to say that ICE vehicles don't incur their own CO2 emissions but BEVs are not a free ride in that respect either. *[8]*

On-road operation is where BEVs excel at reducing CO2 output versus internal combustion engines but the electricity they consume is not free from emissions. Depending on the operating region and subsequent grid power source, the net emissions may not be all that clean. The below graphic from the Alternative Fuels Data Center (AFDC) *[2]* shows the national averages for energy power sources and the equivalent CO2 emissions which is 4,091 lbs for a BEV and 11,435 lbs for an ICE vehicle annually. This 7,344 lbs annual difference is multiplied out to ~73,000 lbs over a 10-year life expectancy and would be several times greater for a commercial BEV. In a state like California, the 10-year difference is nearly 95,000 lbs and in New York, it's 97,000 lbs. However, in a coal-producing state like West Virginia that gets 90% of its power from coal, that 10-year difference falls to just 23,000 lbs.

Regardless of location, there is a net emissions reduction for using a BEV and that should be measured carefully with each OEM as models are released.

ANNUAL EMISSIONS PER VEHICLE



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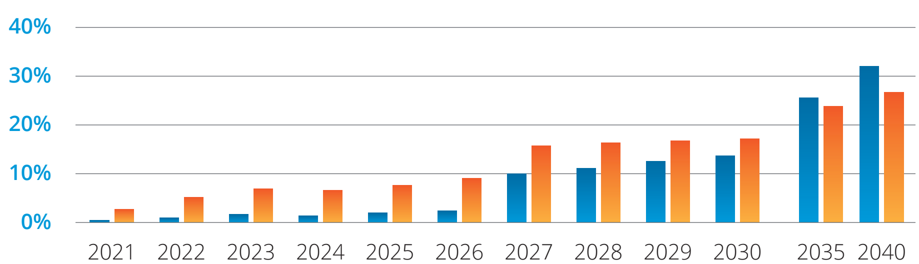
TRANSITION TIMING

When adding the multiple factors that affect EV transition timing on light and medium-duty vehicles, regulation timing will begin to force a transition to ZE by 2023. However, that effect will largely be limited to the states where the regulation exists which, as stated, is currently only in California which has ~12% of the refrigerated truck population in the US. Therefore, the larger timing factor will be TCO which, as discussed, will begin to have a business case within a few years and by 2027 will likely be the clear choice. Full nationwide truck ZE transition (all applications) is not expected to occur until 2050 or later with only ~1/3 of the transition occurring by 2040.

% EV ADOPTION RATE



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Sources:

[1] https://www.sciencedirect.com/science/article/abs/pii/S0360319915312659

[2] https://ww2.arb.ca.gov/news/15-states-and-district-columbia-join-forces-accelerate-bus-and-truck-electrification

[3] https://ww2.arb.ca.gov/resources/documents/informational-document-changes-tru-rulemaking

[4] https://theicct.org/publications/california-hdv-ev-update-jul2020

[5] https://earthjustice.org/features/electric-vehicles-explainer

[6] https://www.bloomberg.com/news/articles/2021-02-03/biden-s-climate-adviser-leading-talks-with-auto-utility-sectors?sref=vmaN3Oj2

[7] https://leandesign.com/ev-vs-ice-cost-breakdown-and-its-effects-on-ev-adoption/

[8] https://www.motorbiscuit.com/do-electric-cars-produce-a-lot-of-carbon-dioxide-co2/

[9] https://afdc.energy.gov/vehicles/electric_emissions.html

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