Fast Sled Propulsion (7/30/2023 by FSP Staff)

The Duel with Diesel Emissions

Note: Click on the superscript notations in the paragraphs below to bring up the respective Bibliography segment. To return to that specific paragraph section, click on the same enlarged notation within the Bibliography.

GOOD PROGRAMS

The EPA and private organizations, such as NACFE (North American Council for Freight Efficiency), are working alongside truck manufacturers and operators to reduce diesel emissions, provide higher efficiencies, and increase electrification for freight hauling.[A1] Their aim is to drastically reduce emissions thereby decreasing carbon footprint in these vehicles for each mile of freight transportation service. Pivotal dates for required goals have been set by government agencies and the OEM's themselves, to obtain these progressive steps, thus increasing the pressure for innovation.[A2]

THE ELEPHANT

However, if *Coal Fired Generating Plants* up their output and emissions to supply power for vehicle batteries (they are 33% efficient[B1]), considering an 11% loss for grid distribution and at least 13% for charging system losses[B2], then generating electricity with 50% efficient Fuel engines[B3] at the point of use will have a 93% greater effect on efficiency and reducing emissions than simply charging the batteries by plugging them in.[B4] In the words of Bill Combs, VP at Penske: "*The Elephant in the room with zero tailpipe emissions is that the energy is created somewhere that potentially burns fossil fuels*".[B5]

Now introducing Compound Electric Hybrids in long haul Heavy Freight Trucks, could not only generate electricity much more efficiently for their own use but also enable 'Electric Only Mode' while traveling. This feature allows for **zero emissions** in smog-affected areas, helping to alleviate smog-related sickness and greatly contributing to the reduction of their carbon footprint whenever implemented.

COVID-19

Covid-19 shutdowns proved that clean air is beautiful and healthy in congested cities that had not seen consistent clear blue skies for decades. This was observed in cities like Los Angeles & New Delhi.[C1] The impact on public health & welfare in cities using designated "*zero emission sectors*"[C2] (areas of no combustion engine use) to improve air quality in their smog-afflicted urban centers holds great promise!

Additionally, with Compound Electric Hybrids, zero emissions are possible at all ports, loading docks, weigh stations, and other high-density locations. Furthermore, this hybrid eliminates unnecessary idling in traffic-jams, truck yards, and rest stops during overnight stays in sleeper cabs (known by truckers as hoteling).

BEV NICHE

Current solutions of Battery Electric Vehicle (BEVs) in heavy freight trucks are primarily focused on a market niche of regional short haul trips, covering distances of 250 miles or less per day (with the need to return to the yard for charging)[D1] This niche currently represents only 0.7% of truck sales for medium through heavy duty trucks (class 4 to class 8[D2]), and the charger along with electrical service upgrade must be purchased separately. From 2017 to 2022 a total of 300 units of class 7 & 8 trucks have been deployed in the USA out of an over 4 million truck fleet.[D2] Unfortunately, there are currently no zero-emissions options available for extended long-haul freight trucks that cover distances which could be 1,500 to 2,000 mile or more.[D3] BEV's rely on travel locations with available charging ports to park at, and currently lack alternative solutions. Unlike Diesel, businesses cannot store the necessary electricity at the truck yard to compensate for electrical blackouts, peak usage cut-offs, rolling brown outs, or other infrastructure issues resulting from higher overall demand and recurring spikes in usage.[D4] Route planning for BEV's is carefully determined based on the availability of the next open time at a charging station port. These barriers, along with infrastructure limitations, battery costs, and battery operating temperature restrictions, among other factors, have led to significant deployment constraints for BEV's.[D5] The EPA estimates from 2033 & beyond only 4.3% of Heavy Class 8 Truck sales will be ZEV.[D6]

GIGAWATTS

In 2021, the US transportation sector consumed 46.82 billion gallons of Diesel fuel.[E1] Various concerned organizations, truck manufactures, and government agencies have set often-touted goals for future dates to reduce Diesel fuel consumption.[E2] & [A1] The universal goal is to achieve '<u>net zero emissions</u>' is by 2050, with a typical 50% reduction by 2040.[E3] However, when

converting gallons of Diesel to electricity, this 50% reduction alone would require an additional 416,000 Gigawatts of electric power production by 2040,[E4] even after accounting for higher efficiency in electric motors. This alone for transportation represents a 10.4% increase in total US electrical production.[E5] To put this in perspective, it would take approximately 20 more Grand Coulee Dams or 90 Hoover Dams[E6] (along with the necessary distribution grid and reservoirs).

This projected increase in giga-wattage by 2040 does not include the additional electricity demand from other electric cars entering the market, as well the growing non-transportation needs for electricity in commercial, residential, and industrial sectors. And, currently those other sectors already account for most of the annual 4+ trillion kilowatt-hours of electricity produced in the USA.[E7] So, to meet the future increased demand, well over 40 Grand Coulee Dams could be needed!

An alternative and achievable approach to reducing 50% of transportation diesel consumption would involve utilizing hybrid and other emerging technologies to increase the national average fuel efficiency of these trucks from 6.4 MPG to 13MPG by 2040, or potentially even earlier. This can be accomplished without the need for constructing additional dams or infrastructure!

The current development of the "Super Truck" [G1] is aimed at this issue. And the NACFE Run on Less study, coupled with technology upgrades, has shown average results of 10 MPG.[E8] If these upgrades were to include a Compound Electric Hybrid, it could be fine-tuned to achieve the goal of 13+ MPG (Even 16MPG [E9]). This would lead to one of the most significant immediate benefits, which is cutting current fuel costs in half for trucks. All of this can be achieved without the need to change or add expensive infrastructure. Therefore, it is easy to see high potential for a substantial return on investment in the development and implementation of new technology such as the Compound Electric Hybrid for long-haul heavy truck freight transportation.[E10]

DISPOSING DILEMMA

Operating a Long-Haul semi-truck solely on batteries with current technology would require 8.3 tons of battery packs for a 500-mile trip to the next charging station,[F1] without any reserve. In contrast, running a Compound Electric Hybrid truck for a much longer 2,800-mile trip with zero emissions in regions of high impact, as listed above, would only require a 1.3-ton battery pack.[F1] Furthermore the Hybrid does not depend on charging station with wait times, although it can still be plugged in for charging when desired. Aside from substantial battery costs, there is significant concern regarding the environmental Impact associated with mining, processing, manufacturing, and disposing of these batteries, as revealed through Life Cycle Assessment studies.[F2] These batteries will only last (at most) 2 years in continual long-haul truck freight applications, covering the usual 100,000+ miles per year.[F3] However, in a Compound Electric Hybrid, the use can be tailored to extend the battery useful life out 4 to 5 years.

So, now comparing the use of Compound Electric Hybrid in 2 million semi-trucks (about half of the current fleet[F4]) instead of using Battery Electric Vehicles (BEVs), it would **save 7.6 million tons** of battery manufacture and disposal every year from just the need to swap out batteries![F5] This would have a tremendous positive environmental impact and lead to significant economic gains. Additionally, it would reduce the need for a more extensive infrastructure grid, which would require additional “Fuel Burning Power Plants” to be brought online (with their own environmental impact).

The Compound Electric Hybrid approach combined with other advancements (Like Bio Fuel) would certainly surpass the cradle-to-grave environmental and economic efficiency impact that BEV’s strive for.[F6] This is particularly true when considering that BEV’s still depend on fossil fuels for generating sufficient electricity.

TAXES & GASES

As more electric vehicles hit the road, governments will seek ways to recover tax revenue lost from reduced fossil fuel sales, which funds infrastructure and government oversight for roads and bridges. Currently, existing Class 8 Semi-trucks have an average 6.4 mpg.[G1] Based on average per gallon diesel gas tax rates in the USA,[G2] this translates to 10 cents of tax revenue per mile. For comparison, the average electric Heavy Truck consumes 2.2 kWh of electricity per mile.[G3]

And considering the median electricity rates for businesses at 12.8 cents per kWh,[G4] additional taxes to replace the lost diesel gas tax revenue per mile would be approximately 4.5 cents per kWh (10 / 2.2). This represents a significant 35% increase (4.5 / 12.8) in cost per kWh, which will be an unexpected jump in rates. These tax & electric rate increases will also need to contribute funding new infrastructure required to support the additional billions of kWhs needed. Moreover, along with the historical increases to supply a growing demand in all non-transportation electrical use, as well as any peak use charges, all these factors could result in significantly higher electricity costs for every customer. It is important to note that demand for other fuels may not necessarily decrease as energy consumption shifts over towards electricity, since fossil fuels are still used to generate electricity.

Another significant issue is the 'close proximity' of greenhouse gas emission (GHG) percentages between the transportation sector and the electricity generation sector.[G5] Currently, they differ by only 3 percentage points. With the focus on reducing vehicle-related GHG emissions by transitioning to electricity, which requires fuel for generating more electricity (while all other electricity usage categories also increase), it is predicted that the electricity generation sector will soon surpass the transportation sector as the leading emitter of greenhouse gasses - again.[G6] (As in years past it held that number one spot.) This shift can only be avoided if renewable sources make substantial progress for electricity generating in the future. There has been a significant increase in wind turbine installations for the electricity generation sector over the last two decades.[G7]

DOUBLING UP

The current projection indicates that demand for road freight is expected to double by 2050, with the total revenue increasing 50% by 2032.[H1] However, Electric Grid Infrastructure and distribution are struggling to meet the projected needs for vehicle charging, even for the current demand, let alone doubling it.[H2] This is without taking into account the doubling or even tripling of electricity demands resulting from advancements in non-transportation sectors. (i.e. King county in Washington state is now incorporating codes allowing only electricity to be used for heating in new home construction.[H3]) Building upon the previous example of the Grand Coulee Dam, it appears now that meeting this growing demand for 2050 could necessitate the construction of over 80 additional Grand Coulee Dams.

Urgent action is needed to explore additional solutions and innovative options. The Compound Electric Hybrid presented here is one such option. Sustainable Fuels like renewable diesel and biodiesel are also gaining traction as highly viable solutions,[H4] bridging the gap until the advent of a truly renewable sourced, fully electric era. By leveraging sustainable fuels, high efficiency engines, and Compound Electric Hybrids, significant progress can be made in meeting transportation demands and working towards neutralizing greenhouse gas emissions.

AMERICAN TRANSPORTATION RESEARCH INSTITUTE

The American Transportation Research Institute (ATRI) published a crucial paper in December 2022 titled "***Challenges for US Electric Vehicle Fleets***" (**link**), which is highly recommended for those seeking a comprehensive understanding of the opportunities and obstacles related to battery electric heavy-duty trucks.[I1] This paper thoroughly examines the batteries, electric grid infrastructure, and charging issues that have been briefly mentioned previously.[I2]

According to the study, fully electrifying the entire US heavy trucking fleet would necessitate a 40% increase in current electricity production.[I3] Moreover, the batteries would require materials that, in some cases, account for over 7.4 years of current global production. And, for the US fleet alone, these materials could consume up to 64.4% of global reserves for certain strategic resources.[I4] It's important to note that these figures do not account for used battery replacements or the production of batteries for other electric vehicles. (Or for the doubling of road freight by 2050, as also mentioned previously.)

Additionally, the ATRI study sheds light on the overarching challenge of integrating truck charging with truck parking, all while accommodating the mandatory rest stops required for drivers as mandated by Federal Hours-of-Service work regulations. This threefold interconnected conundrum highlights the need for more chargers than there are parking spaces, at an estimated cost exceeding 35 billion dollars.[I5] (Meanwhile the current truck parking crisis is yet to be solved.) The study emphasizes that this existing dilemma, combined with the potential frustration of more frequent and lengthier charging times, results in shorter trip durations before requiring another stop for parking and recharging.[I6]

This situation is comparable to the experience of refueling more frequently in long waiting lines, causing major supply chain delays for customers and income loss for drivers.[I7] Easily making the Covid-19 supply chain crisis pale in comparison.

A summary of the ATRI findings can be found at the end of the below bibliography. [J3]

CONCLUDING REMARKS

It is evident that the term ZEV (Zero Emissions Vehicle) can be misleading in public discourse.

For as long as the generating of electricity or hydrogen contributes to a carbon footprint, the simple ZEV acronym doesn't tell the complete story. However, the EPA's *formula "Carbon footprint grams per mile / per ton of freight"* (g/ton-mile), used for regulatory impact assessment,[J1] can easily be adapted to provide a more comprehensive and up-to-date metric. If, and most importantly, this metric encompasses all the carbon emissions from upstream and downstream sources, accounting for the lifecycle (cradle to grave) impact of all components, energy, minerals, and chemicals involved, along with their respective distribution and process related GHG effects. (Battery materials, manufacturing & disposal is one example.) **This concept is clearly illustrated in the paper at ATRI link, specifically on pages 17 to 29.** A summary of this paper can also be found at this link. Additionally, these papers highlight significant technological advantages beyond BEV's.

Merely labeling a vehicle ZEV will overlook significant carbon footprint issues if all these other factors are not considered. Unfortunately, the EPA does not include all the above in their analysis.

The "**all-inclusive carbon g/ton-mile**" metric thus emerges as the most suitable measure for comparing GHG emissions in any freight transportation application or style. The transportation of freight and its multifaceted impact is far more complex than can be determined solely by examining the tailpipe emissions. By utilizing this more informative measure, well-informed decisions can be made regarding the necessary steps to achieve the lowest possible carbon footprint for each ton of freight transported across every mile.

A1

[Final EPA Standards for Heavy-Duty Vehicles to Slash Dangerous Pollution and Take Key Step Toward Accelerating Zero-Emissions Future | US EPA]

December 20, 2022

Contact Information

EPA Press Office (press@epa.gov)

WASHINGTON – Today, the U.S. Environmental Protection Agency (EPA) finalized the strongest-ever national clean air standards to cut smog- and soot-forming emissions from heavy-duty trucks beginning with model year 2027. The new standards, which is the first update to clean air standards for heavy duty trucks in more than 20 years, are more than 80% stronger than current standards.

Accelerating a Zero Emissions Future

Today's announcement is the first of three major actions being taken under EPA's Clean Trucks Plan. In the coming months, EPA intends to release the proposals for the remaining two steps in the Clean Trucks Plan. These include the proposed "Phase 3" greenhouse gas (GHG) standards for heavy-duty vehicles beginning in Model Year 2027, as well as the proposed multipollutant standards for light- and medium-duty vehicles beginning in Model Year 2027.

https://ww2.arb.ca.gov/news/carb-approves-historic-26-billion-investment-largest-date-clean-cars-trucks-mobility-options

"California is backing up our commitment to clean the air in overburdened communities with the largest state investment yet in zero-emission vehicles and sustainable transportation," CARB Chair Liane Randolph said. "These incentives continue to support our equitable transition to zero-emission cars, as well as accelerate the commercialization of zero-emission technologies for trucks and buses and provide support for small owner-operator truck fleets. They also focus on improving access to clean mobility options in communities hardest hit by pollution. The Board's action today will enable us to surge ahead in our effort to move away from fossil fuels and reach carbon-neutrality by 2045 or sooner."

The investments are part of California's comprehensive strategy for improving air quality and reducing greenhouse gas emissions in the transportation sector, the state's largest source of air pollution and climate-changing gases. The 2022 state budget expands these efforts by $6.1 billion

— in addition to an existing multi-year $3.9 billion commitment — for a total investment of $10 billion through fiscal year 2026-27 to decarbonize California's most polluting sector.

The $2.6 billion, part of the administration's California Climate Commitment, will accelerate our transition to clean cars, trucks and equipment to meet Governor Newsom's direction for 100% ZEV car and medium-duty truck sales by 2035, and heavy-duty trucks by 2045 to benefit hard hit communities.

A2

Clean Trucks Plan | US EPA

The regulatory actions that make up the Clean Trucks Plan are as follows:

- Setting stronger nitrogen oxide (NOx) standards for heavy duty trucks beginning in model year (MY) 2027 and tightening the "Phase 2" greenhouse gas (GHG) emissions for MY 2027 and beyond.
- Setting stronger emissions standards for medium-duty commercial vehicles for MY 2027 and later. These revised standards will be proposed in combination with new standards for light-duty vehicles for MY 2027 and beyond.
- • Setting "Phase 3" GHG standards for heavy-duty vehicles beginning as soon as MY 2030 that are significantly stronger than the MY 2027 GHG standards.

https://www.cummins.com/news/2022/03/23/cummins-zero-emissions-road-map

"On the path to zero emissions, we want to remind the industry that it's a path to zero emission, it's not a light switch event," says Mike Fowler, Cummins Director and General Manager On Highway Asia Pacific. "The plan is to minimise carbon emissions over the period between now and 2050. Waiting for vehicles which create zero emissions actually yields a worse carbon footprint over time than adopting a path to zero which has near-term wins in it."

"A good path to zero emissions has to lower emissions today in the lead up to 2030," says Mike. "Whatever technology you develop today has to have the capacity to drive wide spread customer adoption as well as reducing well-to work or well-to wheel emissions."

If the world moves over to battery electric trucks, but the power grid remains coal powered there has been no improvement. From the point of view of an operation like Cummins, there is a need to reduce particulate matter and nitrogen oxides as well and carbon emission in this decade.

The path from current product to the final goal involves a number of smaller steps, each delivering a better carbon outcome. The next stage in the future is the delivery of a new engine platform which will enable the lower emissions technology and fuel to deliver the results required.

B1

https://www.energy.gov/fecm/transformative-power-systems#:~:text=The%20average%20coal%2Dfired%20power,States%20operates%20near%2033%25%20efficiency.

Fossil fuels are the world's primary energy source and account for more than 60% of the electricity generated in the United States. Fossil-fueled power plants provide stability and reliability to the operation of the U.S. power grid. A recent report from the International Energy Agency (IEA) indicates that coal will continue to be the largest source of electricity production in the world by 2040. The U.S. Department of Energy is committed to improving the efficiency, reliability, and performance of the current U.S. coal fleet of fossil-fueled power plants simultaneously addressing flexibility and stability due to renewable penetration, while also advancing technologies that will underpin the coal-fired power plant of the future.

The average coal-fired power plant in the United States operates near 33% efficiency. The Transformative Power Systems Research Program aims to increase the efficiency of existing plants by 5% by 2023 and for new plants by 2027. This will be accomplished by improving the underlying technologies, components, systems, and operations that would incorporate novel sensors and artificial intelligence (AI) technologies within existing plants.

B2

https://blog.se.com/energy-management-energy-efficiency/2013/03/25/how-big-are-power-line-losses/

Electricity has to be transmitted from large power plants to the consumers via extensive networks. The transmission over long distances creates power losses. The major part of the energy losses comes from Joule effect in transformers and power lines. The energy is lost as heat in the conductors.

Considering the main parts of a typical Transmission & Distribution network, here are the average values of power losses at the different steps*:

- 1-2% – Step-up transformer from generator to Transmission line
- 2-4% – Transmission line
- 1-2% – Step-down transformer from Transmission line to Distribution network
- 4-6% – Distribution network transformers and cables

The **overall losses** between the power plant and consumers is then in the range **between 8 and 15%**.

https://t20e.net

Wireless vs Wired EV Charging: Comparable Efficiency • WiTricity

Plug-in charging is not 100% efficient. Energy loss, primarily in the form of heat, occurs every step of the way from grid to battery. What's more, regardless of the brand, a plug-in EV charger is made of many components, any one of which may be more or less efficient than similar components in another charger. So, the "efficiency" of the transfer of energy from the grid all the way to battery encompasses a range; a typical Level 2 home charger operates in the range of about 83-94% efficiency grid-to-battery depending on which one you buy.

Measurement of power loss during electric vehicle charging and discharging - ScienceDirect

Abstract

When charging or discharging electric vehicles, power losses occur in the vehicle and the building systems supplying the vehicle. A new use case for electric vehicles, grid services, has recently begun commercial operation. Vehicles capable of such application, called Grid-Integrated Vehicles, may have use cases with charging and discharging summing up to much more energy transfer than the charging only use case, so measuring and reducing electrical losses is even more important. In this study, the authors experimentally measure and analyze the power losses of a Grid-Integrated Vehicle system, via detailed measurement of the building circuits, power feed components, and of sample electric vehicle components. Under the conditions studied, measured total one-way losses vary from 12% to 36%, so understanding loss factors is important to efficient design and use. Predominant losses occur in the power electronics used for AC-DC conversion. The electronics efficiency is lowest at low power transfer and low state-of-charge, and is lower during discharging than charging. Based on these findings, two engineering design approaches are proposed. First, optimal sizing of charging stations is analyzed. Second, a dispatch algorithm for grid services operating at highest efficiency is developed, showing 7.0% to 9.7% less losses than the simple equal dispatch algorithm.

Vehicles | Free Full-Text | Influence of Charging Losses on Energy Consumption and CO2 Emissions of Battery-Electric Vehicles (mdpi.com)

Abstract

Due to increasing sales figures, the energy consumption of battery-electric vehicles is moving further into focus. In addition to efficient driving, it is also important that the energy losses during AC charging are as low as possible for a sustainable operation. In many situations it is not possible or necessary to charge the vehicle with the maximum charging power e.g., in apartment buildings. The influence of the charging mode (number of phases used, in-cable-control-box or used wallbox, charging current) on the charging efficiency is often unknown. In this work, the energy consumption of two electric vehicles in the Worldwide Harmonized Light-Duty Vehicles Test Cycle is presented. In-house developed measurement technology and vehicle CAN data are used. A detailed breakdown of charging losses, drivetrain efficiency, and overall energy consumption for one of the vehicles is provided. Finally, the results are discussed with reference to avoidable CO2 emissions. The charging losses of the tested vehicles range from 12.79 to 20.42%. Maximum charging power with three phases and 16 A charging current delivers the best efficiencies. Single-phase charging was considered down to 10 A, where the losses are greatest. The drivetrain efficiency while driving is 63.88% on average for the WLTC, 77.12% in the "extra high" section and 23.12% in the "low" section. The resulting energy consumption for both vehicles is higher than the OEM data given (21.6 to 44.9%). Possible origins for the surplus on energy consumption are detailed. Over 100,000 km, unfavorable charging results in additional CO_2 emissions of 1.24t. The emissions for an assumed annual mileage of 20,000 km are three times larger than for a class A+ refrigerator. A classification of charging modes and chargers thus appears to make sense. In the following work, efficiency improvements in the charger as well as DC charging will be proposed.

B3

https://www.internationaltrucks.com/en/blog/2023/supertruck-ii

Brake thermal efficiency (BTE) is how the fuel-burning efficiency of an internal combustion engine is measured. Potential energy is lost in internal combustion engines due to heat and friction.

Engines that have a higher percentage of BTE enjoy better overall fuel economy. Many modern truck diesel engines see their BTE hover around 35% to 40%. That means over half of the engine's potential energy is lost. International SuperTruck II's 55.2% BTE makes more efficient use of the engine's potential energy, which translates to better fuel economy.

Finding ways to improve BTE has been a key objective for International Truck. SuperTruck II demonstrates this major step forward to improve customers' total cost of ownership as well as greenhouse emissions.

Nissan Working on Engine With 50-Percent Thermal Efficiency (roadandtrack.com)

This engine will be used in a future generation of Nissan's e-POWER system, which is currently employed in the Japanese-market Note. Nissan was able to achieve 50-percent thermal efficiency in testing by essentially tuning the engine to operate within a very specific range of speed and load. Because the engine doesn't drive the wheels, it doesn't have to work with such wide parameters.

"In a conventional engine, there are restrictions on controlling the air-fuel mixture's dilution level to respond to changing driving loads, with several trade-offs between various operating conditions, such as in-cylinder gas flow, ignition method, and compression ratio which can sacrifice efficiency for power output," Nissan said in a press release. "However, a dedicated engine running at an optimal range of speed and load for electrical generation makes it possible to dramatically improve thermal efficiency."

Cummins aims to boost heavy-duty diesel efficiency to 55% (sae.org)

Future Diesel 55% Efficient

The Energy Department recently awarded Cummins, the nation's only independent diesel engine maker, a two-year, $4.5-million grant to boost its previous mark by 5 percentage points to 55% brake thermal efficiency, Eckerle said. "Now we're aiming to demonstrate another substantial increase in efficiency in a real-world duty cycle, an effort that leverages and carries forward what we were doing on the SuperTruck project."

The Heavy Duty Engine Enabling Technologies Project, a 50-50 cost-shared R&D endeavor, aims to "leverage the design, analysis and development work that has been invested through the Cummins SuperTruck program to demonstrate a peak diesel engine system efficiency of 55% Brake Thermal Efficiency (BTE) while also implementing an advanced, highly integrated combustion/after-treatment system," states DOE documents.

B4

1000KW of fuel equivalent x 33% generating efficiency = 333 KW.
333KW x 89% from grid efficiency = 296 KW
296 KW x 87% at port charging system efficiency = 258 KW into the vehicle
(Before battery efficiency loss taken into consideration)
Therefore a 25.8% efficiency from a Coal fueled generator ends up going into an electric vehicle battery.

1000KW of fuel equivalent x 50% efficiency engine = 500 KW
500KW is put into the vehicle electric motor or the batteries or both.
Therefore, generating power with this engine at point of use stays at 50% efficient
(Before driveline efficiency loss is considered here and in the above)

50 / 25.8 = 1.94
Therefore a 94% increase of greater efficiency is realized generating power at point of use.

B5

https://bcx.omeclk.com/portal/public/ViewCommInBrowser.jsp?Sv4%2BeOSSucwPWC6KD%2FITpAbDk5fWs%2FWyEI%2B4d19Iegr5cF2jg03R7c4tR%2B%2B4Dh4%2Ba698wvz0mRNxCnlGKuxqbQ%3D%3DA

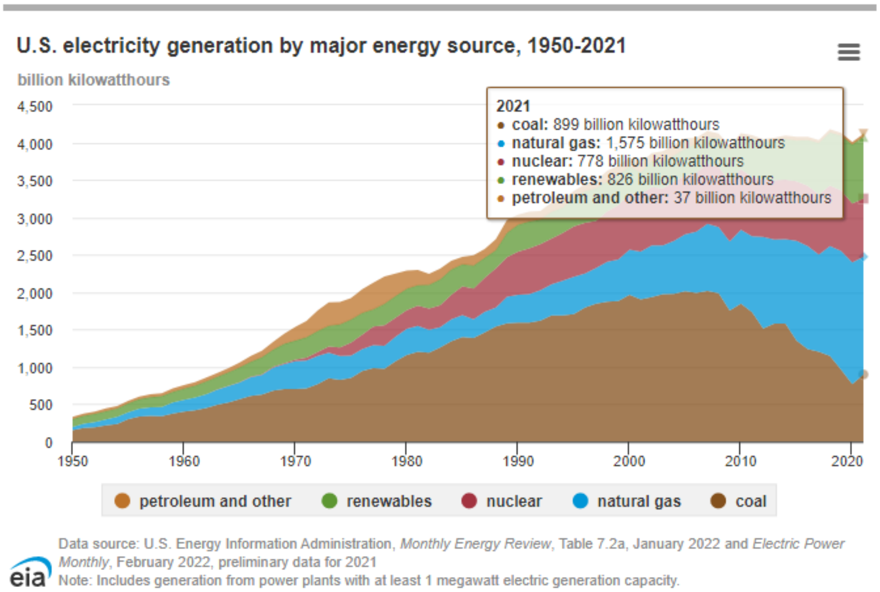
"There's a lot more belief that it's important to reduce emissions, and we're talking zero emissions out of the tailpipe," Combs added. "The elephant in the room with zero tailpipe is that the energy is created somewhere that potentially burns fossil fuels. It's definitely an all-hands-on-deck movement, but by starting with the vehicle and reducing emissions at the tailpipe, we can start to focus on managing a lot of vehicles' power plans as opposed to power plans separate on each vehicle."

(The composition of how all US electricity is generated … 60% is from Fossil fuels)
https://www.eia.gov/energyexplained/electricity/electricity-in-the-us.php

Fossil fuels are the largest sources of energy for electricity generation

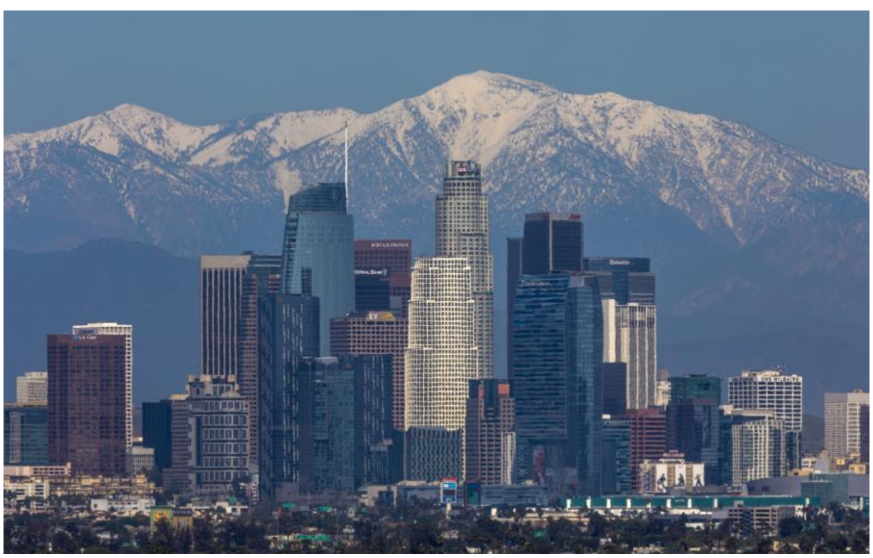
Natural gas was the largest source—about 40%—of U.S. electricity generation in 2022. Natural gas is used in steam turbines and gas turbines to generate electricity.

Coal was the third-largest energy source for U.S. electricity generation in 2022—about 18%. Nearly all coal-fired power plants use steam turbines. A few coal-fired power plants convert coal to a gas for use in a gas turbine to generate electricity.



C1

What Covid Lockdowns Did for Urban Air Pollution - Bloomberg



A rare sight emerged for L.A. residents in April 2020: the snow-capped peaks of the San Gabriel mountains, clearly visible in the smog-free atmosphere.

Photographer: David McNew/Getty Images North America.

https://t20e.net

The first COVID-19 lockdowns improved air quality. Where are we a year later? | UCLA
Then and now: Pandemic clears the air - BBC News

Images: Reuters

Credit: Staff/Reuters/Newscom

New Delhi's India Gate was obscured by haze on Oct. 17, 2019 (top), but during the country's COVID-19 lockdowns, the air was cleaner, and the view was clearer, as in this photo taken from the same spot on April 8, 2020.

C2

https://www.google.com/books/edition/Advanced_Hybrid_Powertrains_for_Commerci/OuKbEAAAQBAJ?hl=en&gbpv=1

Low-Emissions Zones

Some cities around the world have established low-emissions zones in efforts to improve urban air quality, and although these zones have been created to reduce toxic emissions rather than CO_2, any improvement in a vehicle's fuel efficiency can help it comply with lower toxic emissions targets.

In 2003, the Tokyo Metropolitan Government launched regulations that prevent commercial vehicles that do not comply with certain emissions standards from entering the metropolitan area. In London, a zone was established in 2008 that applies to all diesel commercial vehicles of more than 3500 kg GVW. There was a phased introduction of the scheme from February 4, 2008 through to January 2012. Different vehicles will be affected over time, and increasingly tougher emissions standards will apply. The daily fees for heavy vehicles to enter the zone can be as much as £200 if they do not comply with Euro 3 for PM emissions or Euro 4 from 2012. Milan trialed similar systems during 2008, under which trucks and buses that failed to comply were subject to a charge of €10 per day. In Germany, Berlin started a low-emission zone in the central city area on January 1, 2008, as did Cologne and Hanover. The mayors of Paris, Mexico City, Madrid, and Athens have announced that they will stop the use of all diesel-powered cars and trucks by 2025 in order to improve air quality [1.23].

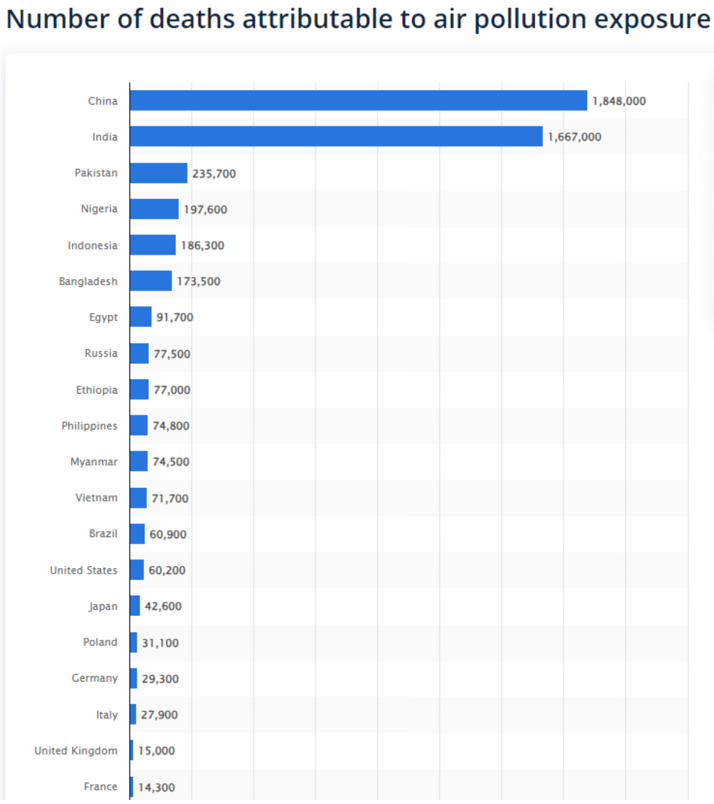
In 2009, only vehicles carrying a yellow label that indicates "low emissions" will be allowed within Beijing's fifth ring road and the low-emissions zone was extended to the city's sixth ring road. Shanghai is planning a similar exclusion zone within its Middle Ring Road.

No-Idling Laws

There are increasing efforts to reduce toxic emissions and increase fuel economy by preventing vehicles from idling the engine while stationary, particularly in urban areas. As a consequence, more and more new light vehicles are now being fitted with stop-start technology to enable the rapid restarting of the ICE once the driver is ready to move off from rest.

As of 2019, there are three current federal statutes related to reducing vehicle idling and Twenty-nine states and the District of Columbia have laws that regulate engine idling, but each of these states has different applications of idle reduction and various exemptions. Some states regulate only certain vehicle types, such as school buses, state vehicles, commercial vehicles, diesel vehicles, or vehicles over a certain weight rating. Some states regulate idling geographically, such as on school property, in business districts, or in certain counties. Other states have time limits on how long an engine may be idled, or idle limits during certain times of the year [1.25, 1.26].

Global deaths due to air pollution by country 2019 | Statista



D1

https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10178RN.pdf

According to the FHWA "Freight Facts and Figures 2017,"3 trucks move more than 60 percent of all hazardous materials shipped within the U.S.; however, truck ton-milesii of hazardous shipments account for only about 33 percent of all transportation ton-miles due to the relatively short distances these materials are typically carried by trucks. Trucks move this freight an average of 63 miles per shipment whereas rail shipments travel an average of 640 miles per trip. In terms of growing international trade, trucks are the most common mode used to move imports and exports between both borders and inland locations. Table 1-2 shows the tons and value moved by truck compared to other transportation methods.

Table 1-2 Domestic Mode of Exports and Imports by Tonnage and Value from 2012-2045 [3]

Domestic Mode	Tons (thousands)			Value (millions of 2012 $)		
	2012	2020	2045	2012	2020	2045
Grand Total	2,057,833	2,479,699	4,540,300	3,764,477	5,265,375	14,595,630
Truck	807,077	985,757	2,188,843	1,964,961	2,679,834	7,782,009
Rail	315,760	342,393	661,910	310,757	413,456	962,844
Water	156,140	199,892	333,216	160,235	222,772	531,973
Air (including truck-air)	5,355	7,138	22,120	538,275	835,816	2,883,803
Multiple modes and mail	109,251	134,851	368,665	375,541	537,949	1,576,807
Pipeline	359,021	582,716	708,596	174,962	324,515	354,333
Other and unknown	4,740	6,076	15,962	38,855	105,330	324,385
No domestic mode	300,489	220,875	240,988	200,892	145,704	159,477

https://nacfe.org/research/run-on-less-electric/

Conclusions

RoL-E demonstrated that for four market segments — vans and step vans, medium-duty box trucks, terminal tractors and heavy-duty regional haul tractors — the technology is mature enough for fleets to be making investments in production CBEVs.

NACFE encourages fleets to begin deploying CBEVs in these market segments as early adopters are validating an acceptable total cost of ownership in these four market segments.

https://mailchi.mp/nacfe.org/nacfe-newsletter-may22-2401161

From Executive Director Mike Roeth

Generally speaking, smaller trucks are easier to electrify than larger ones. We have been reporting on the easier to electrify market segments recently such as vans, step vans and terminal tractors, and soon we will share some thoughts on medium-duty box trucks. But even though there are a lot of these trucks, they burn far less fuel and create far less emissions than their heavy-duty brethren.

Big challenges exist for electrifying heavy-duty tractors, both regional and long haul, specifically issues of heavier payloads, longer distance, routes that require freeways, and even public charging. These vehicles operate three to 10 times longer distances in an unpredictable manner.

D2

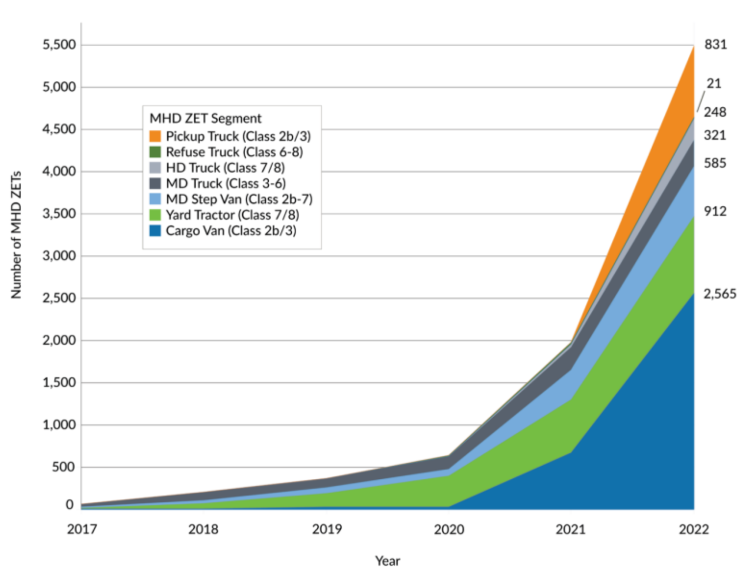
https://calstart.org/wp-content/uploads/2023/05/Zeroing-in-on-ZETs-May-2023-Market-Update.pdf

Page 2

- As of 2022, diesel-powered trucks constitute 38% of registered Class 2b vehicles, increasing to 97% of registered Class 8 vehicles. Class 2b–3 vehicles are composed of 44% gasoline-powered, 46% diesel-powered, and 10% flexible fuel-powered trucks.[8] Class 4–8 vehicles are composed of 9% gasoline-powered, 89% diesel-powered, and 0.7% electric- and hybrid diesel-powered trucks. As MHD ZET deployments cut into these market shares, the numerous benefits these vehicles offer over their gasoline- and diesel-powered counterparts, such as improved air quality, mitigated effects of climate change, and operational savings, will increase.

Page 5

Figure 3: Cumulative U.S. MHD ZET Deployed Sales by Segment (2017–2022)



Record-setting end to 2021: December Sales of new Class 8 trucks finish with better-than-expected results - TheTrucker.com

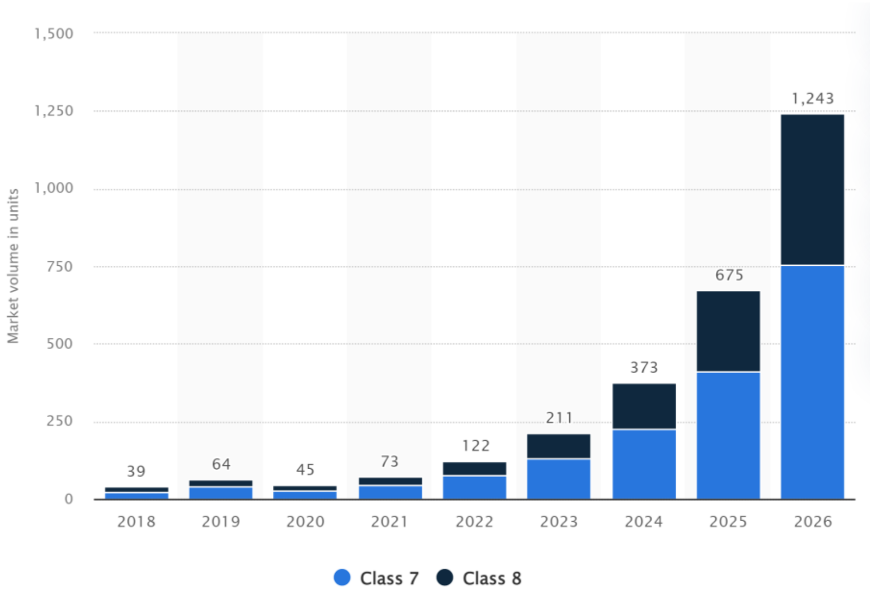
221,000 class 8 trucks sold per 1st below link from Trucker.com and 3rd link ttnews.com
73 class 8 trucks sold per 2nd link below from Statista
% of Electric Battery Semi-trucks of total semi-trucks sold 2021 approx. 73/221,000 = .0004%
(by 2026 … approx. 1,246 / 221,000 = .006%)

For the year, Freightliner sold 8,315 trucks on the U.S. market, good for 33.6% of trucks sold by the major manufacturers. Peterbilt was next with sales of 32,810 and 14.8% of the market, while Kenworth followed with 32,301 sold and a 14.6% share. Together, the PACCAR companies represented 29.3% of the new Class 8 market in the U.S. for the year.

Volvo captured 10.0% of the 2021 market with sales of 22,104, while Mack took 8.4% with sales of 18,668. Together, the Volvo-owned companies were responsible for 18.4% of Class 8 trucks sold.

International's year ended with 11.9% of the new, Class 8 market with sales of 26,387. Finally, Western Star's 6,022 trucks sold took 2.7% of the market.

U.S.: heavy-duty electric truck market volume forecast by class 2026 | Statista



https://t20e.net

October Class 8 Sales Show Broad Gains Over Year Earlier | Transport Topics (ttnews.com)

ACT forecast U.S. Class 8 sales in 2022 would hit 259,000 units. That compared with 221,889 a year earlier, according to Wards Intelligence.

Among the truck makers with higher sales, all but one climbed by double digits.

https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10178RN.pdf

As shown in Figure 1-4, AEO 2022 estimates for the full range of Class 3 vehicles show less than 1 percent of 2021 sales are BEVs while fuel cell electric vehicles (FCEV) have no sales, and hybrid and alternate fuel vehicles make up less than 1 percent of sales. AEO 2022 estimates Class 4–6 vehicles BEV and FCEV sales comprise less than 1 percent of total sales in 2021. Hybrid sales also are estimated to make up less than 1 percent of sales while flex fuel vehicles make up 3.8 percent of vehicle sales in 2021 for Class 4–6 vehicles. AEO 2022 estimates for Class 7–8 vehicles are that BEV and FCEV sales make up less than 0.1 percent, hybrid sales are less than 0.2 percent of sales, and alternate fuel vehicles are 1.8 percent of sales in 2021.

Figure 1-4. In 2050, hybrid sales are estimated to still make up less than 1 percent of sales while alternate fuel vehicles are estimated to increase to 8.8 percent of vehicle sales for Class 4–6 vehicles. For Class 7–8 vehicles, AEO 2022 estimates that BEV and FCEV sales will continue to make up less than 0.3 percent of sales in 2050, as shown in Figure 1-4. In 2050, hybrid sales are expected to be less than 0.5 percent of sales and alternate fuel vehicles are expected to increase to 4.9 percent of sales for Class 7–8 vehicles.

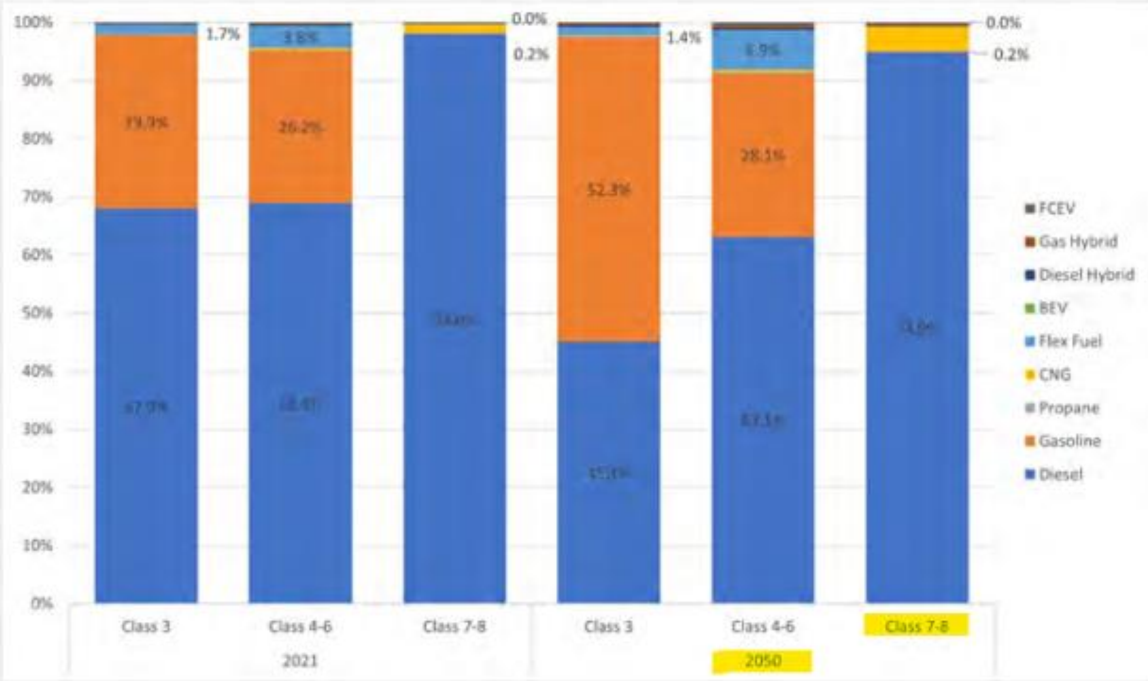


Figure 1-4 AEO 2022 Sales Percent by Weight Class and Energy Use for 2021 and 2050

Table 1-4 contains the raw values of projections from AEO 2022.[55] Their projections do not include any assumptions for new regulations beyond those established by November 2021.[vi] The Bipartisan Infrastructure Law is included in AEO 2022 as it was passed in November of 2021, whereas the Inflation Reduction Act was passed in August of 2022 and is not included in AEO 2022. Note that the projections show increased purchase of gasoline-powered vehicles relative to diesel-powered vehicles due to lower initial vehicle prices and lower maintenance costs when compared to diesel-powered vehicles.[56] The 2050 Class 3–6 vehicle sales are 1.4 times the 2022 sales levels and for Classes 7–8 include about a 25 percent decrease in sales relative to 2021 levels. Alternate fuel vehicles are also projected to increase from 2022 to 2050 with a 1.3 times increase for Class 3, a 2.5 times increase for Classes 4–6, and a 2.1 times increase for Classes 7–8. Hybrids increase 3.3 times for Class 3, 3.4 times for Classes 4–6, and 1.8 times for Classes 7–8. Fuel cells are not seen as a solution for Class 3 vehicles but are expected to increase 3.4 times for Classes 4–6 and 1.8 times for Classes 7–8, from 2022 to 2050.

Though ZEVs are being introduced in the HD market, their adoption is currently low, and their representation in the resale market is almost non-existent. There is uncertainty surrounding the ability of the original owners to recover their original investment. In addition, the uncertainties mentioned above for new HD ZEV buyers, including those related to payback, durability, and infrastructure, also exist for purchasers of used ZEVs. However, some uncertainties will likely be reduced. For example, the used ZEV market will mature more slowly than the new ZEV market, giving time for future ZEV owners to learn about the technology and for the supporting infrastructure to mature. As more used ZEVs enter the market, uncertainty related to ZEVs and the supporting infrastructure will shrink.

D3

https://www.cleanfreightcoalition.org/4-questions-policymakers-need-answer-bevs

When will the infrastructure be ready?

The trucking industry already faces a chronic and severe shortage of commercial truck parking nationwide, which strains the supply chain and jeopardizes highway safety. Electrifying the nation's truck fleet would require more chargers than there are parking spaces currently. Bear in mind that the truck charging needs at a single rural rest area would require enough daily electricity to power more than 5,000 homes.

Lithium-ion batteries also dramatically increase the weight of trucks, meaning less freight and revenue per truck, leading to more trucks on our roads and more traffic congestion.

Hyliion Announces Long-Range Version of Hypertruck ERX™ Targeting Zero-Emission Vehicle Credits - Hyliion

https://t20e.net

AUSTIN, Texas–(**BUSINESS WIRE**)–**Hyliion Holdings Corp**. (NYSE: HYLN) ("Hyliion"), a leader in electrified powertrain solutions for Class 8 semi-trucks, today announced a long-range variant of the Hypertruck ERX™, which will be the first version brought to market. This enhanced option, which will offer 75 miles of all-electric range, will enable Hypertruck ERX™ equipped production trucks to qualify for zero-emission vehicle (ZEV) credits by meeting California's Advanced Clean Truck (ACT) Rule.

The Hypertruck ERX™ will offer more than 1,000 miles of total range, enabling freight hauling capabilities that are comparable to diesel. The innovative electric powertrain system uses an onboard generator to continually recharge the battery pack while driving, eliminating the significant range and charging infrastructure challenges that battery-only electric trucks now face. The Hypertruck ERX™ is also plug-in capable, allowing fleets the operational flexibility to recharge with low-cost renewable electricity from the grid.

US Hybrid Announces Near-Zero-Emission Natural Gas-Powered Parallel Hybrid Powertrain Technology for Drayage and Long-haul Trucks (prnewswire.com)

- **Less Fuel:** A smaller 8.9 liters Near-Zero NOx engine will operate more efficiently, resulting in double fuel economy than a standard 15-liter engine and reducing fueling costs.
- **Better Range:** Preliminary testing suggests this fuel-efficient technology can deliver up to 1,000 miles of range per fuel fill, doubling range, power, and torque for similar CNG/RNG trucks.
- **Increased Efficiency:** The improvement in CNG engine performance paralleled with the electric motor, with appropriate controls, for transient load uptake results in lower NOx emissions and lower fuel consumption
- **Near-Zero-Emission:** Our technology emits lower than 0.02 g/bhp-hr of nitrogen dioxide and will significantly improve the air quality of neighborhoods near ports and warehouses.
- **Zero-Emission Port and Harbor Transportation Operations:** Our technology delivers a lower HSE (Health, Safety, and Environmental) impact on port operations and the surrounding communities.

Splitting the difference: Hybrid solutions for long-haul trucks (fleetequipmentmag.com)

"The fully electric trucks are a wonderful, ideal solution for short-haul, local delivery, where you can set up a recharging station at your warehouse and you can charge it up when it goes out for the day and when it gets back at night you can plug it back in," Healy says. The way Healy sees it, building a sufficient network of charging station across the U.S. to recharge vehicles like a Class 8 electric truck is going to take more than a decade.

D4

Here's how to accelerate the electric vehicle revolution | World Economic Forum (weforum.org)

What are the real challenges for EV charging infrastructure?

Challenges to the widespread adoption of EVs

- Inadequate charging infrastructure.
- Risk of grid overload.
- High-carbon grid profile.
- Finite critical minerals and rare earth metals.
- Smart and flexible charging.
- Smart energy management for effective EV load management.
- Battery monitoring, analytics and recycling.

Jan 31, 2022

weforum.org
https://www.weforum.org › agenda › 2022/01 › the-ev-r...

https://www.powermotiontech.com/technologies/article/21245890/volvo-sees-continued-growth-opportunity-in-electrification?oly_enc_id=2435H7540089D0Q

Infrastructure Remains a Challenge

One of the largest hurdles to the uptake of battery-electric and hydrogen powered vehicles is the infrastructure necessary to recharge and refuel them. While there has been growth in this area, more development is needed around the world.

Volvo is among the companies working to aid these development efforts. Volvo Group is a founding member of H2Accelerate, a group of companies collaborating to advance development of hydrogen trucks in Europe. Shell, another member of the group, has installed a hydrogen refueling station at Volvo CE's test track where it is testing the HX04.

As a fuel company, Shell understands the need to expand into other fuel options to best serve evolving market requirements. The company has been involved in many research projects involving alternative fuels such as those made from algae.

"Providing the fueling infrastructure for this innovative project gave Shell the opportunity to demonstrate our technical capabilities in hydrogen, and enabled us to support one of our key global collaboration partners in taking another step forward in their decarbonization journey, which goes to the heart and intent of Shell's Powering Progress strategy," said Oliver Bishop, Shell's general manager for Hydrogen Mobility, in Volvo CE's press release.

D5

https://mailchi.mp/nacfe.org/february-2024-newsletter-2401362?e=2449bfbb05

by Mike Roeth:

BEVs are not going to work in every application at this point in their development, so let's stop worrying about the square peg in the round hole. Rather let's continue to explore applications, duty cycles and use cases where BEVs do fit and let's learn as much as we can about the best way to deploy them in those applications in larger numbers.

I believe it seems like the worst of times because there are some issues surrounding BEVs in commercial applications that still need to be worked out. For one thing, infrastructure is taking too long to get built and become operational, battery weights still need to come down, and we need to get better about matching BEVs to the applications where they work best.

I know the trucking industry will continue to work on these issues and will find solutions. Just as there are Arctic insulation packages available for trucks that operate in extreme cold, someone will develop a cold weather package for BEVs, and others will figure out how to get infrastructure build outs to happen more quickly. Trucking has a long history of figuring things out.

https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10178RN.pdf

External factors, especially temperature, can have a strong influence on the performance of the battery; for example, lower temperatures typically result in lower useable energy. For more efficient operation, batteries are maintained at a particular operating temperature range, this is commonly referred to as conditioning of the battery. Heavy-duty BEVs today include thermal management systems to keep the battery operating within a desired temperature range. If the battery is plugged in overnight, the manufacturer may allow for grid energy to maintain this temperature range. Generally, this is referred to as pre-conditioning. However, during operation, the energy will have to come from the energy stored within the battery itself. Therefore, additional energy for battery conditioning will be required for vehicles operating in hot and cold climates.[100] Cold temperatures, in particular, can result in reduced useable energy as a result of reduced mobility of the lithium ions in the liquid electrolyte; for the driver, this may mean lower range. Battery thermal management is also used during hot ambient temperatures to keep the battery from overheating.

Another important battery design consideration is the durability of the battery. Durability is frequently associated with cycle life, where cycle life is the number of times a battery can fully charge and discharge before the battery is no longer used for its original purpose. In 2015 the United Nations Economic Commission for Europe (UN ECE) began studying the need for a Global Technical Regulation (GTR) governing battery durability in light-duty vehicles. In 2021 it finalized United Nations Global Technical Regulation No. 22, "In-Vehicle Battery Durability for Electrified Vehicles,"[101] or GTR No. 22, which provides a regulatory structure for contracting parties to set standards for battery durability in light-duty BEVs and PHEVs. Likewise, although not finalized, the UN ECE GTR working group began drafting language for HD BEVs and

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For batteries that are used in HD BEVs, the state-of-health (SOH) is an important design factor. The environmental performance of electrified vehicles may be affected by excess degradation of the battery system over time. However, the durability of a battery is not limited to the cycling of a battery, there are many phenomena that can impact the duration of usability of a battery. As a battery goes through charge and discharge cycles, the SOH of the battery decreases. Capacity fade, increase in internal resistance, and voltage loss, for example, are other common metrics to measure the SOH of a battery. These parameters together help better understand and define the longevity or durability of the battery. The SOH and, in turn, the cycle life of the battery is determined by both the chemistry of the battery as well as external factors including temperature. The rate at which the battery is discharged as well as the rate at which it is charged will also impact the SOH of the battery. Lastly, calendar aging, or degradation of the battery while not in use, can also contribute to the deterioration of the battery.

Page 31

On a sheer quantity basis and probably also on a value basis, battery minerals are likely to be the most important mineral-related constraint on ZEV production during the time frame of the rule.

https://truckingresearch.org/wp-content/uploads/2022/05/ATRI-Understanding-CO2-Impacts-of-Zero-Emission-Trucks-May-2022.pdf
PAGE 13
(Also note that the 55% cost of batteries below have to be replaced during life of the truck 2 or 3 times at that total of $240,000 each time – plus inflation)

Realities of Zero-Emission Trucks: What Trucking Companies Need to Know

While there is a strong public policy push toward ZET adoption, there are several critical realities that the trucking industry faces:

Vehicle Cost. ZET vehicle costs (especially for early adopters) will be a strong barrier to entry. While a new Class 8 diesel truck tractor may cost roughly $135,000 - $150,000, the purchase price of a new Class 8 BEV can be as much as $450,000.[18] ACT Research estimates that the battery pack for a Class 8 BEV accounts for roughly 55 percent of the cost of the BEV truck.[19] This cost, in theory, may fall as battery production and the extraction of raw materials expands.

The same issue will likely impact the FCEV. Estimates for fuel cell truck costs range from $200,000 to $600,000 with 60 percent of the overall cost solely credited to the fuel cell propulsion system.[20] The fuel cell propulsion unit and hydrogen storage system together are estimated to comprise roughly 80 percent of the total vehicle cost. Additionally, the hydrogen required to power an FCEV is costly; 70 percent of retail hydrogen stations in California sell hydrogen above $16 per kilogram.[21]

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Battery Life. Battery life depends on numerous vehicle-based factors, including number of charges and charging rate (examples include 120v, 240v, Direct Current Fast Charge).

It is well understood that lithium-ion batteries begin to slowly degrade once the charging and discharging process commences. Battery degradation is greatly influenced by the number of charge cycles and charging rates. This degradation can be measured through a battery's state-of-health (SOH) status, which is a battery's current state of maximum charge versus its rated state of charge. A vehicle's battery may have a SOH of 80 percent, for instance, after several hundred or even several thousand charging cycles. For long-haul trucking the SOH remains an unknown. To illustrate this, the 1,622 kWh battery would have a maximum capacity of 1,297 kWh when the SOH is 80 percent. This of course means that the vehicle can travel fewer miles per charge.

Lithium-ion battery life is strongly influenced by the number of charging cycles the battery is subjected to. A charging cycle for a BEV occurs when a battery is charged, and then the energy is discharged as the vehicle operates. For trucking, it is expected that annual vehicle charging cycles will be far more intensive than a typical automobile. The ATRI *Operational Cost of Trucking* dataset indicates that the average truckload-only carrier mileage per year per truck is 101,529 miles.[69] For the BEV modeled in the earlier section, that would be approximately 143 full charges annually if the battery were to charge to its rated level, and it would be 178 when its SOH is at 80 percent.

Separate from the number of charging cycles, there is evidence that the *rate* at which a BEV is charged could impact battery life. Because of operational constraints (such as driver hours-of-service) and the large energy capacity of a truck battery, faster charging may be necessary. While there is still research needed in this area, there is evidence from automotive research that faster charging will lead to a slightly faster decrease in battery SOH.[70]

Battery Performance. Ambient temperatures can affect the battery performance of electric vehicles. Cold weather slows the chemical and physical reactions that make batteries work, specifically conductivity and diffusivity, leading to longer charging times and a temporary reduction in range.

Conversely, higher temperatures generally lead to faster chemical and physical reactions. This often means that the "unwanted" chemical reactions that make batteries degrade happen faster at higher temperatures. In addition, low or elevated temperatures can initiate the use of electric air conditioning or heating systems, which can draw significant amounts of battery power – with an accompanying reduction in driving range.

Testing conducted by the American Automobile Association (AAA) on five electric passenger vehicles, using the Society of Automotive Engineers' J1634 test procedure, documented an average 12 percent decrease in combined driving range when the cars were operated at 20°F as opposed to 75°F.[71] A four percent decrease in combined driving range was found at 95°F when compared to 75°F.

More significantly, use of heating and air conditioning was found to decrease combined driving range by an average of 41 percent at 20°F and by 17 percent at 95°F when compared to the 75°F baseline. The study notes that owners of electric vehicles should be aware of environmental conditions, and plan for reduced driving ranges during periods of hot or cold temperatures. Other analyses of electric car performance offer similar findings.[72]

Based on anonymized data from 5.2 million trips taken by 4,200 electric cars representing 102 different make/model/year combinations, 70°F was found to be the most efficient temperature for operations.[73]

Topography also has a strong influence on energy consumption and battery operation as well. On an uphill grade, all vehicles expend more energy than when traveling on level ground. Energy consumption for electric vehicles tends to steadily increase as road grade increases.[74] Although little data has been generated for trucks, consumption steadily increases for automobiles as the grade changes from downhill to flat, and then drastically increases on uphill grades.

https://t20e.net

According to respondents to a survey distributed by GNA, 65% of surveyed fleets have used a BEV in the past two years and 92% of fleets with BEVs intend to grow their use in the next five years. Orders for medium-duty vehicles were nearly 30,000 in 2022 (a surge of 640%) and demand for heavy-duty vehicles remained steady overall, with tractor and transit vehicles seeing orders in the mid-hundreds and school bus orders climbing to 2,400. BEVs currently comprise an average of 4% of a fleet's vehicle population per survey results.

Despite this growth, supply chain disruptions, high costs, and infrastructure availability and reliability persist as barriers to larger deployments, the report states.

- **Supply chain barriers**: Ford paused Lighting orders temporarily and Rivian slashed production targets, while Lightning eMotors reoriented to focus on repowers—three examples of manufacturers adapting to ongoing supply chain troubles. The more mature passenger car market saw raw materials costs rise 140% between May 2020 and May 2022, while battery prices rose by at least 14%.
- **Cost barriers**: The base price of a Class 8 BEV tractor is approximately $350,000 to $500,000, or three to five times the price of a new diesel truck.
- **Infrastructure barriers**: Fleets that overcome the vehicle price barrier can still face multi-year queues for electrical service and concern over charging during flex alerts and rolling brownouts and blackouts. Government and the trucking industry have committed billions of dollars to infrastructure development in 2022 to bridge the gap, but grid capacity must grow by 60% before 2030 to meet national electrification goals, the report states.

D6

https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10178RN.pdf

ZEV adoption is calculated as the product of the proportion of national HD vehicle sales that belong to states that have adopted ACT and the ZEV sales percentages required by ACT. All ZEV sales are assumed to be BEVs, except for long-haul single-unit and combination trucks (source types 53 and 61), which are assumed to be FCEVs. We could find no data that suggests ZEV adoption will preferentially displace ICE vehicles of any particular fuel type. While we increased the HD ZEV adoption in MOVES, we maintained the current relative fuel distribution between diesel, gasoline, and CNG heavy-duty vehicles into the future.

Overall, Table 4-6 shows the national adoption of HD ZEVs by source type in the reference case.

Table 4-6 National heavy-duty ZEV adoption in the reference case

Model Year	Class 4-8 Group	Class 7-8 Tractors Group
	Source Types 41-54	Source Types 61, 62
2024	1.1%	0.3%
2025	2.0%	0.7%
2026	2.4%	1.0%
2027	3.4%	1.4%
2028	5.1%	1.9%
2029	7.1%	2.5%
2030	9.1%	3.0%

Model Year	Class 4-8 Group	Class 7-8 Tractors Group
	Source Types 41-54	Source Types 61, 62
2031	10.5%	3.5%
2032	11.4%	4.1%
2033	12.4%	4.3%
2034	13.4%	4.3%
2035	14.4%	4.3%
2036 and beyond	14.8%	4.3%

E1

https://www.eia.gov/energyexplained/diesel-fuel/use-of-diesel.php#:~:text=Diesel%20fuel%20is%20important%20to%20the%20U.S.%20economy&text=In%202021%2C%20distillate%20fuel%20consumption,128%20million%20gallons%20per%20day.

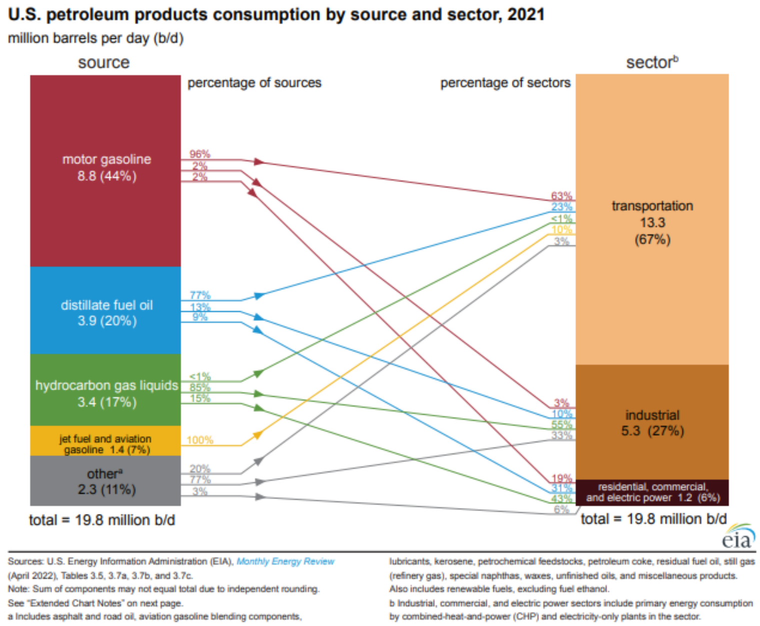
Diesel fuel is important to the U.S. economy

Most of the products we use are transported by trucks and trains with diesel engines, and most construction, farming, and military vehicles and equipment also have diesel engines. As a transportation fuel, diesel fuel offers a wide range of performance, efficiency, and safety features. Diesel fuel also has a greater energy density than other liquid fuels, so it provides more useful energy per unit of volume.

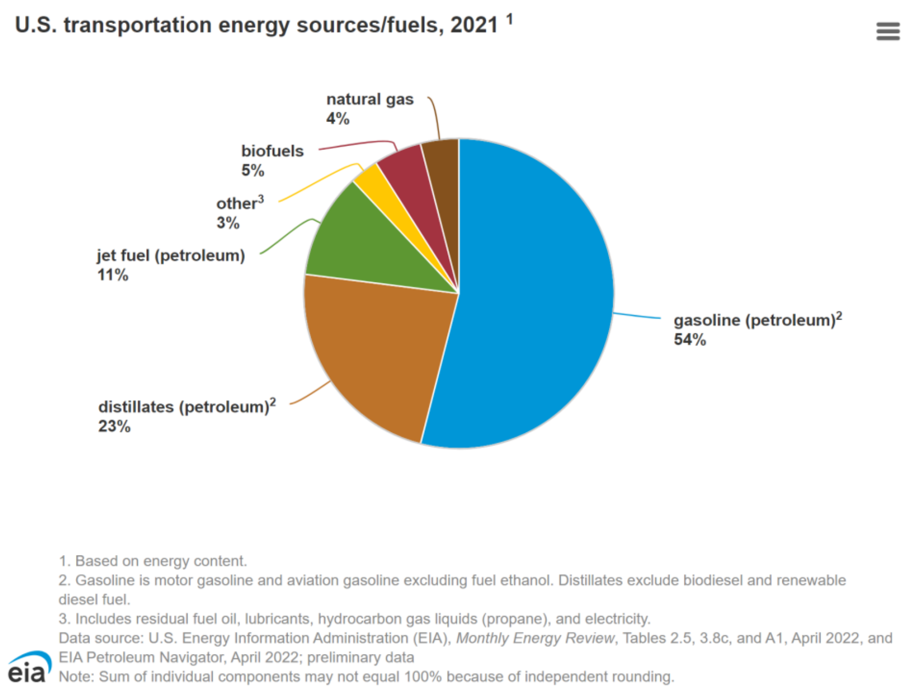
In 2021, distillate fuel consumption by the U.S. transportation sector, which is essentially diesel fuel, was about 46.82 billion gallons (1.11 billion barrels), an average of about 128 million gallons per day. This amount accounted for about 77% of total U.S. distillate consumption, about 15% of total U.S. petroleum consumption, and on an energy content basis, about 25% of total energy consumption by the U.S. transportation sector.

Use of diesel - U.S. Energy Information Administration (EIA)

In 2021, distillate fuel consumption by the U.S. transportation sector, which is essentially diesel fuel, was about **46.82 billion gallons** (1.11 billion barrels), an average of about 128 million gallons per day. This amount accounted for about 77% of total U.S. distillate consumption, about 15% of total U.S. petroleum consumption, and on an energy content basis, about 25% of total energy consumption by the U.S. transportation sector.U.S. petroleum products consumption by source and sector, 2021 (eia.gov) https://t20e.net



https://www.eia.gov/energyexplained/use-of-energy/transportation.php



https://t20e.net

Table MF-27 / Highway Statistics 2019 - Policy | Federal Highway Administration (dot.gov)

Highway Use of Motor Fuel - 2019 (1)

Printable PDF Version [49 KB]

November 2020

(Thousands of Gallons)

Table MF-27

State	Gasoline (2)	Percent of Gasoline Total	Special Fuels	Percent of Special Fuel Total	Total (3)	Percent of Grand Total
Alabama	2,659,652	1.949	874,206	1.987	3,533,859	1.958
Alaska	242,562	0.178	126,670	0.288	369,232	0.205
Wisconsin	2,461,020	1.803	863,778	1.964	3,324,798	1.843
Wyoming	293,603	0.215	368,810	0.838	662,413	0.367
Total	136,078,199	100.0	43,912,758	100.0	179,990,957	100.0

E2

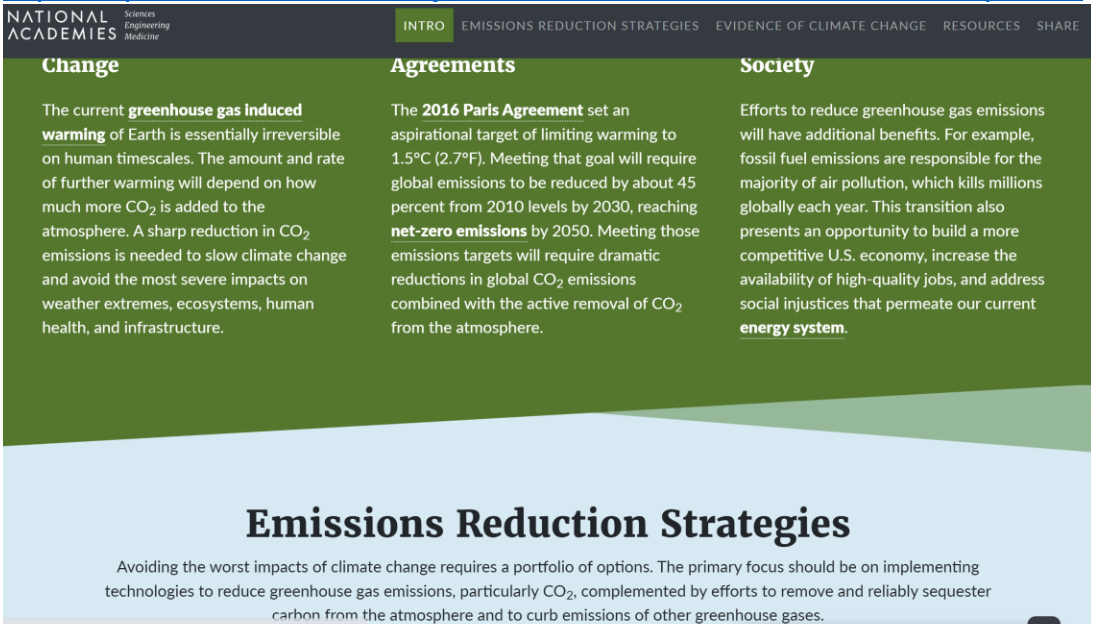
https://www.whitehouse.gov/wp-content/uploads/2021/10/US-Long-Term-Strategy.pdf

The most recent report from the Intergovernmental Panel on Climate Change (IPCC) vividly illustrates, with robust scientific confidence, the need to limit warming to 1.5°C, or as close as possible to that crucial benchmark, to avoid these severe climate impacts. Achieving this target will require cutting global greenhouse gas (GHG) emissions by at least 40% below 1990 levels by 2030, reaching global net-zero GHG emissions by 2050 or soon after, and moving to net negative emissions thereafter[*]. To meet these global milestones, we must retool the global energy economy, transform agricultural systems, halt and reverse deforestation, and decisively address non- carbon dioxide emissions—focusing particular attention on methane (CH4), which accounts roughly 0.5°C of the current observed net warming of 1.0°C.1 We must also pursue negative emissions through robust and verifiable nature-based and technological carbon dioxide removal. IN LIGHT OF THIS URGENCY, THE UNITED STATES HAS SET A GOAL OF NET-ZERO GREENHOUSE GAS EMISSIONS BY NO LATER THAN 2050.

[*] Greenhouse gas emissions in total have contributed 150% of the observed warming of 1.0°C, but emissions of cooling aerosols have counteracted some of that warming.

https://t20e.net

https://nap.nationalacademies.org/resource/other/dels/net-zero-emissions-by-2050/



AFFS-2022-Report-FINAL-1.pdf (nacfe.org)

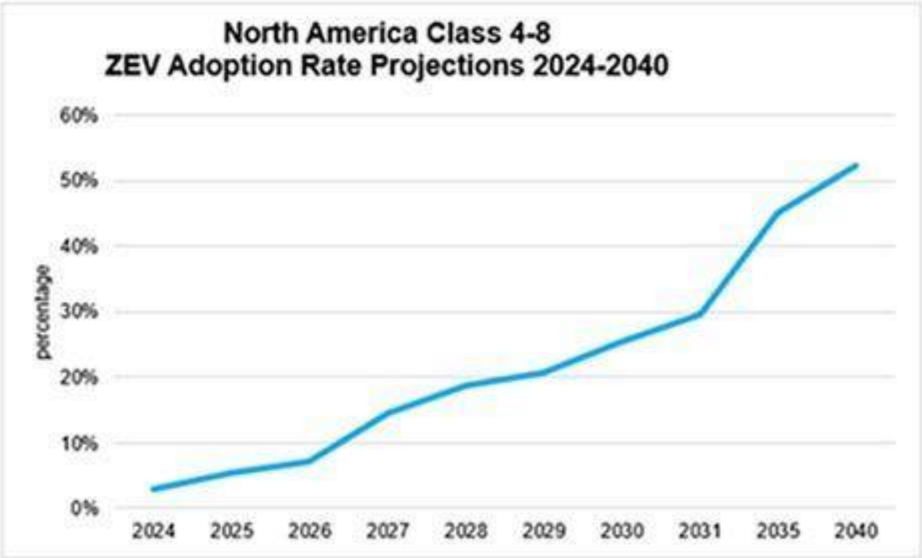
Regulations will drive freight efficiency through the next two decades. GHG 2024 and 2027 steps are coming quickly. The GHG phase 2 regulations have steps for the OEMs to comply with in Model Years 2024 and 2027. These are significant MPG improvements that will have OEMs develop, offer and sell new features on their tractors and trailers that will show up in this study in future years. NHTSA and the EPA have announced studies for future efficiency regulations which will likely deliver a GHG phase 3 for implementation throughout the 2030s.

E3

https://www.fleetequipmentmag.com/half-commercial-vehicles-zero-emissions-2040/?utm_source=omeda&utm_medium=newsletter&utm_campaign=Wisconsin%E2%80%99s+Kriete+Truck+Centers+achieves+EV+certification%2C+fuel+costs+chip+away+at+favorable+shippers+market++&oly_enc_id=1883H7223956D9U

ACT Research says half of all commercial vehicles will be zero emissions by 2040

By 2027, eight states will have joined California in adopting Advanced Clean Trucks, resulting in moderate growth in adoption rates.



Source: ACT Research Co. Copyright 2023

According to ACT Research's recently released edition of its Charging Forward study, the adoption rates for zero-emission and decarbonization vehicles will reach 25% by 2030 and 50% by 2040. The study notes that regulations are a key factor in the earlier years, particularly for higher GVW applications, while many lower GVW applications already provide a better total cost of ownership (TCO) today.

Related Articles

- ACT Research: Used truck prices stabilize in October
- Five truck trend takeaways from November
- FTR Shippers Conditions Index shows positive readings in September as diesel prices fall

"We forecast a relatively low adoption rate from 2024 through 2026, reflecting the fact that BEV sales of commercial vehicles are still in their early years," noted Ann Rundle, vice president of electrification and autonomy at ACT Research. "This begins to change in 2027, in part due to the cost increases for diesels because of the increased stringency of U.S. EPA's 2027 low-NOx regulations. In addition, by 2027, eight states will have joined California in adopting Advanced Clean Trucks, resulting in moderate growth in adoption rates."

By 2030 ACT Research is forecasting 25% adoption rates, as by then the remaining nine states that signed the MOU to adopt CARB Advanced Clean Trucks will have enacted those regulations. Additionally, it is assumed by the study that improved battery technology will negate battery replacement costs, and charging infrastructure utilization will significantly increase, decreasing those costs in the TCO.

Rundle concluded, "By 2040 we are forecasting that adoption of ZEVs will account for just slightly above 50%—essentially half of all CVs will be zero emissions, primarily BEVs."

E4

40.7 kW-hrs per gallon of diesel (Gallon of Diesel Oil [US] to Kilowatt Hour Converter (hextobinary.com))
40.7 x 46.82 billion gallons of diesel (see E1) = 1,902 billion kW-hrs of diesel used in transportation 2019

35% Diesel Truck engine efficiency (Thermal Efficiency for Diesel Cycle | Equation | nuclear-power.com)

- If 1,902 billion kW-hrs Diesel consumed @ 35% = 665.7 billion kW-hrs effectively used/applied from the fuel pump to the motor output shaft.

80% Efficiency of an electric vehicle power plant computed:

- Efficiency of charging system for BEV 94% x Battery pack efficiency 95% x Controller w/ Voltage Converter efficiency 95% x Electric Motor efficiency 94% = 80% overall from power to the charger to output at the motor shaft.
    - FYI: Automobile electric vehicle efficiency =77% (All-Electric Vehicles (fueleconomy.gov))

Therefore, if all electric power plants in transportation vehicles output 665.7 billion KWH at 80% efficiency – then they would consume input power at the charger of (665.7 / .8) 832 billion KWH in comparison to Diesel use at lower efficiency.

- Therefore: 832 billion KWH total needed to put in & get out of batteries to replace the same KWH work done by diesel power plants in vehicles.
- Thus total saving of KWhrs: 832 / 1,902 = 43.7%
    - (for example: would only use 437 KW of electricity vs 1000 KW of Diesel).
    - So, rather than use 1,902 billion KW-hrs of Diesel … only use 832 billion KW-hrs of electricity instead

Therefore, replacing just 50% of Diesel with Electricity: 832 /2 … equals 416 billion KWH needed

- 416 billion KWH needed of electricity to replace half of all Transportation diesel used in one year like 2021.
- Or equivalent 416,000 Gigawatts

https://www.rapidtables.com/electric/watt.html#conversion_calculator

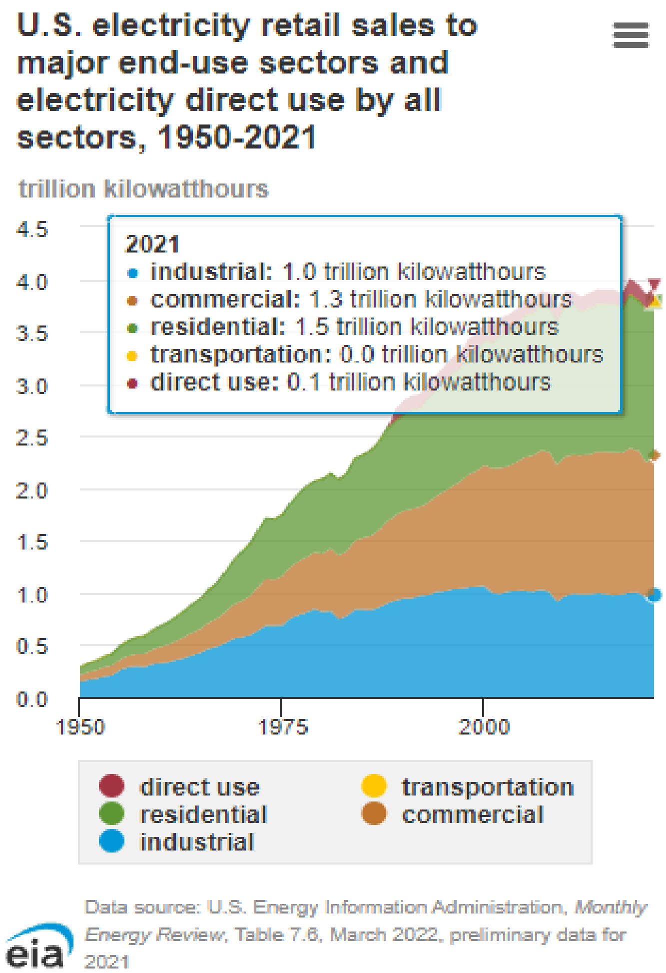
Enter watts:	1000000000000	W
Enter kilowatts:	1000000000	kW
Enter megawatts:	1000000	MW
Enter gigawatts:	1000	GW

E5

In 2021 transportation used neglagible amount of total us killowatthours.

But adding 416 Billion KWhrs to the below 4 trillion = a 10.4% increase in watt production annually.

- 416 / 4,000 = .104 or approx 10.4% added to the graph below to replace just 50% of 2021 Transportation diesel
    - then add more for all other electrical use increases in the 3 major catagories below



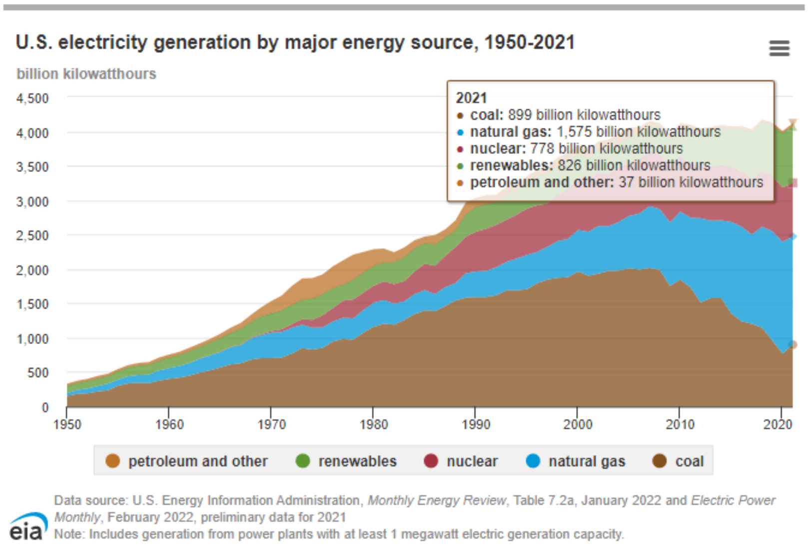
(The composition of how all US electricity is generated)

https://www.eia.gov/energyexplained/electricity/electricity-in-the-us.php

Fossil fuels are the largest sources of energy for electricity generation

Natural gas was the largest source—about 40%—of U.S. electricity generation in 2022. Natural gas is used in steam turbines and gas turbines to generate electricity.

Coal was the third-largest energy source for U.S. electricity generation in 2022—about 18%. Nearly all coal-fired power plants use steam turbines. A few coal-fired power plants convert coal to a gas for use in a gas turbine to generate electricity.



https://www.fleetequipmentmag.com/ev-realities/?utm_source=omeda&utm_medium=newsletter&utm_campaign=Time+to+embrace+some+EV+realities&oly_enc_id=1883H7223956D9U

David Carson, the senior vice president of sales & marketing for Daimler Trucks North America, had a keynote. One of his takes was that if you go to any truck stop, let's say we electrified truck stops, and 50 trucks plug in to charge, it'll take down any grid in the country.

David Sickels: They say, "As the number of EVs on the road increases, annual demand for electricity to charge them would surge from 11 billion kilowatt hours now to 230 billion kilowatt hours in 2030. The demand estimate for 2030 represents approximately 5% of total electricity demand here in the United States. Projections indicate that nearly 30 million chargers would be needed to deliver so much electricity in that year." 30 million. Now, they do say that a lot of those chargers would be those that are residential, in your garage or whatever that might be. But that being said, that is an enormous number that we are nowhere close to meeting right now.

E6

21 billion KWH are produced per year at Grand Coulee Dam About Grand Coulee Dam | Bureau of Reclamation (usbr.gov)

416 / 21 billion KWH per year is equal to 20 more Grand Coulee Dams to replace the 50% of transportation diesel. Or. 90 more Hoover Dams Hoover Dam | Bureau of Reclamation (usbr.gov)

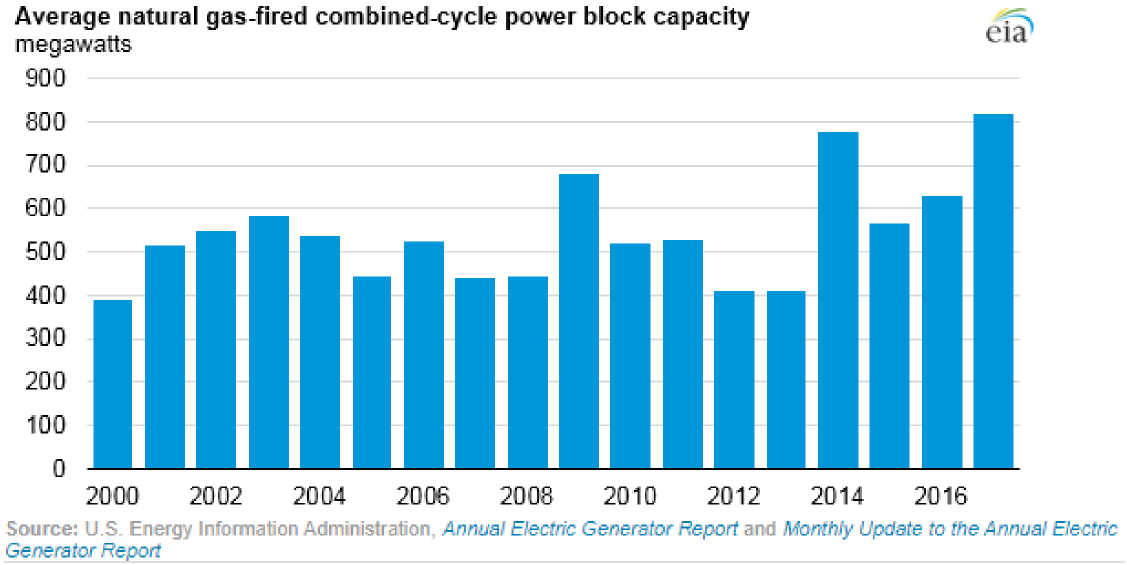
[IF THERE WAS ENOUGH WATER TO RUN THE DAMS]

- Or 100,000 more average wind turbines
  - (89,000 presently in US & growing at 3,000 units per year)
  - See G6

21 billion kilowatt-hours / 1 million kilowatt-hours/gigawatt-hour = 21 gigawatt-hours. Therefore, Grand Coulee Dam produces 21 gigawatt-hours of electricity per year.

(**Or 268 Natural Gas Fired generating plants**)

U.S. Energy Information Administration - EIA - Independent Statistics and Analysis



The average combined-cycle power block installed between 2002 and 2014 was about 500 megawatts (MW). After 2014, power block capacity increased, reaching an average of 820 MW in 2017. 575 billion KWH natural gas total generation divided by 987 plants = 1.596 avg. per plant billion KWH

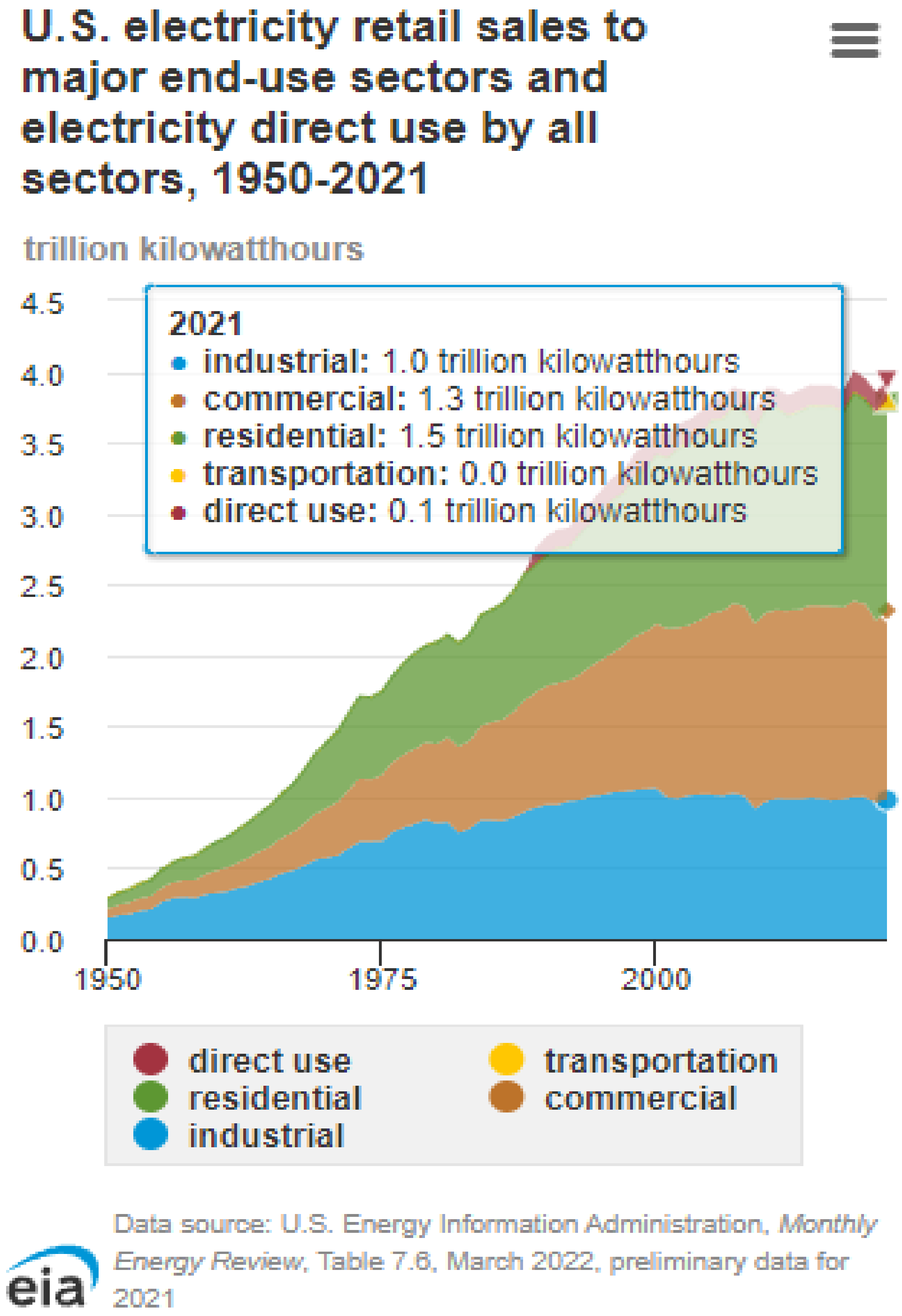
https://www.cleanfreightcoalition.org/4-questions-policymakers-need-answer-bevs

Where will the power come from?

New research from the American Transportation Research Institute exposes severe limitations for the U.S. electricity grid when it comes to electrifying the nation's vehicle fleet. Converting all vehicles to battery-electric would amount to more than 40% of the nation's current electricity consumption. For freight trucks alone, 14%. California, for instance, will need to increase its electricity generation by more than 57.2% to convert all vehicles to battery-electric, at a time when the state already experiences rolling blackouts.

E7

Use of electricity - U.S. Energy Information Administration (EIA)

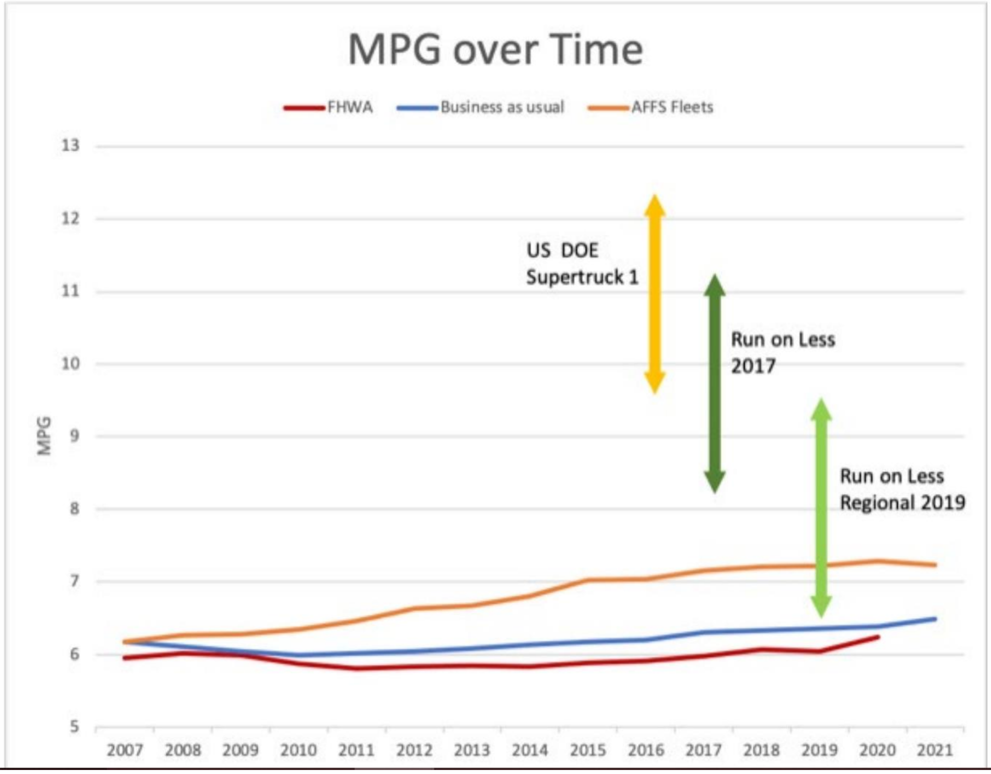


E8

The NACFE Run on Less program initiative with tests on combinations of technology -- AFFS-2022-Report-FINAL-1.pdf (nacfe.org)

- The Run on Less 2017 performance of 8.5 to 11.5 MPG,
- The NACFE AFFS latest model year truck range from 7.2 to 9.5 MPG in 2018, and
- The Run on Less 2019 Regional results of about 6.5 to 9.6.

There continues to be a multitude of developments underway that are sure to continue the performance increases in efficiency of these trucks. Such efforts include the Shell Starship initiative, DOE SuperTruck 2 effort, which now includes five teams, the developments underway for commercial battery electric vehicles, hydrogen fuel cell electric vehicles, diesel hybrid trucks, and on and on.



E9

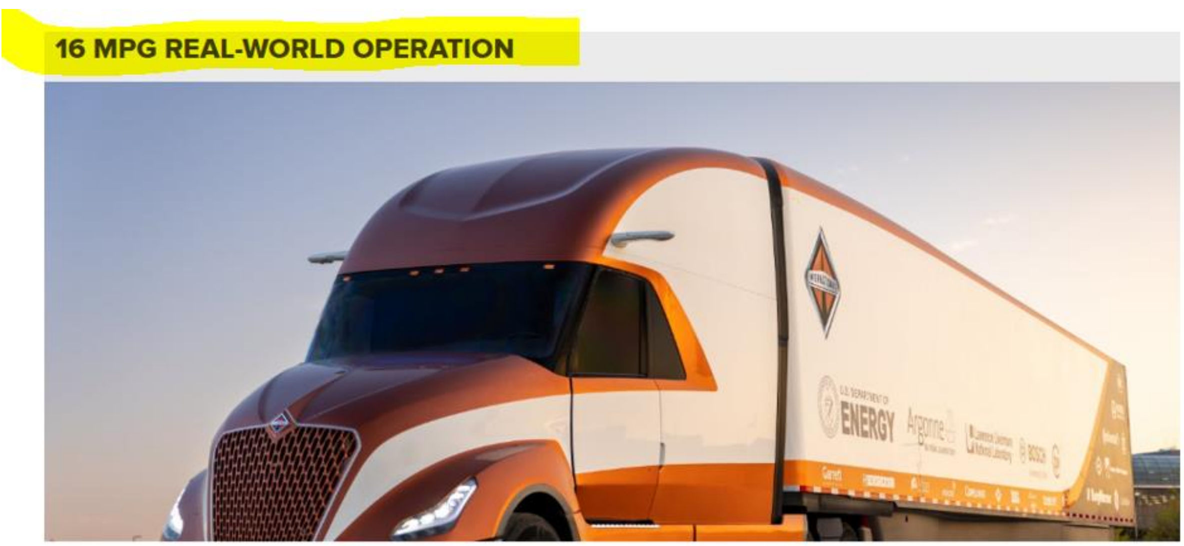
SuperTruck II | International® Trucks (internationaltrucks.com)

International SuperTruck II was built as a hybrid vehicle that features a combustion engine and high-voltage accessories and technologies, making it easier for future development into fully electric vehicles. Engine improvements were made in key areas, including combustion, friction, gas exchange, and airflow through the engine.

It includes a 100% composite box designed for minimum aerodynamic drag with light weight, integrated cross members, controlled underbody flow with composite aero treatments, 6.7-kilowatt solar panels with connectivity options, and ride height control.

Freight-ton efficiency (FTE) is measured in ton-miles per gallon and is one of the most effective ways to measure the amount of energy required to transport goods. In short, the most freight-ton efficient trucks make the most of fuel mileage.

Thanks to structural composites that are made with lightweight materials, which allowed designers to be more aggressive with the design, International SuperTruck II is lighter and can handle more cargo. This also means the fuel it takes to transport each pound of cargo is much less — especially when combined with the improved fuel efficiency of the truck. The 170% improvement in FTE means a much more efficient drive for your fleets.



https://t20e.net

E10

The results from International SuperTruck II demonstrates innovative vehicle efficiency improvements and advancements to high-voltage electrification. Co-funded by the Department of Energy (DOE), the SuperTruck II program highlights reduced emissions from on-road freight transportation with partner companies. Building on the success of the first SuperTruck program, engineers at Navistar developed next-generation technologies in the areas of weight reduction, rolling resistance, aerodynamics, and powertrain – all designed to deliver enhanced freight efficiency and help reduce U.S. dependency on fossil fuels in the commercial vehicle sector.

> “The fundamental philosophy behind the design was an opportunity to develop high-voltage technologies outside of electric vehicles. These efforts were started six years ago, before electric even existed. And a lot of these technologies are currently being used in our electric vehicles today.
>
> *Dean Oppermann / Navistar Inc.*

“Our goal is to continue to advance internal combustion engine technology as efficiently and sustainably as possible until there is parity with zero-emissions vehicles,” said Oppermann. “Development of both technologies concurrently ensures a smooth transition of technology to best serve customer needs. We are focused on the entire product ecosystem – product development itself as well as infrastructure charging, service and support of vehicle operation, end of life for batteries.”

F1

https://nacfe.org/wp-content/uploads/edd/2022/05/HD-Regional-Haul-Report-FINAL.pdf

NACFE reported in Electric Trucks – Where They Make Sense that battery pack weights derived from various sources range from 25 lb/kWh down to projected goals of 5 lb/kWh. [2] A reasonable estimate today for a production battery pack is 15 to 20 lb/kWh. That value is expected to continue to improve with newer generations of battery pack designs. The battery weight is estimated as a function of the energy density and battery pack capacity as shown in Figure 8.

Battery Weight (lb)
as a function of Energy Density and Battery Capacity

Energy Density (lb/kWh)	Battery Capacity (kWh)									
	100	200	300	400	500	600	700	800	900	1,000
5.0	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000
10.0	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
15.0	1,500	3,000	4,500	6,000	7,500	9,000	10,500	12,000	13,500	15,000
20.0	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000
25.0	2,500	5,000	7,500	10,000	12,500	15,000	17,500	20,000	22,500	25,000
30.0	3,000	6,000	9,000	12,000	15,000	18,000	21,000	24,000	27,000	30,000

Figure 8. Battery weight (lbs.) as a function of energy density and range (NACFE)

An example of using the chart, if the battery capacity is 400 kWh, and the estimated energy density is 20 lb/kWh, then the battery weight is 8,000 lbs. Alternately, if the battery is known to weigh 4,500 lbs. and is nominally a 300-kWh pack, then the estimated energy density is 15 lb/kWh

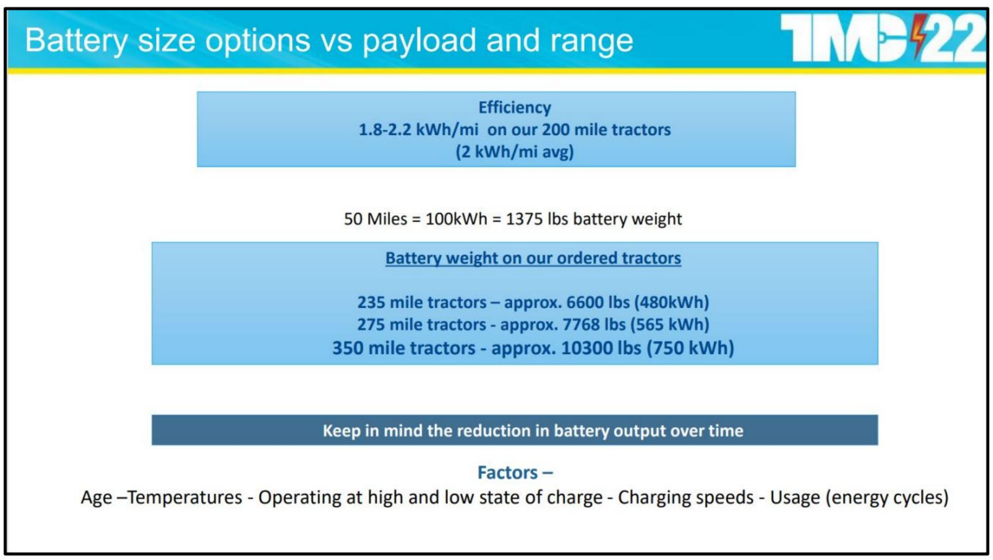


Figure 9. Example production BEV weight, range and consumption (NFI/TMC)

Therefore:

- 500 miles x 2.2 KWH per mile x 15 lbs per KWH = 16,500 lbs
- 75 miles x 2.2 KWH per mile x 15 lbs per KWH = 2,475 lbs

F2

https://sgp.fas.org/crs/misc/R46420.pdf
page 1 and 14

Congressional Research Service
Informing the legislative debate since 1914

Environmental Effects of Battery Electric and Internal Combustion Engine Vehicles

Broadly speaking, a review of the literature shows that in most cases BEVs have lower life cycle greenhouse gas (GHG) emissions than ICEVs. In general, GHG emissions associated with the raw materials acquisition and processing and the vehicle production stages of BEVs are higher than for ICEVs, but this is typically more than offset by lower vehicle in-use stage emissions, depending on the electricity generation source used to charge the vehicle batteries. The importance of the electricity generation source used to charge the vehicle batteries is not to be understated: one study found that the carbon intensity of the electricity generation mix could explain 70% of the variability in life cycle results.

In addition to lower GHG emissions, many studies found BEVs offer greater local air quality benefits than ICEVs, due to the absence of vehicle exhaust emissions. However, both BEVs and ICEVs are responsible for air pollutant emissions during the upstream production stages, including emissions during both vehicle and fuel production. Further, BEVs may be responsible for greater human toxicity and ecosystems effects than their ICEV equivalents, due to (1) the mining and processing of metals to produce batteries, and (2) the potential mining and combustion of coal to produce electricity. These results are global effects, based on the system boundaries and input assumptions of the respective studies.

In addition to a review of the literature, CRS focused on the results of one study in order to present an internally consistent example of an LCA. This specific study finds that the life cycle of selected lithium-ion BEVs emits, on average, an estimated 33% less GHGs, 61% less volatile organic compounds, 93% less carbon monoxide, 28% less nitrogen oxides, and 32% less black carbon than the life cycle of ICEVs in the United States. However, the life cycle of the selected lithium-ion BEVs emits, on average, an estimated 15% more fine particulate matter and 273% more sulfur oxides, largely due to battery production and the electricity generation source used to charge the vehicle batteries. Further, the life cycle of the selected lithium-ion BEVs consumes, on average, an estimated 29% less total energy resources and 37% less fossil fuel resources, but 56% more water resources. These results are global effects, based on the system boundaries and input assumptions of the study.

IMPORTANT EXPLANATIONS:

Terminology in Transportation Sector LCAs

In addition to the "upstream" and "downstream" terms used in this report, LCA practitioners use certain terminology to enable comparisons between vehicle types with different power sources, fuel use, and associated effects. These terms are based on the concept of the fossil fuel life cycles for ICEVs, and they have been adopted for BEVs.

- Well-to-Tank (WtT) refers to any environmental effects from the processes needed to extract and transform crude oil into useable fuel for ICEVs. For BEVs, WtT refers to any environmental effects from electricity production occurring upstream of vehicle charging. WtT corresponds to the term "upstream."
- Tank-to-Wheels (TtW) refers to any environmental effects from the combustion of the fuel in the vehicle's engine for ICEVs. For BEVs, TtW refers to the direct environmental effects of driving the vehicle. TtW corresponds to the term "downstream."
- Well-to-Wheels (WtW) refers to the WtT and TtW stages collectively for both ICEVs and BEVs.

R47227 (congress.gov)
Page 1 and 12

Congressional Research Service
Informing the legislative debate since 1914

Critical Minerals in Electric Vehicle Batteries

Expected growth of electric vehicle (EV) sales has led to concern about securing mineral inputs used in EV batteries. Various countries and companies have stated policies to accelerate the adoption of EVs in the transportation sector. Such public and private commitments suggest that EV sales could continue into the expected future, with some estimates indicating 200 million total EVs sold by 2030. More than 16 million total EVs have been sold worldwide, with about 6.6 million EVs sold in 2021. The U.S. EV market is small when compared to those in China and Europe: new U.S. EV registrations were slightly less than 10% of new global EV registrations in 2021, while registrations in China were 50% of the global total and European registrations were 35%

The order of the minerals presented starts with cathode minerals: lithium is first, as it is used in all cathodes considered, followed by cobalt, manganese, and nickel. Graphite, the mineral used in the anode, follows the cathode minerals. The subsection "Secondary Mineral Supply" discusses EV battery recycling as a potential supply option available for the five minerals. Each mineral subheading contains information on the element's mineralization and geologic formation. While this information can be quite technical, it can provide a starting point to understanding why some minerals are found in geographically dispersed locations, while others are concentrated in limited locations.[49]

Table 2. Selected Statistics for Five EV Battery Minerals

In metric tons, unless indicated otherwise

	Lithium	Cobalt	Manganese	Nickel	Graphite
NIR (%)	>25	76	100	48	100
U.S. Production	withheld	700	0	18,000	0
Global Production	100,000	170,000	20,000,000	2,700,000	1,000,000
Exports	1,900	4,800	1,000	25,000	8,400
Imports	2,500	9,900	460,000	110,024	53,000

Electric Car Batteries And The Environment — Coltura - moving beyond gasoline

If EV batteries continue to be made of lithium ion, the primary concerns are: 1) labor practices for mining cobalt; 2) environmental impacts of extracting lithium; 3) sufficient supply of materials for EV batteries; 4) carbon emissions from battery manufacture; and 5) toxic waste from disposal of used batteries.

https://www.cleanfreightcoalition.org/4-questions-policymakers-need-answer-bevs

Where will the batteries come from?

To mass produce lithium-ion batters, tens of millions of tons of cobalt, graphite, lithium and nickel will be needed, which could take as long as 35 years to acquire given current levels of global production. Expanding that capacity creates a giant environmental footprint, producing considerably more CO2 and pollution than the manufacture of internal combustible engines. In some operations, a minimum of one million gallons of water are used to produce a single pound of lithium.

Moreover, child and other exploitive labor practices are common in many of the countries that produce these minerals. In the Congo Republic, which exports more than half of the world's total Cobalt, at least 40,000 children are enslaved in the labor trade according to the United Nations.

F3

https://www.nationalgrid.com/stories/journey-to-net-zero-stories/what-happens-old-electric-car-batteries

How long do electric car batteries last?

The hundreds of gently topped-up cells inside an EV battery mean that each battery pack is expected to retain its charging-discharging capacity from 100,000 to 200,000 miles. Manufacturers are so confident of the battery's road use that most electric cars come with an extended warranty of eight years, or 100,000 miles.

https://batteryuniversity.com/article/bu-1003a-battery-aging-in-an-electric-vehicle-ev

Figure 2 illustrates the driving range of a Tesla EV model carrying an 85kWh battery as published on social media. **Section 1** delivered a steady range up to 95,000 miles on the odometer reading. **Section 2** demonstrates a 5% decrease in range, and Section 3 denotes a software upgrade at 130,000 miles. This reduces the driving range by about 10% by adding grace capacity.

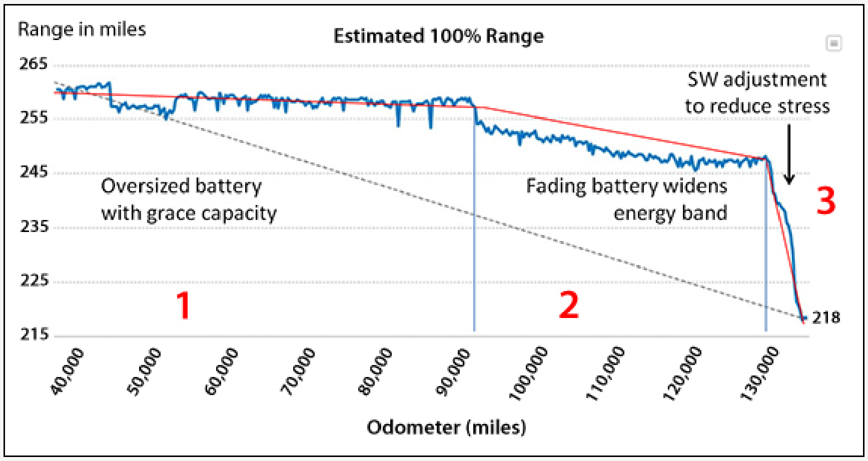


Figure 2: Driving range of an EV is divided into three sections

https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10178RN.pdf

(BELOW NOT INCLUDING CHARGER % IN 2027 & BEYOND)

Page 165 & 166

Table 2-38 BEV Component Efficiencies in MY 2027-2032

Component	2027	2028	2029	2030	2031	2032
Battery	95%	95%	95%	95%	95%	95%
Inverter	97.0%	97.0%	97.0%	97.5%	97.5%	97.5%
E-Motor	94.5%	94.5%	94.5%	95.0%	95.0%	95.0%
Total System Efficiency	*87%*	*87%*	*87%*	*88%*	*88%*	*88%*

When sizing the battery, we also accounted for the battery depth of discharge, or the amount of discharge level during a discharging cycle, and battery deterioration over time. For BEV battery depth of discharge, we sized the battery by limiting the battery to a maximum depth of discharge of 80 percent, which is a common allowable depth of discharge for lithium batteries; therefore, an additional 20 percent increase in battery size is needed to allow a depth of discharge of 80 percent.[52] To account for battery deterioration, the battery is over-sized by 20 percent in HD TRUCS so that at least 80 percent of original battery capacity is available to account for potential battery deterioration. These values are multiplied together to determine additional sizing requirement to account for these parameters.

Table 2-39 ANL Performance Targets

	Vocational				Tractors	
Weight Class Bin	2b-3	4-5	6-7	8	7	8
0-30 mph Time (s)	7	8	16	20	18	20
0-60 mph Time (s)	25	25	50	100	60	100
Cruise Speed (mph) @ 6 % grade	65	55	45	25	30	30

2.4.2 Battery Weight and Volume

Performance needs of a BEV can result in a battery that is so large or heavy that it impacts payload and, thus, potential work accomplished relative to a comparable ICE vehicle. We determined the battery weight and physical volume for each vehicle application in HD TRUCS

Page 165 & 166

2.4.1.1.2 Effects of Temperature on the Battery

Battery range and life can be impacted by ambient temperatures, as described in Chapter 1. Therefore, in general, BEVs have thermal management systems to maintain battery core temperatures within an optimal range of approximately 68 to 95 degrees Fahrenheit (F) (20 to 35 degrees Celsius).[48] Since BEVs may not have an additional energy source beyond what is stored inside the battery, some stored energy in the battery is used to maintain a constant battery temperature. The Basma et al. report discusses the battery conditioning power requirements at various temperatures; Figure **2-6**, based on Basma et. al, shows the power demand for battery conditioning as a function of ambient temperature.[49]

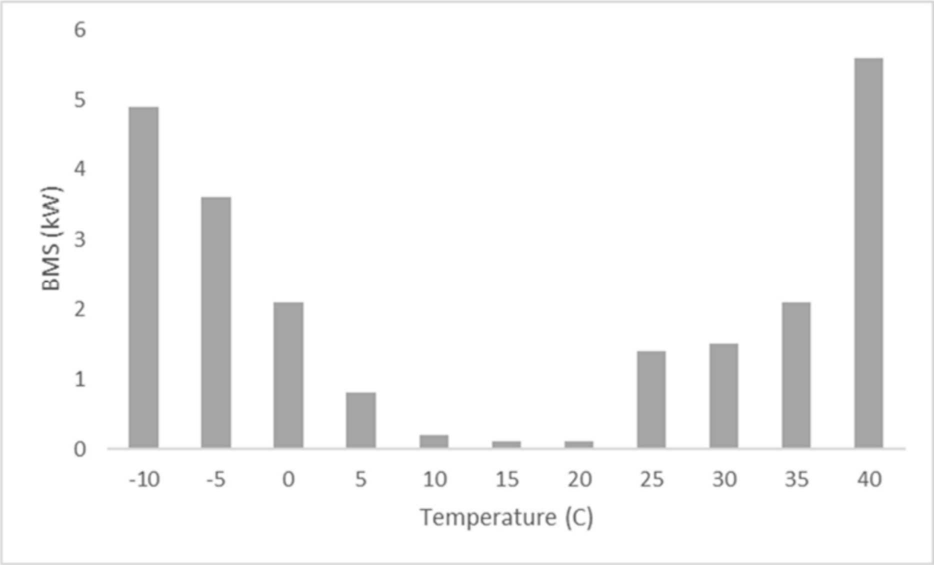


Figure 2-6 **Modeled Power Demand for Battery Conditioning for Class 8 Transit Bus with a 300 kWh Battery**

Page 164

Covid-19 and other global disruptions have placed pressure on battery supply chains that could affect prices in the short-term. The Federal Consortium for Advanced Batteries published a National Blueprint for Lithium Batteries in June 2021 to guide investments and developments in the lithium-battery manufacturing value chain and establish a domestic supply chain that is more sheltered from global price dynamics.[60] BloombergNEF predicted that battery prices could reach $100/kWh in 2026.[61] In December 2022, prices of lithium-ion batteries increased for the first time in over a decade due to higher raw material and component costs.[62]

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F4

Economics and Industry Data | American Trucking Associations

AMERICAN TRUCKING ASSOCIATIONS

MOVING BOC-3 FILING MEMBERSHIP ADVOCACY NEWS PROGRAMS EVENTS

Economics and Industry Data

Revenue:

$875.5 billion in gross freight revenues (primary shipments only) from trucking, representing 80.8% of the nation's freight bill in 2021.

Tonnage:

10.93 billion tons of freight (primary shipments only) transported by trucks in 2021, representing 72.2% of total domestic tonnage shipped.

Number of Trucks:

- 38.9 million trucks registered and used for business purposes (excluding government and farm) in 2020, representing 24.1% of all trucks registered.
- 4.06 million Class 8 trucks (including tractors and straight trucks) in operation in 2021, up 2.3% from 2020.

Mileage:

- 302.14 billion miles traveled by all registered trucks in 2020.
- 177.26 billion miles traveled by combination trucks in 2020.

Number of Companies:

According to the U.S. Department of Transportation, as of June 2022, the number of for-hire carriers on file with the Federal Motor Carrier Safety Administration totaled 1,102,799, private carriers totaled 718,594, there were 153,191 carriers identified as both for-hire and private carriers and other* interstate motor carriers totaled 37,718.

** Other' motor carriers are those that did not specify their segment or checked multiple segments. All other categories were excluded.*

- 95.7% operate 10 or fewer trucks.
- 99.7% operate fewer than 100 trucks.

Employment:

- 7.99 million people employed throughout the economy in jobs that relate to trucking activity in 2021 excluding the self-employed.

F5

Consider:

- 2 million trucks x 8.3 tons of batteries each = 16.6 million tons of batteries
    - 16.6 million tons of batteries / lifespan of 2 years = 8.3 million tons of batteries to swap each year.

Compared to:

- 2 million Hybrid trucks using 1.3 tons of batteries each = 2.6 million tons of batteries
    - 2.6 million tons batteries / lifespan of 4 years = 650,000 tons of batteries to swap each year

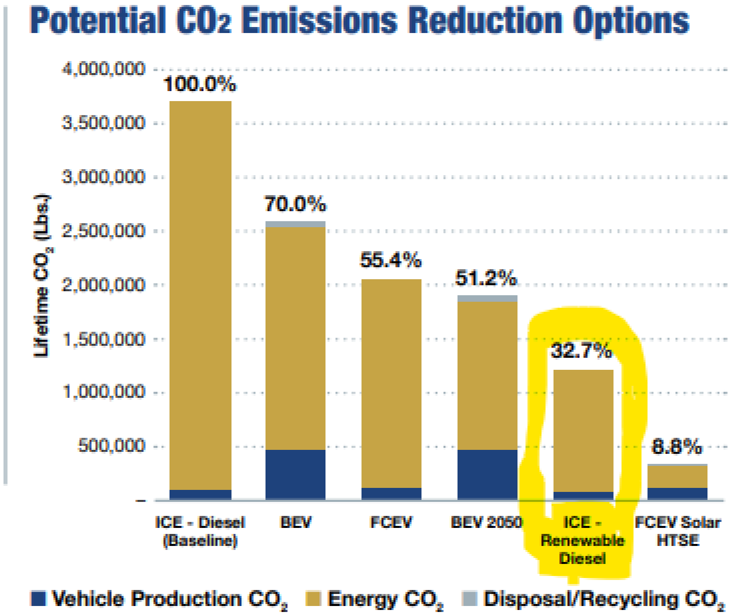
Therefore:

- 8,300,000 - 650,000 = 7,650,000 tons of batteries each year avoided in cost & environmental impact

F6

https://truckingresearch.org/wp-content/uploads/2022/05/ATRI-Environmental-Impacts-of-Zero-Emission-Trucks-Exec-Summary-5-2022.pdf

PAGE 2 Below (Plus add the positive effect of Compound Electric Hybrids with Zero Emissions)



https://truckingresearch.org/wp-content/uploads/2022/05/ATRI-Understanding-CO2-Impacts-of-Zero-Emission-Trucks-May-2022.pdf

G1

AFFS-2022-Report-FINAL-1.pdf (nacfe.org)
Page 40

5.3 Benchmarking MPG

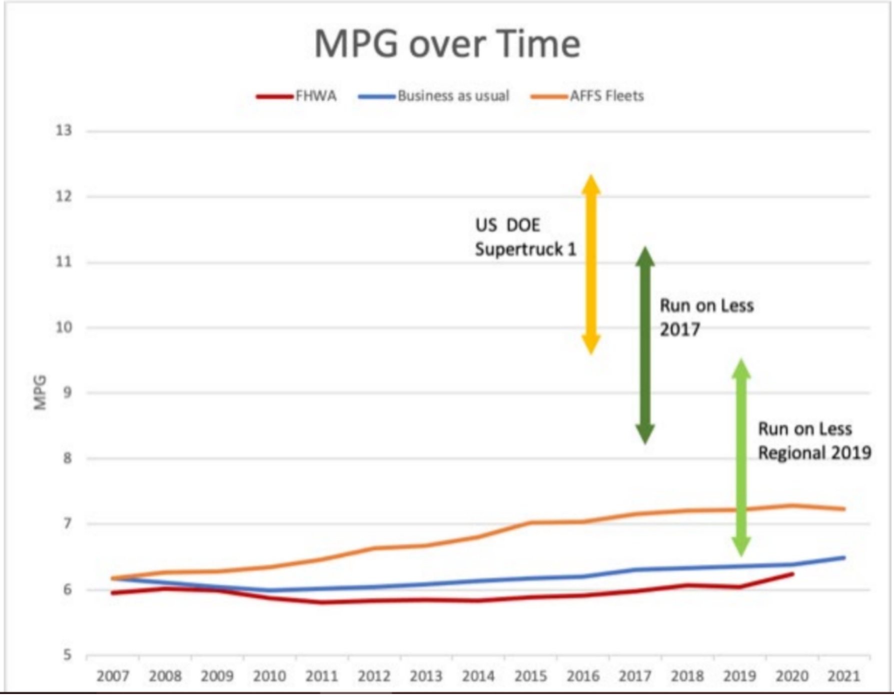
There have been other efforts to improve the fuel efficiency of moving goods with large trucks. The US Department of Energy (DOE) helped fund four SuperTruck 1 teams to build prototype tractors and trailers that would double freight efficiency. Four teams created equipment that reported fuel economy in the 10 to 12.5 MPG range. Results of these truck program demonstrations were reported by the teams at the DOE Annual Merit Reviews in 2015 and 2016. [5] Five SuperTruck 2 projects are nearing completion here at the end of 2022 and surpassing the levels of their SuperTruck 1 prototypes. Results of final testing will become available throughout 2023. [15]

Figure 21 provides a comparison of the various benchmarks of Class 8 tractor-trailer performance mentioned so far in this report. Shown are:

- The national average of all US Class 8 tractor-trailers at 6.24 MPG in 2020,
- The NACFE AFFS fleet-wide average of 7.23 MPG in 2021
- The Department of Energy SuperTruck 1 trucks ranging from 10 to 12.5 MPG.

- The Run on Less 2017 performance of 8.5 to 11.5 MPG,
- The NACFE AFFS latest model year truck range from 7.2 to 9.5 MPG in 2018, and
- The Run on Less 2019 Regional results of about 6.5 to 9.6.

There continues to be a multitude of developments underway that are sure to continue the performance increases in efficiency of these trucks. Such efforts include the Shell Starship initiative, DOE SuperTruck 2 effort, which now includes five teams, the developments underway for commercial battery electric vehicles, hydrogen fuel cell electric vehicles, diesel hybrid trucks, and on and on.



https://t20e.net

https://nacfe.org/wp-content/uploads/edd/2022/12/AFFS-2022-Report-FINAL.pdf

The average fleet-wide fuel economy of the trucks in this study was 7.23 mpg in 2021 — a slight increase from the 7.15 in 2017. There is variability in each fleet's yearly fuel efficiency depending on many factors, but overall, these fleets had a very impressive average annual rate of improvement in MPG of 2.0% from 2011 to 2017.

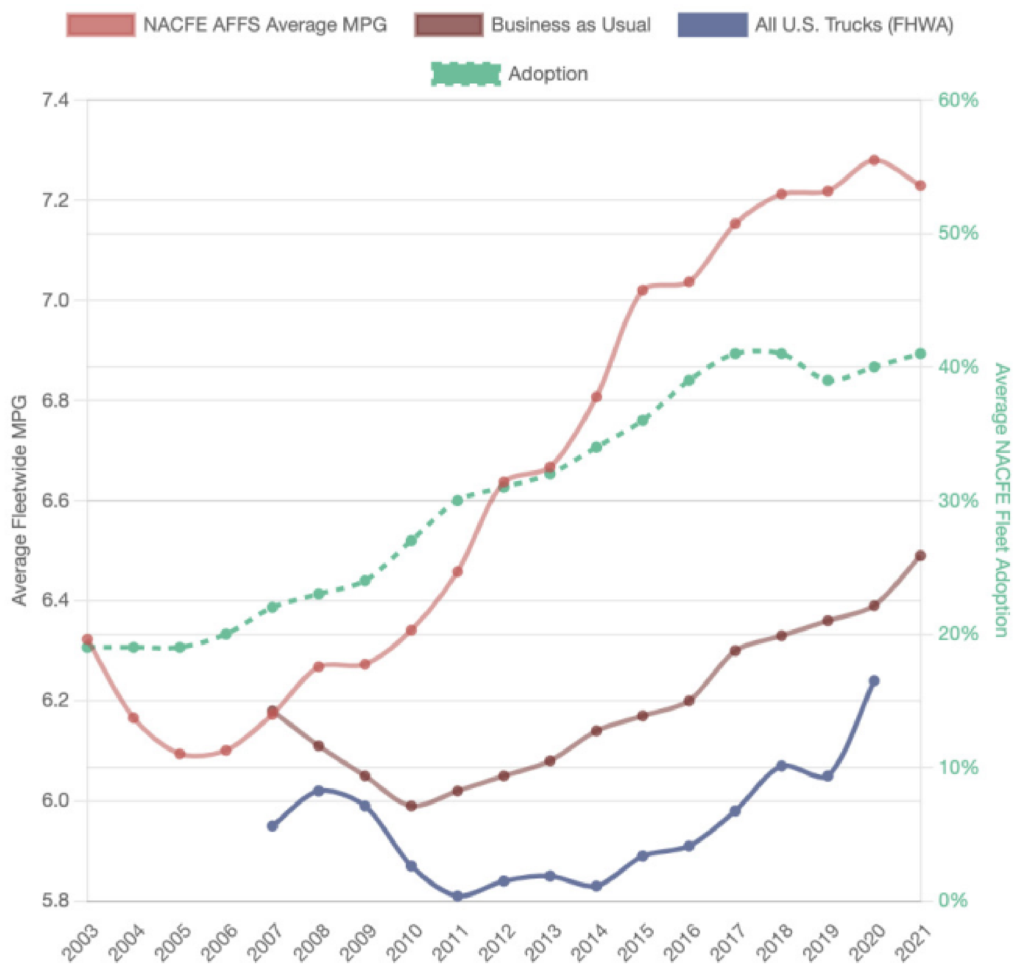
Figure ES2 shows the average fleet-wide fuel economy for the combined population of trucks in this study compared to the overall U.S. truck population. A business-as-usual (BAU) line is included for comparison. The BAU shows a projection of what average MPG might have been given the combined impact of 2002, 2007, and 2010 emission regulations, and the effect of the 2014 and 2017 Greenhouse Gas (GHG) base powertrain improvements. In other words, this suggests the level of efficiency had the 15 fleets not purchased the technologies that are available to them as options.

The national average for the approximately 1.7 million tractors in over-the-road use is shown and was obtained using International Fuel Tax Reporting data from the Federal Highway Administration (FHWA, 2019). Of note this year is that the national average of these trucks jumped to 6.24 MPG in 2020, a reflection of the fact that the MPG increases over the last 10 years are starting to be reflected in the overall population's efficiency. As of the finalization of this report, 2021 data was not yet available.

During NACFE's Run on Less demonstration in September of 2017, the tractor-trailers equipped with the best of the best currently available technologies attained 10.1 MPG.

FIGURE ES2

AVERAGE FLEET-WIDE FUEL ECONOMY OVER TIME



https://t20e.net

https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10178RN.pdf

The values were summed to calculate the energy consumption by regulatory class. The resulting values for weighted energy consumption per mile at the axle are shown in Table 2-13. As described above, HVAC loads have been removed, and neither PTO loads nor regenerative braking benefits are included in Table 2-13.

Table 2-13 GEM Weighted Energy Consumption per Mile

Regulatory Subcategory	Weighted Axle Work per Mile (kWh/mi)
C8_SC_HR	2.18
C8_SC_MR	2.38
C8_SC_LR	2.17
C8_DC_HR	2.29
C8_DC_MR	2.37
C8_DC_LR	2.20

Page 129 & 130

Navistar Reveals International® SuperTruck II Results with Improved Fuel and Freight Efficiency, Goals for Hybridization - Jun 20, 2023

LISLE, Ill., June 20, 2023 /PRNewswire/ -- Navistar today revealed the results of the International® SuperTruck II, a project in partnership with the U.S. Department of Energy (DOE). International SuperTruck II demonstrates 16 miles per gallon (MPG) fuel efficiency through hybridization and a 170% improvement in freight efficiency, among other advancements over the 2009 baseline vehicle, its International SuperTruck I. It also proves innovative technical approaches to weight reduction from rolling resistance technologies, aerodynamic improvements, and powertrain technologies designed to deliver premium freight efficiency to assist in reducing U.S. dependency on fossil fuels in the commercial vehicle sector.

G2

https://www.api.org/-/media/files/statistics/state-motor-fuel-taxes-charts-january-2022.pdf

	Gasoline				Diesel			
State	State Excise Tax	Other State Taxes/Fees	Total State Taxes/Fees	Total State plus Federal Excise Taxes (@ 18.4 cpg)	State Excise Tax	Other State Taxes/Fees	Total State Taxes/Fees	Total State plus Federal Excise Tax (@ 24.4 cpg)
VT	12.10	20.04	32.14	50.54	28.00	4.00	32.00	56.40
VA	26.20	8.20	34.40	52.80	27.00	8.30	35.30	59.70
WA	49.40	0.00	49.40	67.80	49.40	0.00	49.40	73.80
WV	20.50	15.20	35.70	54.10	20.50	15.20	35.70	60.10
WI	30.90	2.00	32.90	51.30	30.90	2.00	32.90	57.30
WY	23.00	1.00	24.00	42.40	23.00	1.00	24.00	48.40
U.S. avg	**26.16**	**12.53**	**38.69**	**57.09**	**26.72**	**13.52**	**40.24**	**64.64**

Therefore:

- 64.64 / 6.4 average MPG = **10 cents per mile for Tax Revenue**

G3

https://engsfinance.com/blog/the-true-cost-of-electric-semis-how-do-they-compare-to-traditional-diesel/

Cost of Fuel

Electricity is cheaper than diesel, and electric trucks don't require the same level of maintenance as their diesel counterparts. Electric trucks also have regenerative braking, which helps to extend the life of the brakes as well as extend the range per charge in certain instances. When you figure the average mileage is 7mpg for a diesel truck, and with the current fuel price surge in the U.S., the national average is $5.65 per gallon, providing an eye-popping $0.81/mile in fuel cost alone. The estimates from most electric semi manufacturers is between 2 and 2.5KWh per mile, and the current range of electricity pricing is $0.12-$0.20/KWh, an electric truck can be easily $0.50/mile cheaper to run. When you factor in all of these cost-savings, electric semis start to look a lot more attractive from a TCO perspective.

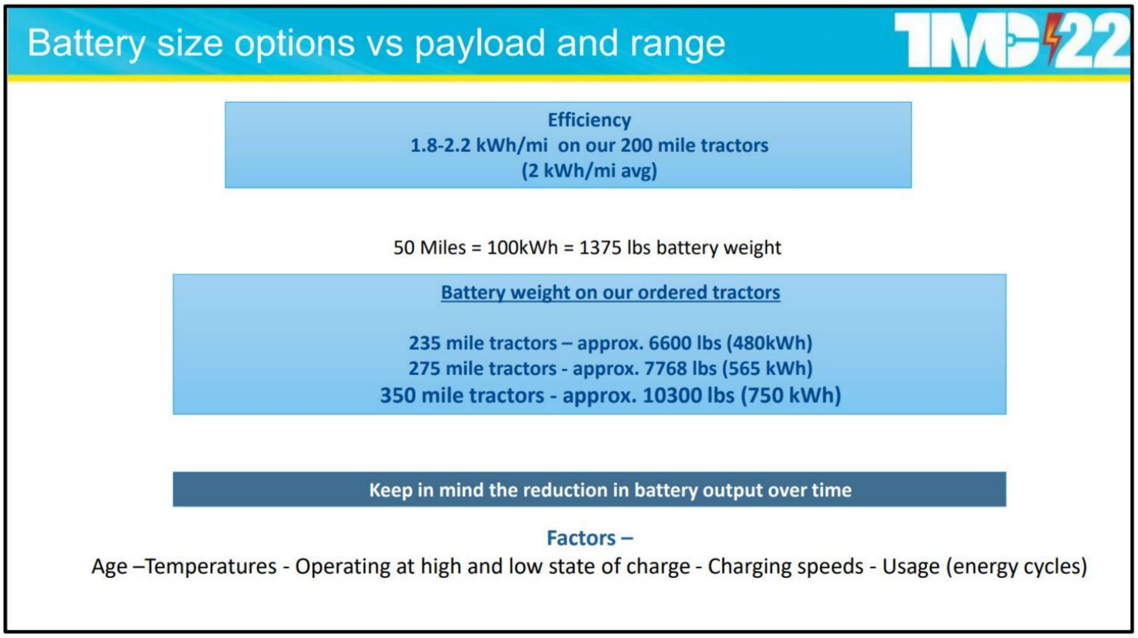
https://nacfe.org/wp-content/uploads/edd/2022/05/HD-Regional-Haul-Report-FINAL.pdf
page 29 & 31

Battery Capacity (kWh)
as a function of Energy Consumption and Range

Energy Consumption (kWh/mi)	Range (mi)			
	50	100	150	200
1.0	50	100	150	200
1.2	60	120	180	240
1.4	70	140	210	280
1.6	80	160	240	320
1.8	90	180	270	360
2.0	100	200	300	400
2.2	110	220	330	440
2.4	120	240	360	480
2.6	130	260	390	520
2.8	140	280	420	560
3.0	150	300	450	600

Figure 7. Battery capacity kWh as a function of consumption and range

An example of using the chart, if the manufacturer's specification sheet states there is a 400 kWh battery pack with an estimated range of 200 miles, then the estimated consumption is 2 kWh/mi. Alternatively, if consumption is known to be 2.2 and the range is estimated as 100 miles, then the useable battery pack capacity is estimated as 220 kWh.



G4

https://www.globalpetrolprices.com/USA/electricity_prices/

USA electricity prices

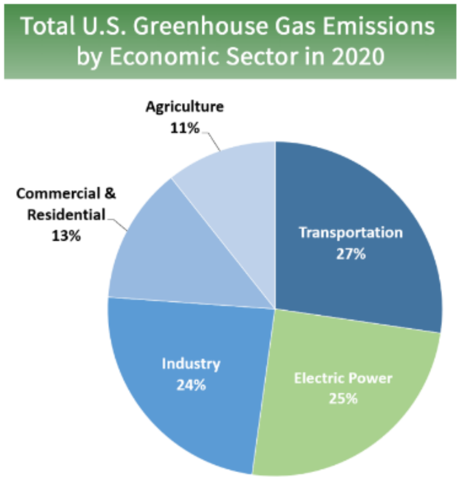
USA electricity prices	Household, kWh	Business, kWh
U.S. Dollar	0.162	0.128
U.S. Dollar	0.162	0.128

USA, March 2022: The price of electricity is 0.162 U.S. Dollar per kWh for households and 0.128 U.S. Dollar for businesses which includes all components of the electricity bill such as the cost of power, distribution and taxes. For comparison, the average price of electricity in the world for that period is 0.146 U.S. Dollar per kWh for households and 0.140 U.S. Dollar for businesses. We calculate several data points at various levels of electricity consumption for both households and businesses but on the chart we show only two data points. For **households**, the displayed number is calculated at the average annual level of household electricity consumption. For **businesses**, the displayed data point uses 1,000,000 kWh annual consumption.

The latest business and household electricity price data from September 2022 are available for download.

G5

https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions
(2020 figures as of Jan. 2022)



Total Emissions in 2020 = 5,981 Million Metric Tons of CO_2 equivalent. Percentages may not add up to 100% due to independent rounding.

* Land Use, Land-Use Change, and Forestry in the United States is a net sink and removes approximately 13% of these greenhouse gas emissions. This net sink is not shown in the above diagram. All emission estimates from the *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2020.*

G6

https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10178RN.pdf

EGU is “Electric Generating Units” (plants)

From 2027 through the 2030s, EGU emission increases are expected to start small and grow as HD ZEV adoption drives greater increases in energy demand. But through the 2040s, a substantial increase in the use of renewable energy sources is expected to take place in the national power generation mix, driven in part by the IRA. This is expected to lead to decreases in EGU emissions at a national level, including decreases in EGU emissions attributable to HD ZEVs and the proposed standards.

Figure 4-14 shows the same information as Table 4-19. The plot shows the projected increase in EGU emissions, peaking in 2039 before dropping until 2050. Figure 4-15 shows that the same trend is projected for criteria pollutants, where all but SO_2 emissions are projected to peak in 2040. SO_2 emissions are projected to peak in 2035. SO_2 emissions are primarily driven by power generation using coal, which is the first fossil fuel expected to be phased out, especially when accounting for the IRA.

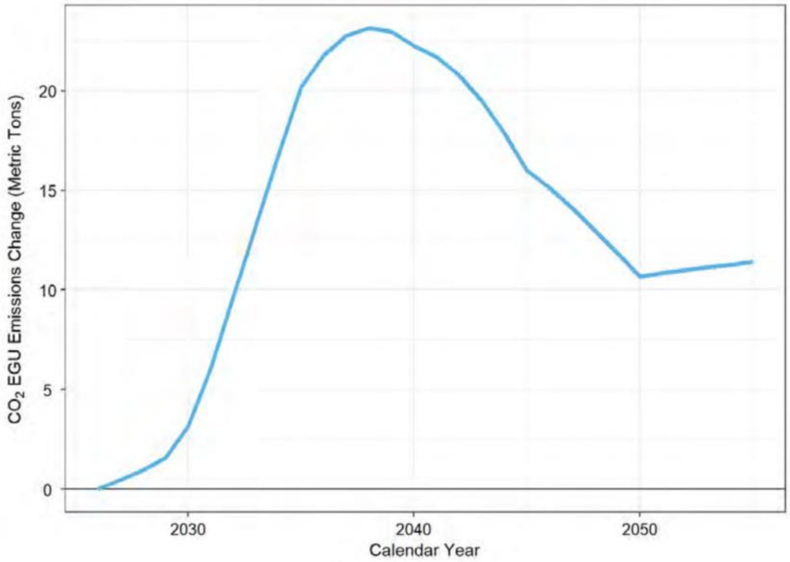


Figure 4-14 Yearly CO_2 emissions changes from EGUs from the proposed CO_2 emission standards from 2027 through 2055

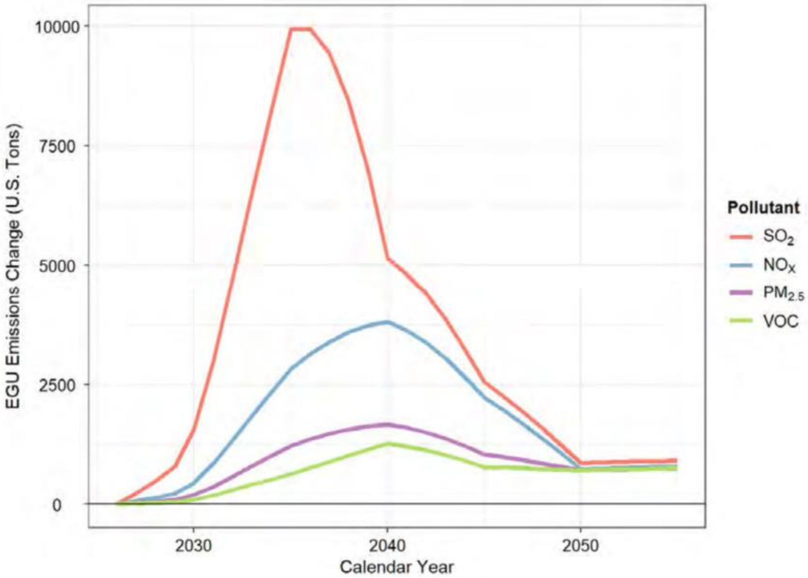


Figure 4-15 Yearly criteria pollutant emissions increases from EGUs from the proposed CO_2 emission standards from 2027 through 2055

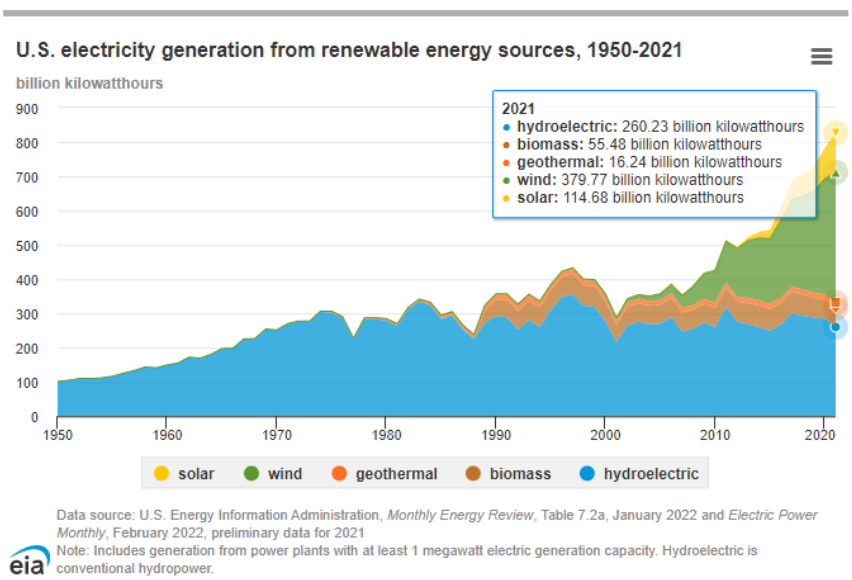
G7

[Wind Market Reports: 2022 Edition | Department of Energy]
Chart data compiled from the Distributed Wind Market Report: 2022 Edition. In 2021, cumulative distributed wind capacity reached 1,075 megawatts (MW) from **over 89,000** wind turbines across all 50 states, Puerto Rico, the U.S. Virgin Islands, and Guam.
Equals 4.267 billion kilowatt hours per 1,000 wind turbines.

Wind Turbine average annual megawatt hours:

> To answer that question, AWEA's manager of industry data analysis, John Hensley, did the following math: 4.082 billion megawatt-hours (the average annual US electricity consumption) divided by 7,008 megawatt-hours of annual wind energy production per wind turbine equals approximately **583,000 onshore turbines**. Sep 26, 2016

The breakdown of how all renewable electricity generating is sourced:
https://www.eia.gov/energyexplained/electricity/electricity-in-the-us.php



H1

https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10178RN.pdf

Table 1-2 Domestic Mode of Exports and Imports by Tonnage and Value from 2012-2045 [3]

Domestic Mode	Tons (thousands)			Value (millions of 2012 $)		
	2012	2020	2045	2012	2020	2045
Grand Total	2,057,833	2,479,699	4,540,300	3,764,477	5,265,375	14,595,630
Truck	807,077	985,757	2,188,843	1,964,961	2,679,834	7,782,009
Rail	315,760	342,393	661,910	310,757	413,456	962,844
Water	156,140	199,892	333,216	160,235	222,772	531,973
Air (including truck-air)	5,355	7,138	22,120	538,275	835,816	2,883,803
Multiple modes and mail	109,251	134,851	368,665	375,541	537,949	1,576,807
Pipeline	359,021	582,716	708,596	174,962	324,515	354,333
Other and unknown	4,740	6,076	15,962	38,855	105,330	324,385
No domestic mode	300,489	220,875	240,988	200,892	145,704	159,477

https://www.bts.gov/newsroom/freight-activity-us-expected-grow-fifty-percent-2050

Freight Activity in the U.S Expected to Grow Fifty Percent by 2050

Monday, November 22, 2021

Contacts: BTS/Todd Solomon (202) 366-0573 todd.solomon@dot.gov

FHWA/Nancy Singer (202) 366-0660 Nancy.Singer@dot.gov

The U.S. Department of Transportation's Bureau of Transportation Statistics (BTS) and Federal Highway Administration (FHWA) today jointly released a new version of freight flows forecast data from the Freight Analysis Framework (FAF), the most comprehensive, publicly available, national-level dataset of freight movement in the U.S.

New long-term projections released today show that, between 2020 and 2050, U.S. freight activity will grow by fifty percent in tonnage to 28.7 billion tons and will double in value to $36.2 trillion (in 2017 dollars). Trucks represent the predominant freight carrier model now and are expected to remain so in the future. Trucks currently carry 65 percent of U.S. freight tonnage. Published FAF5 forecasts provide a range of future freight demands representing three different economic growth scenarios, through 2050, by various modes of transportation.

https://t20e.net

https://www.trucking.org/news-insights/ata-us-freight-transportation-forecast-2032

- Trucks handled an estimated 72.5% of total domestic tonnage and accounted for 80.4% of the nation's freight bill in 2020;
- The total revenue derived from primary freight shipments in the U.S. will increase from an estimated $1,083 billion in 2021 to $1,627 in 2032.

With many companies making strategic business decisions over long time periods, ATA's U.S. Freight Transportation Forecast to 2032 provides critical data for informed decision making. A long-term forecast is key to understanding where our industry, as well as all modes of freight transportation, are going.

H2

Here's how to accelerate the electric vehicle revolution | World Economic Forum (weforum.org)

What are the real challenges for EV charging infrastructure?

Challenges to the widespread adoption of EVs

- Inadequate charging infrastructure.
- Risk of grid overload.
- High-carbon grid profile.
- Finite critical minerals and rare earth metals.
- Smart and flexible charging.
- Smart energy management for effective EV load management.
- Battery monitoring, analytics and recycling.

Jan 31, 2022

weforum.org
https://www.weforum.org › agenda › 2022/01 › the-ev-r...

https://www.powermotiontech.com/technologies/article/21245890/volvo-sees-continued-growth-opportunity-in-electrification?oly_enc_id=2435H7540089D0Q

Infrastructure Remains a Challenge

One of the largest hurdles to the uptake of battery-electric and hydrogen powered vehicles is the infrastructure necessary to recharge and refuel them. While there has been growth in this area, more development is needed around the world.

Volvo is among the companies working to aid these development efforts. Volvo Group is a founding member of H2Accelerate, a group of companies collaborating to advance development of hydrogen trucks in Europe. Shell, another member of the group, has installed a hydrogen refueling station at Volvo CE's test track where it is testing the HX04.

As a fuel company, Shell understands the need to expand into other fuel options to best serve evolving market requirements. The company has been involved in many research projects involving alternative fuels such as those made from algae.

"Providing the fueling infrastructure for this innovative project gave Shell the opportunity to demonstrate our technical capabilities in hydrogen, and enabled us to support one of our key global collaboration partners in taking another step forward in their decarbonization journey, which goes to the heart and intent of Shell’s Powering Progress strategy," said Oliver Bishop, Shell’s general manager for Hydrogen Mobility, in Volvo CE's press release.

H3

WA building council votes to require heat pumps in new homes and apartments | The Seattle Times

H4

The three paths to decarbonizing trucking | FleetOwner

Consider alternative fuels: While diesel is the predominant fuel in the trucking industry today, there are other options available that might make sense in some duty cycles. Look into alternatives like compressed natural gas and liquified natural gas, hybrids, battery-electric, and hydrogen fuel cells. Some of these technologies may have a place in your operation. Research these alternatives and talk to fleets that are having success with them. Remember, no one solution is right for every fleet or even for every duty cycle. It is likely that a poly-fuel option will be the choice of many fleets over the next decade.

https://t20e.net

Fuels and Vehicle Technology | US Department of Transportation

Alternative Fuels Strategies

An alternative fuel, most generally defined, is any fuel other than the traditional selections, gasoline and diesel, used to produce energy or power. The emissions impact and energy output provided by alternative fuels varies, depending on the fuel source. Examples of alternative fuels include biodiesel, ethanol, electricity, propane, compressed natural gas, and hydrogen.

Fleet Equipment:
https://bcx.omeclk.com/portal/public/ViewCommInBrowser.jsp?Sv4%2BeOSSucwPWC6KD%2FITpAbDk5fWs%2FWy6ye0Q5CuXaPIuofgpQ23DBjR0ohC7Bh2luRcvRWLCijE3ohaSaUnhQ%3D%3DA
page 3

Sustainable fuels offer sustainable solutions

Heralded as a bridge solution that can help fleets decarbonize while electrification, hydrogen and other zero-carbon solutions grow to market-scale and decrease in cost, sustainable fuels can lower fleet emissions without requiring any modifications or upgrades to equipment or infrastructure. Although electrification is key to long-term decarbonization, the transition to net-zero transportation will take time. The development of a smarter, more modern electrical grid, adequate adoption of electric vehicles, wide-scale development of charging infrastructure, and progression to a point where the increased load from EVs is matched by decarbonized renewable grid energy will take years to accomplish. In the meantime, low-carbon alternative fuels are available to help close the gap, ensuring we make as much progress as possible in the ongoing energy transition.

Sustainable fuels, also called alternative fuels, are low- or zero-carbon fuels, often made from renewable resources like plants or waste, that offer the ability to lower emissions of vehicles without relying on only electrification. There are over a dozen alternative fuels in development, including ethanol blends, biodiesel, hydrogen, and renewable diesel. Renewable diesel, created from biomass, is nearly identical to conventional diesel, so it works in diesel fleets with no loss of performance and no infrastructure changes needed, but can offer up to 70% lower lifecycle emissions.

Recognizing the growing need for a diversity of sustainable solutions, federal and state governments have been working to simulate progress on sustainable fuel development alongside the larger push for electrification.

In April 2022, a bipartisan group of senators introduced the Renewable Diesel and Sustainable Aviation Fuel Parity Act of 2022, which would require the Energy Information Administration to report on U.S. production and foreign imports of renewable diesel and sustainable aviation fuel, while also reducing red tape that hinders sustainable fuel adoption and establishing incentives to boost renewable diesel and sustainable fuel production here at home.

https://www.fleetequipmentmag.com/zero-emissions-trucks-market/?utm_source=omeda&utm_medium=newsletter&utm_campaign=Balancing+passion+and+pragmatism+to+bring+zero-emissions+trucks+to+the+market&oly_enc_id=1883H7223956D9U

https://t20e.net

"What continues to exceed my expectations is the awareness and the drive of our customers and their customers on driving their sustainability strategy."

Exciting to be sure, but Voorhoeve is as pragmatic as he is passionate. He's quick to balance the growing electric truck segment hype with supporting (and continuing to develop) diesel trucks, which still drive the industry.

"We are continuously developing the diesel engine, and we'll be pumping money into diesel and other zero-emissions technologies for a long time," he said. "We want to offer 100% zero-emissions products in the market by 2040, but by the way: 'Zero emissions' also means that we will still have internal combustion engines. We will not go completely electric."

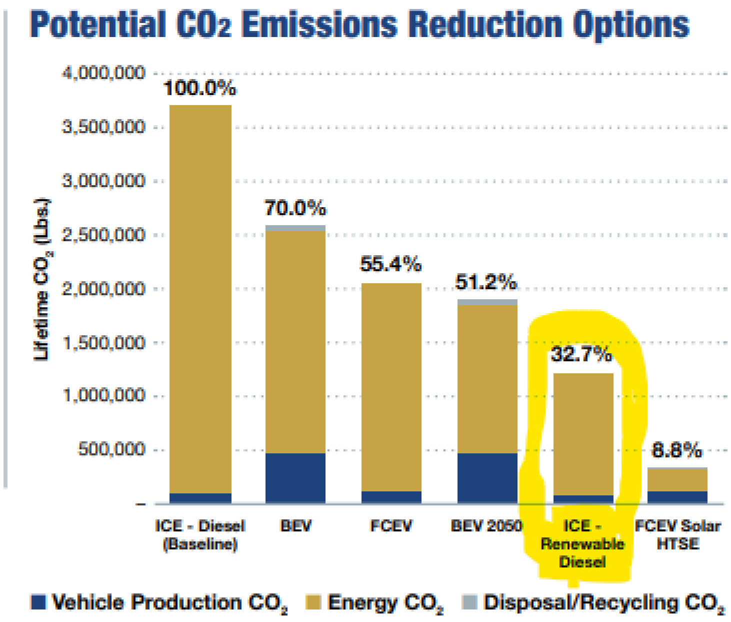
Voorhoeve detailed the three-pronged Volvo Trucks zero-emissions approach: battery electric vehicles, hydrogen fuel cell electric vehicles and internal combustion engine vehicles using renewable fuels.

"It can be biodiesel, it can be renewable diesel, it can be hydrogen if you want to use it in an ICE because we will continue to develop the internal combustion engine," he reiterated.

Volvo Trucks's equipment bet is placed on sustainability as a whole, not a single technology.

https://truckingresearch.org/wp-content/uploads/2022/05/ATRI-Environmental-Impacts-of-Zero-Emission-Trucks-Exec-Summary-5-2022.pdf

https://t20e.net

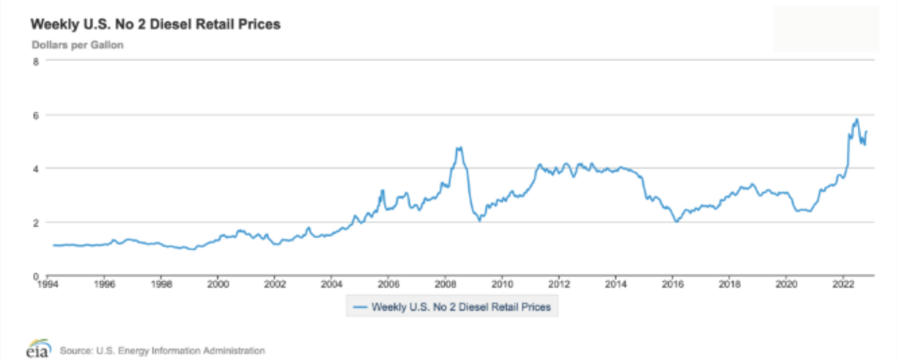


https://nacfe.org/research/affs/#fuel-economy-overview

No one knows for sure what the price of fuel will be in the future, but fleets should conduct sensitivity analyses with respect to fuel prices and expectations about the ownership life of their assets. Regardless of the cost of fuel, it is a very significant operating expense for fleets and needs to be managed.

Price of Fuel

The fuel costs faced by the trucking industry are a significant part of the expense to operate a tractor-trailer in North America. According to the 2021 American Transportation Research Institute's (ATRI) report on the Operating Costs of Trucking, fuel has been as high as $0.65 per mile driven occurring in 2013 and then dropped to $0.34 and $0.31 by 2016 and 2020, respectively.



But throughout 2021, the price per gallon for diesel skyrocketed to an all-time high of $5.81 on June 20, 2022. For a point of reference, using a cost of even $5.00 per gallon and 7 MPG driven over an annual amount of 100,000 miles, the cost to fuel one tractor-trailer for a year would be more than $70,000. A new tractor might cost $150,000, so that tractor will spend in fuel the complete cost of the tractor in its first two years of use.

https://t20e.net

https://truckingresearch.org/wp-content/uploads/2022/12/ATRI-Charging-Infrastructure-Challenges-for-the-U.S.-Electric-Vehicle-Fleet-12-2022.pdf

Charging Infrastructure Challenges for the U.S. Electric Vehicle Fleet

December 2022

Jeffrey Short
Vice President
American Transportation Research Institute
Atlanta, GA

Alexandra Shirk
Research Associate
American Transportation Research Institute
State College, PA

Alexa Pupillo
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American Transportation Research Institute
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I2

https://t20e.net

https://truckingresearch.org/wp-content/uploads/2022/12/ATRI-Charging-Infrastructure-Challenges-for-the-U.S.-Electric-Vehicle-Fleet-12-2022.pdf

Page 41

The trucking industry will require and consume an immense amount of electricity to maintain operations. Unlike passenger vehicles, trucks are tasked with moving freight across long distances. To accomplish this, a BEV truck battery will be heavier and require a much larger energy capacity than a BEV car battery.

Long-haul trucks travel larger geographies, logging many more rural miles than car travel. FHWA's VMT statistics indicate that 73.7 percent of car travel is urban, compared with 46.6 percent of long-haul truck travel. [105] Thus, nearly three-quarters of car travel occurs in charging-accessible areas. Long-haul trucking, on the other hand, has less than half of its mileage in charging-accessible areas.

This sentiment is found in the energy literature as well. In a 2022 statement, the EIA noted:

> "Highway charging … presents some specific difficulties. When transport corridors are located in areas with existing grids, the installation of chargers does not have major barriers, provided that the grid is not already congested. But to provide charging in more remote locations, grid upgrade costs can become a barrier."[106]

Consequently, the challenges associated with providing charging services to the long-haul trucking industry are considerable. It is important to understand the regulatory constraints that impact drivers, the ongoing truck parking shortage, and the anticipated charging capacity needs of long-haul trucking.

I3

https://t20e.net

https://truckingresearch.org/wp-content/uploads/2022/12/ATRI-Charging-Infrastructure-Challenges-for-the-U.S.-Electric-Vehicle-Fleet-12-2022.pdf

Page 17

CHALLENGE ONE: U.S. ELECTRICITY SUPPLY AND DEMAND

Electricity Issue One: U.S. Electrical Infrastructure is Aging while Demand is Set to Increase

Table 2: U.S. Truck Fleet Electricity Consumption Estimates*

Truck Type	Fleet Size (2019)	Miles per kWh	Total Annual Vehicle Miles Traveled (Billions)	Average Annual Miles Per Truck	Billions of kWh Required Annually	Annual kWh per Truck
Light-Medium-Duty	3,830,000	1.64	50.75	13,250	30.9	8,079
Medium-Duty	3,440,000	0.75	45.58	13,250	60.8	17,667
Heavy-Duty Trucks – Single Unit	2,144,790	0.64	28.42	13,250	44.4	20,703
Heavy-Duty Trucks – Combination	2,925,210	0.42	175.31	59,929	417.4	142,688
Total	12,340,000	-	300.05	-	**553.5**	-

The electricity that would be consumed by the U.S. trucking fleet is also significant – at 553.5 billion annual kWh it represents 14.0 percent of all electricity consumed in the U.S. in 2019 (3,954 billion kWh). Within the trucking category, long-haul combination trucks would make up the largest roadway consumer of electricity, using 417.4 billion kWh or 10.6 percent of all U.S. consumption in 2019. It should be noted that in Table 2, FHWA's VMT mileage of 59,929 includes considerable local truck tractor activity. In ATRI's 2019 *Operational Costs of Trucking* report, long-haul truck tractors reported an average of 93,955 miles per year.[32] Applying this figure to the methodology would generate a much larger estimate for electricity demand by the long-haul segment of industry – which moves the majority of freight tonnage in the U.S.

In summary, with full electrification of today's light-, medium- and heavy-duty vehicles in the U.S., an additional 1,593.8 billion kWh of electricity would be needed. This represents an increase in annual U.S. electricity consumption of **40.3 percent** to power all vehicles listed in Tables 1 and 2.

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Electricity Infrastructure Issues in the U.S.

Based on the above background information and analysis, the research team has identified the following key issues related to the electricity generation needed to meet the demands of electric vehicles.

Electricity Issue Two: Electrical Outages Could Halt Surface Transportation

The convergence of an aging electrical grid, severe weather, and the limitations of renewable energy sources (e.g. energy production that depends on weather conditions with wind or sun) have resulted in the increased length and frequency of power outages. According to the EIA, the average annual time U.S. customers spent without electricity in 2020 was approximately 8 hours on average, a rise of 4.5 hours since 2013.[40] In 2020 there were 180 major disruptions to the power grid compared to approximately two dozen in 2000.[41]

Page 20 &21

One example of cascading failures resulting in widespread blackouts in the U.S. was the 2003 Northeast Blackout that left over 50 million consumers without power for hours. The origin of the blackout was a downed transmission line and a software bug that left operators unaware that they needed to redistribute the electrical load.[44] Within two hours of the first transmission line failure, an area of 3,700 miles was without power, including New York City where the power was out for 29 hours at a cost of $1 billion. The total cost across all geographies was found to be roughly $6 billion.[45]

The failure of the power grid during the 2021 Texas Power Crisis was caused in part because of electric heating to combat unusually cold temperatures. The resulting high demand combined with downed power lines strained the power grid and eventually left 4.5 million customers in Texas temporarily without power.[47]

California has had to initiate multiple rolling blackouts over the years in response to more frequent heat waves, both to keep the grid from collapsing and to reduce the risk of power cables igniting dried out vegetation and setting off wildfires.[48] The prolonged drought is also a concern; California's electricity generation is made up of 19 percent hydropower.[49] As droughts in the west persist, reservoirs dry up resulting in the shutdown of hydropower plants.

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Electricity Issue Three: Variable Electricity Rates Could Negatively Impact Trucking

The time of day that trucking companies will charge depends on numerous factors, including:

- Vehicle/Battery Range – can a driver operate throughout a workday and charge when off-duty?
- Electricity Price Variation – at what time will electricity be least costly?
- Shipper-Based Delivery Times – shippers dictate delivery times, and charging will have to be scheduled around those shipper scheduling requirements. Using variable pricing to balance electricity consumption will influence industry adoption of BEV trucks. That said, depending on the condition of the grid, such policies could be needed to ensure that peak demand does not result in a supply/demand imbalance.

I4

https://truckingresearch.org/wp-content/uploads/2022/12/ATRI-Charging-Infrastructure-Challenges-for-the-U.S.-Electric-Vehicle-Fleet-12-2022.pdf

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Table 8: Raw Material Weight for U.S. Long-Haul Truck Fleet*

	Cobalt	Graphite	Lithium	Nickel
Truck, Combination: U.S. Fleet Requirements (Tons)	667,403	3,658,929	475,162	2,325,936

Finally, since these raw materials will be demanded by all vehicle types in the U.S., single unit trucks and light-duty vehicles were added to the table using the GREET model assumption approach previously described (above Table 7).[93] The results, by vehicle type, are shown in Table 9.

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Table 11: Tons of Material Needed to Replace the U.S. Truck Fleet*

	Cobalt	Graphite	Lithium	Nickel
Annual Global Production (Tons)	187,393	1,102,310	110,231	2,976,237
U.S. Trucking Needs (Combo and SU) (Tons)	1,145,506	6,280,053	815,551	3,992,152
Total Trucking Demand/Years of Global Production	6.1	5.7	7.4	1.3

There are several caveats to this analysis, however. First, the fleet would not be immediately replaced, so this demand would not arise at a single moment in time. On the other hand, all of this demand for materials is new and is in addition to what is currently produced. Finally, this new production level would only supply a single round of batteries. Replacement batteries would be needed approximately every 6.2 years, assuming a useable life of 500,000 miles.[95] This analysis does not include battery material demand for other countries, so those figures are not included in this analysis.

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The last calculation focuses on U.S. fleet raw material needs as compared to available reserves (Table 13).[96] The cobalt that would be needed by the U.S. vehicle fleet is **64.4 percent of global reserves**.

Table 13: Tons of Material Needed versus Global Reserves

	Cobalt	Graphite	Lithium	Nickel
Global Reserves (Tons)	8,377,556	352,739,200	24,250,820	> 100,000,000
Total U.S. Vehicle Fleet Needs	5,396,733	29,586,708	3,842,239	18,807,908
Fleet Needs as a Percent of Known Reserves	64.4%	8.4%	15.8%	< 18.8%

This analysis does not presume that material supplies will quickly become exhausted, as known reserves and requisite mining activities are certain to increase. But the overall quantities of materials needed, and the availability of those materials, will all play a role in pricing and availability – both of which will heavily influence adoption levels for BEV cars and trucks.

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CHALLENGE TWO: ELECTRIC VEHICLE PRODUCTION

For trucks, this battery (and the raw materials that comprise it) will likely be the largest cost center within the vehicle – ACT Research estimates that the battery pack for a Class 8 BEV truck accounts for roughly 55 percent of the cost of the truck.[68] Regardless of fleet size these truck cost increases will be noticeable. For example, a typical new Class 8 diesel truck tractor may cost roughly $135,000 to $150,000; a comparable Class 8 BEV truck may price at $400,000 to $500,000.[69] Operating margins for truckload carriers were approximately 10 percent of revenue in 2021; the extreme increase in marginal operating costs that would result

from a potential 3+ fold increase in equipment costs would most certainly erase these margins unless the costs can be passed on to consumers.[70]

Raw Materials for BEV Trucks

There is a large body of work on the environmental and social impacts of mining minerals for vehicle batteries and other clean energy uses. A succinct summary of the environmental and social issues related to mining the BEV materials is offered by the International Energy Agency (IEA) below.

- “Significant greenhouse gas (GHG) emissions arising from energy-intensive mining and processing activities.”
- “Environmental impacts, including biodiversity loss and social disruption due to land use change, water depletion and pollution, waste-related contamination and air pollution.”
- “Social impacts stemming from corruption and misuse of government resources, fatalities and injuries to workers and members of the public, human rights abuses including child labor and unequal impacts on women and girls.”
- “[Related] supply disruption, which could slow the pace of clean energy transitions.”[73]

Page 36 & 36

Battery Weight and Cargo Capacity

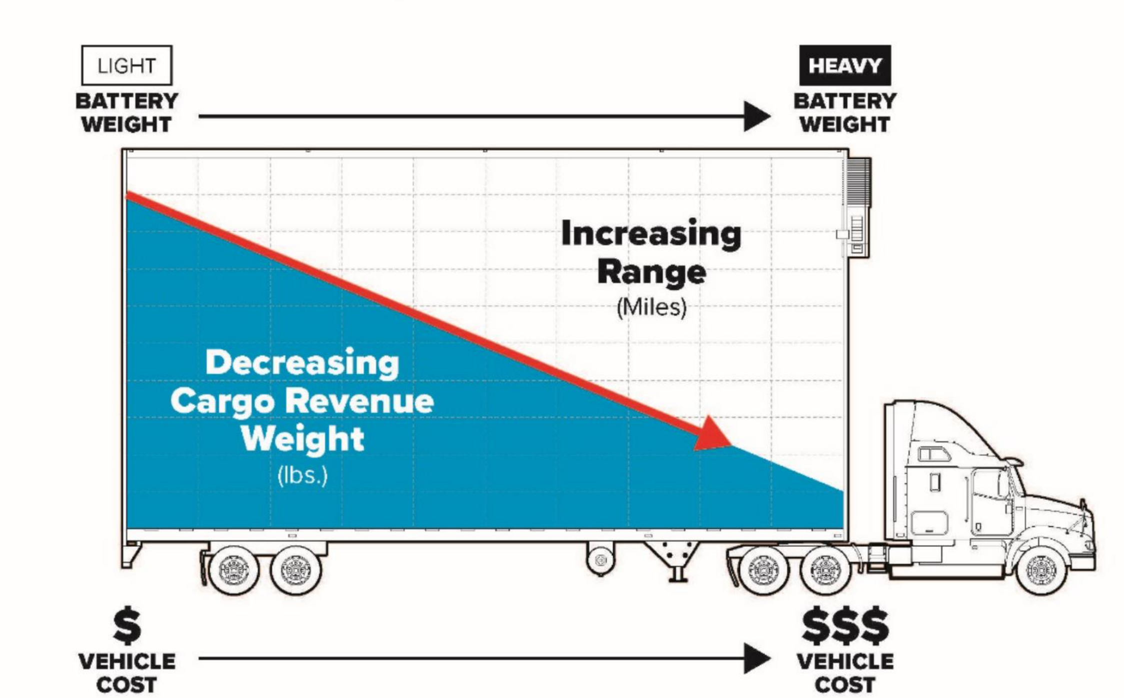
Battery weight may substantially limit the long-haul capabilities of a BEV. As discussed earlier in the baseline analysis, based on the GREET model, the long-haul ICE truck tractor weight is 18,216 lbs., while the BEV’s weight (including the battery) is 32,016 lbs.[94] The details are shown in Table 10.

Table 10: Vehicle, Trailer and Cargo Weight

Weight (lbs.)	ICE	BEV
Maximum Gross Weight	80,000	80,000
Tractor Weight	18,216	32,016
Trailer Weight	11,264	11,264
Vehicle Tare Weight	29,480	43,280
Available Revenue Weight	50,520	36,720
Lost Revenue Weight from Baseline	-	**-13,800**

This "BEV truck conundrum" is further illustrated in Figure 9. Heavier batteries are able to store more energy, thus increasing a truck's driving range. Heavier batteries cost more since they use more raw materials. While this extra cost and weight can help decrease the number of charging stops, it also decreases the amount of cargo weight that can be carried, resulting in lost revenue.

Figure 9: BEV Truck Conundrum



Vehicle Production Issue One: Demand for Raw Materials will Likely Increase Battery Prices and Shortages

https://t20e.net

I5

https://truckingresearch.org/wp-content/uploads/2022/12/ATRI-Charging-Infrastructure-Challenges-for-the-U.S.-Electric-Vehicle-Fleet-12-2022.pdf

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Table 22: U.S. BEV Combination Truck Fleet National Charging Network Cost for Equipment and Installation*

Daily Charging Events Per Charger	Chargers Needed	Charger Cost (billions)
1	1,602,855	$179.5
2	801,427	$89.8
3	534,285	$59.8
4	400,714	$44.9
5	320,571	$35.9
6	267,142	$29.9
7	228,979	$25.6

Based on the estimated charging needs discussed earlier, Table 22 shows that if, for instance, the average charger could deliver five 3.4 hour charges per day, 320,571 chargers would be needed for the U.S. combination truck fleet at a cost of at least $35.9 billion. It should be noted that for charging at private truck stops and public rest areas, there is a limitation with the number of chargers (and the cost) due to the scarcity of truck parking spaces. In all likelihood, the number of charging spaces required far exceeds available parking spaces, and thus the additional chargers would be needed at shipper or carrier facilities or in the form of new public parking capacity. Additionally, these figures do not include the cost of utility connectivity work that would be necessary. It also does not conclude who is responsible for development and management of the charging spaces, an issue that is presently contentious.[137]

Table 20: U.S. BEV Combination Truck Fleet Charger Utilization Matrix

Daily Charging Events Per Charger	Chargers Needed	Time Charging Per Day (Hours)
1	1,602,855	3.4
2	801,427	6.9
3	534,285	10.3
4	400,714	13.7
5	320,571	17.1
6	267,142	20.6
7	228,979	24.0

Truck parking and truck charging will see very similar peaks in demand. As is the case with truck parking, there are times when there are many empty parking spaces, and there will be times when most of the chargers at a given location will not be in use. It should be noted that to reach higher charging events, trucking will have to lose efficiency. Simply put, for a truck charger to be operating all the time, there must be a line of trucks waiting for hours to charge; ultimately this will not be acceptable to the trucking industry. Thus, more chargers will be needed, and those chargers will tend to not be used at their full capacity.

It should be noted that the higher numbers in the "chargers needed" column of Table 20 are not unreasonable. The California Energy Commission identified a need for 157,000 DCFC to support 180,000 medium- and heavy-duty BEV trucks.[130] This is nearly a 1 to 1 ratio of chargers to trucks.

Depending on hardware type and related infrastructure, DCFC systems can deliver between 50 to 350 kW or more.[125] For this type of fast charging however, it is recommended to limit stored battery charges to an 80 percent state-of-charge in order to minimize charging times and prolong battery life.[126] Thus, a battery that is meant to hold 1,000 kWh should only be charged to 800 kWh.

I6

https://truckingresearch.org/wp-content/uploads/2022/12/ATRI-Charging-Infrastructure-Challenges-for-the-U.S.-Electric-Vehicle-Fleet-12-2022.pdf

CHALLENGE THREE: TRUCK CHARGING REQUIREMENTS

The trucking industry will require and consume an immense amount of electricity to maintain operations. Unlike passenger vehicles, trucks are tasked with moving freight across long distances. To accomplish this, a BEV truck battery will be heavier and require a much larger energy capacity than a BEV car battery.

Long-haul trucks travel larger geographies, logging many more rural miles than car travel. FHWA's VMT statistics indicate that 73.7 percent of car travel is urban, compared with 46.6 percent of long-haul truck travel. 105 Thus, nearly three-quarters of car travel occurs in charging-accessible areas. Long-haul trucking, on the other hand, has less than half of its mileage in charging-accessible areas.

This sentiment is found in the energy literature as well. In a 2022 statement, the EIA noted:

> "Highway charging … presents some specific difficulties. When transport corridors are located in areas with existing grids, the installation of chargers does not have major barriers, provided that the grid is not already congested. But to provide charging in more remote locations, grid upgrade costs can become a barrier."[106]

Consequently, the challenges associated with providing charging services to the long- haul trucking industry are considerable. It is important to understand the regulatory constraints that impact drivers, the ongoing truck parking shortage, and the anticipated charging capacity needs of long-haul trucking.

Truck Charging: Synchronizing Drivers, Parking Availability and Federal Work Regulations

Truck driving schedules are complex; they are built around federal Hours-of-Service (HOS) regulations, shipper contract requirements, access to fueling, congestion avoidance, and access to truck parking locations near customer facilities – all factors that impact or dictate where truck charging should or should not be located.

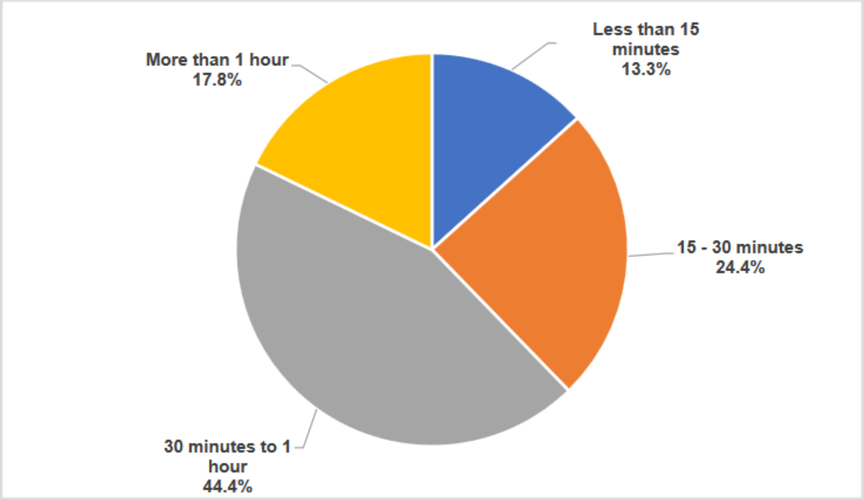
Truck Parking

Additionally, this charging will have to take place at existing truck parking locations along interstate trucking routes; it would be cost prohibitive to build an entirely new parking and charging network in the U.S. There are approximately 313,000 truck parking spaces in the country, as inventoried by FHWA in 2019.109 This includes 40,000 truck parking spaces at public rest areas and 273,000 truck parking spaces at private truck stops.

Truck parking is a significant problem for the trucking industry, identified by drivers as their top industry concern.[110] One ATRI truck parking study found that an average of 56 minutes of drive time per day was lost due to drivers parking early to avoid the risk of not being able to find a place to park later in their duty-cycle; this loss of productivity was equal to nearly $5,000 per driver in lost wages annually.[111]

Drivers report spending significant non-revenue time looking for available parking. Figure 10 shows the amount of time truck drivers spend every day looking for a parking space and underscores that an optimal truck charging network should reduce, rather than exacerbate, truck parking issues.[112]

Figure 10: Time Spent per Day to find Parking



Thus, for electrification of long-haul trucks to be feasible, charging must be available at truck parking spaces while drivers are taking mandatory rest periods.

Truck parking and truck charging will see very similar peaks in demand. As is the case with truck parking, there are times when there are many empty parking spaces, and there will be times when most of the chargers at a given location will not be in use. It should be noted that to reach higher charging events, trucking will have to lose efficiency. Simply put, for a truck charger to be operating all the time, there must be a line of trucks waiting for hours to charge; ultimately this will not be acceptable to the trucking industry. Thus, more chargers will be needed, and those chargers will tend to not be used at their full capacity.

Truck parking and truck charging are entirely interconnected. If there are not enough parking spaces, there will not be enough charging spaces. Hence, if there is not a charger at each parking space the issue will be exacerbated.

For perspective, the Department of Energy estimates that the average household in the U.S. consumes 11,000 kWh of electricity annually, or 30.13 kWh per day.134 The needs of just a small rest area are tremendous when compared to the average household. The Pecos West County Rest Area (outlined in the case study with 67 striped parking spaces) had on average 369 unique truck visits per day. Of this population, 34.2 percent (126 trucks) stayed at the location for 5 hours or longer. If each vehicle in this 5+ hour subset were to consume 1,200 kWh of electricity during a stop, the daily total electricity consumption would be 151,200 kWh, or 55.18 million kWh per year. This is equal to the daily electricity needs of **5,017 average U.S. households**.

I7

https://www.cleanfreightcoalition.org/4-questions-policymakers-need-answer-bevs

What will this mean for the supply chain?

Electric trucks are also significantly more expensive; a typical new Class 8 diesel tractor costs around $135,000 compared to a Class 8 BEV, which prices around $400,000 on the low end. Considering 96 percent of U.S. trucking companies are small businesses that own 10 trucks or fewer, these prohibitive cost increases will decimate countless trucking fleets across the country.

Trucking now moves 72.5% of our nation’s freight tonnage. Over the next decade, trucks will be tasked with moving 2.4 billion more tons of freight than they do today. The moment that slows or stops, Americans will want answers.

J1

https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10178RN.pdf

2.9.2 Calculation of the Proposed CO_2 Standards

The heavy-duty vehicle CO_2 emission standards are in grams per ton-mile, which represents the grams of CO_2 emitted to move one ton of payload a distance of one mile. The proposed Phase 3 vehicle standards fall into two major categories: tractors and vocational vehicles and are then further subdivided into regulatory subcategories standards. The following sections describe how the proposed Phase 3 vehicle standards within each regulatory subcategory are calculated.

Table 1-7: Existing Phase 2 CO_2 Standards for Model Year (MY) 2027 and Later Class 7 and Class 8 Tractors (g/ton-mile)[58]

Subcategory	Phase 2 MY 2027+
Class 7 Low-Roof (all cab styles)	96.2
Class 7 Mid-Roof (all cab styles)	103.4
Class 7 High-Roof (all cab styles)	100.0
Class 8 Low-Roof Day Cab	73.4
Class 8 Low-Roof Sleeper Cab	64.1
Class 8 Mid-Roof Day Cab	78.0
Class 8 Mid-Roof Sleeper Cab	69.6
Class 8 High-Roof Day Cab	75.7
Class 8 High-Roof Sleeper Cab	64.3
Heavy-Haul Tractors	48.3

(SIMILAR CONCEPT)

https://www.internationaltrucks.com/en/blog/2023/supertruck-ii

Freight-ton efficiency (FTE) is measured in ton-miles per gallon and is one of the most effective ways to measure the amount of energy required to transport goods. In short, the most freight-ton efficient trucks make the most of fuel mileage.

Thanks to structural composites that are made with lightweight materials, which allowed designers to be more aggressive with the design, International SuperTruck II is lighter and can handle more cargo. This also means the fuel it takes to transport each pound of cargo is much less — especially when combined with the improved fuel efficiency of the truck. The 170% improvement in FTE means a much more efficient drive for your fleets.

J2

https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P10178RN.pdf

Chapter 4 Emission Inventories

4.1 Introduction

This chapter presents our analysis of the national emissions impacts of the proposal and alternative (collectively referred to as control cases) for calendar years 2027 through 2055 from both downstream and some upstream sources. Downstream emissions are those emitted directly by a vehicle, including tailpipe and crankcase exhaust (from running, starts, or extended idle), evaporative emissions, refueling emissions, and particulate emissions from brake wear and tire wear. Upstream emissions are not emitted by the vehicle itself but can still be attributed to its operation. Examples include emissions from electricity generation for charging battery electric vehicles, the creation of hydrogen fuel for fuel cell electric vehicles, the extracting and refining of crude, and the transporting of crude or refined fuels for internal combustion vehicles.

J3

ATRI SUMMARY OF FINDINGS:

FINDINGS

In this report the research team dissected and analyzed the entire U.S. vehicle electrification ecosystem to identify the key issues that must be addressed if BEV adoption in the U.S. were to proceed on a large scale. Ultimately, three overarching challenges emerged, relating to electricity generation and consumption; vehicle charging requirements and the charging infrastructure; and raw materials sourcing. Key findings in each of these are described below.

Challenge	Findings

U.S. Electricity Supply and Demand	**Electricity Needs are Enormous**
	• Full electrification of the U.S. vehicle fleet will result in a large increase beyond the country's present electricity generation including:
	  ▪ 14 percent for all freight trucks
	    ○ Within this, 10.6 percent for long-haul trucks
	  ▪ 26.3 percent for light-duty vehicles (passenger cars and trucks)
	  ▪ 40.3 percent for all vehicles
	• Individual states will require from 28 to nearly 63 percent of today's energy generation to meet vehicle travel needs.
	• Large-scale infrastructure investment is a necessary precursor to electrification.

Electric Vehicle Production	**Battery Materials Dominate BEV Viability**
	• Tens of millions of tons of cobalt, graphite, lithium and nickel will be needed to replace the existing U.S. vehicle fleet, placing high demand on raw materials.
	  ▪ Depending on the material, this represents:
	    ○ 6.3 to 34.9 years of current global production
	    ○ 8.4 to 64.4 percent of global reserves
	• BEV production has considerable environmental and social impacts.
	  ▪ Mining and processing produce considerable CO_2 and pollution issues.
	  ▪ Exploitation of labor is common in some source countries.
	• BEV Truck Conundrum – battery weight increases price and range, and decreases available cargo weight.
	• Major advances in battery technology are key to solving the vehicle problem.

Truck Charging Requirements	**Truck Charging Availability will be the Truck Parking Crisis 2.0** • Using today's truck and charging requirements, more chargers will be needed than there are parking spaces. • Regardless of advances in battery capacity or charge rates, BEV charging will be limited by HOS and parking availability. • Initial equipment and installation costs at the nation's truck parking locations will top $35 billion. • Other barriers include laws preventing commercial charging at public rest areas and the remoteness of many truck parking locations. • There is research underway for myriad strategies to resolve the potential for charging issues. • To understand the truck parking challenges, ATRI quantified the truck charging needs at a single rural rest area, which would require enough daily electricity to power more than 5,000 U.S. households.

