BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

IN THE MATTER OF:	)	
	)	R2024-017
PROPOSED CLEAN CAR AND TRUCK STANDARDS	)	(Rulemaking – Air)

NOTICE OF FILING

TO:

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Please take notice that I have today filed with the Illinois Pollution Control Board the following documents: Rule Proponents' Second Hearing Exhibits and Certificate of Service, a copy of which is served upon you.

Date: March 10, 2025

Respectfully submitted,

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Exhibit 8

WORLD RESOURCES INSTITUTE

These Countries Are Adopting Electric Vehicles the Fastest

September 14, 2023 By **Joel Jaeger** Cover Image by: anouchka/iStock

Finding

Topic **Electric Mobility**

Electric vehicle sales have been growing exponentially due to falling costs, improving technology and government support. Globally, 10% of passenger vehicles sold in 2022 were all-electric, according to analysis of data from the International Energy Agency. That's 10 times more than it was just five years earlier.

Electric Vehicles (EVs) produce fewer greenhouse gas emissions than internal combustion engine vehicles, such as gasoline- and diesel-powered vehicles. Once the electric grid shifts to zero-carbon power, emissions will be even lower. For this reason, ramping up EVs will be one of the most important steps in reducing transportation emissions — alongside reducing private vehicle travel and shifting to public transit, biking or walking.

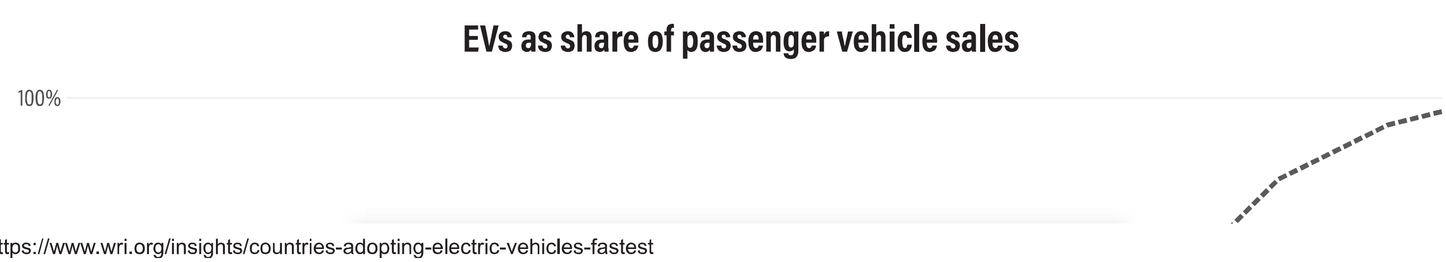
There are already a number of countries switching to EVs at impressive rates. The top 5 countries with the highest share of EV sales are Norway (all-electric vehicles made up 80% of passenger vehicle sales in 2022), Iceland (41%), Sweden (32%), the Netherlands (24%) and China (22%), according to our analysis. China's place on this list is especially significant considering it is the biggest car market in the world. The other two biggest car markets have lower EV sales but are growing quickly: the European Union (12%) and the United States (6%).

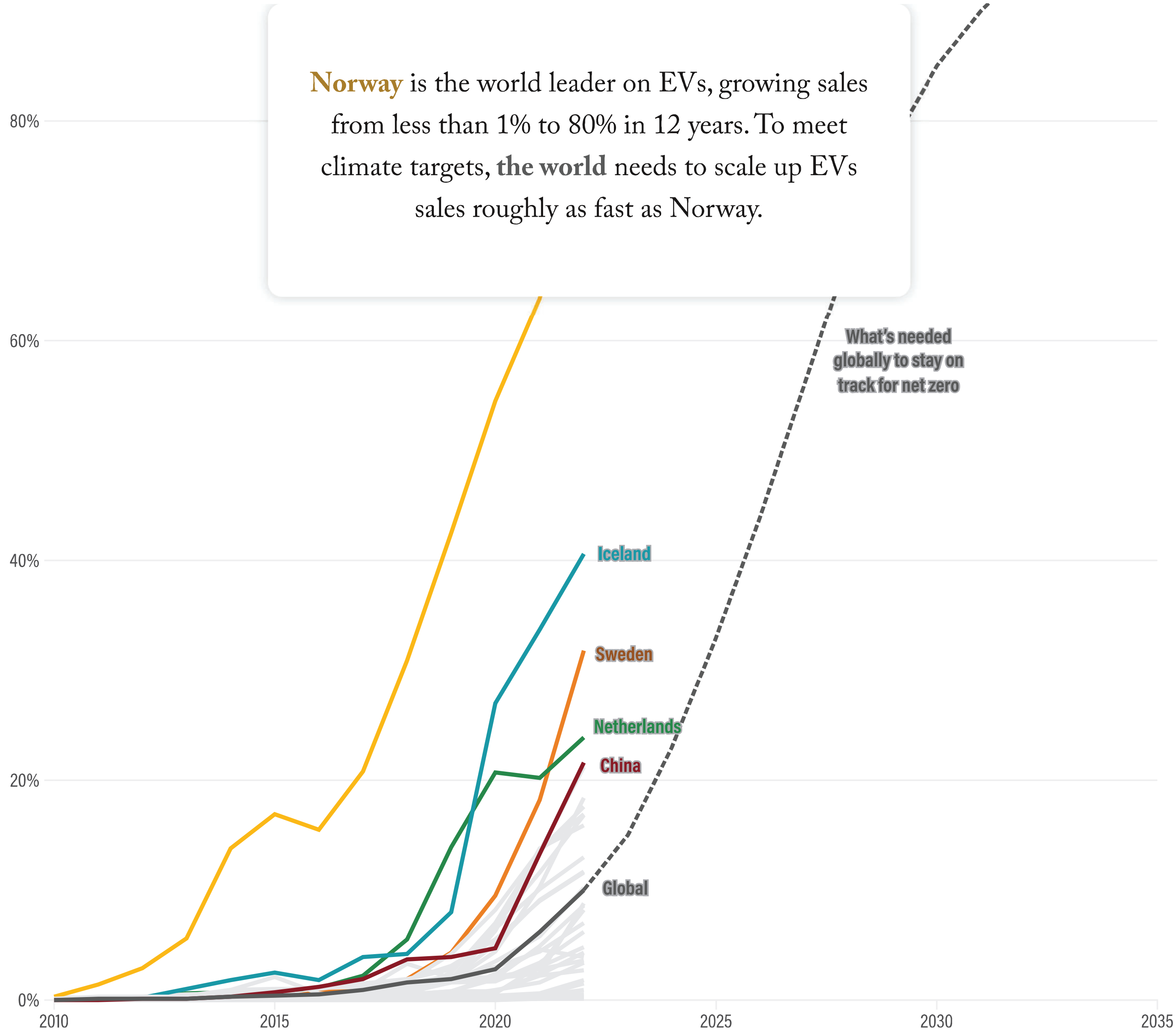
People enter a BYD store in Shanghai, China. The Chinese brand is one of the biggest electric vehicle producers in the world. Photo by Robert Way/iStock.

Globally, EVs need to grow to 75% to 95% of passenger vehicle sales by 2030 to be consistent with international climate goals that limit global warming to 1.5 degrees C (2.7 degrees F) and prevent many harmful impacts from climate change, according to a high-ambition scenario from Climate Action Tracker. This target is within reach given recent exponential growth in EV sales. The average annual growth rate was 65% over the past five years; over the next eight years the world needs an average annual growth rate of only 31%.

National EV Sales Follow a Pattern of Exponential Growth

While EV sales have started accelerating at different years for different countries, they are all following a similar S-curve pattern of growth. This is a typical trajectory for the adoption of innovative technologies. Once a technology reaches a tipping point — for example, when EVs become cheaper than traditional gas- or diesel-powered vehicles — the trajectory curves upward. Eventually, growth diminishes as the technology approaches 100% saturation. When it comes to EVs, no countries have reached this slowing-down phase yet, though Norway may be close. The initial acceleration and eventual slowdown create an S-curve. It will never be a perfect S-shape because policy changes and social and economic factors can speed up or slow down rates of adoption, but the overall pattern holds in most cases.


EVs as share of passenger vehicle sales
100%



Source: Author, based on historical data from IEA. Global target from Climate Action Tracker.
Notes: EVs include all-electric vehicles, not plug-in hybrid electric vehicles.

SYSTEMS CHANGE LAB

Other countries have also begun rapid growth in recent years:

Iceland, **Sweden**, the **Netherlands** and **China** are the leading EV adopters after Norway.

In every country, **once EV sales reached 1%, they accelerated**. This acceleration happened faster in some places than others, but all are following an **S-curve pattern**.

The countries where EV sales have **reached 1% in the past five years** have been growing **faster** than the global average.

Falling costs and advancing technology have made it possible for EV sales to accelerate faster today than in the past. Our analysis of the International Energy Agency's EV Data Explorer shows that countries where EV sales reached 1% in the past five years have grown at a faster rate than countries that did so earlier.

For example, India's EV sales grew from 0.4% to 1.5% in just one year from 2021 to 2022. That's about three times faster than the global average, which took three years to grow from 0.4% EV sales in 2015 to 1.6% in 2018. Israel jumped from 0.6% EV sales to 8.2% in just two years, from 2020 to 2022. It took the world more than five years to achieve that much growth, from 0.5% in 2016 to 6.2% in 2021.

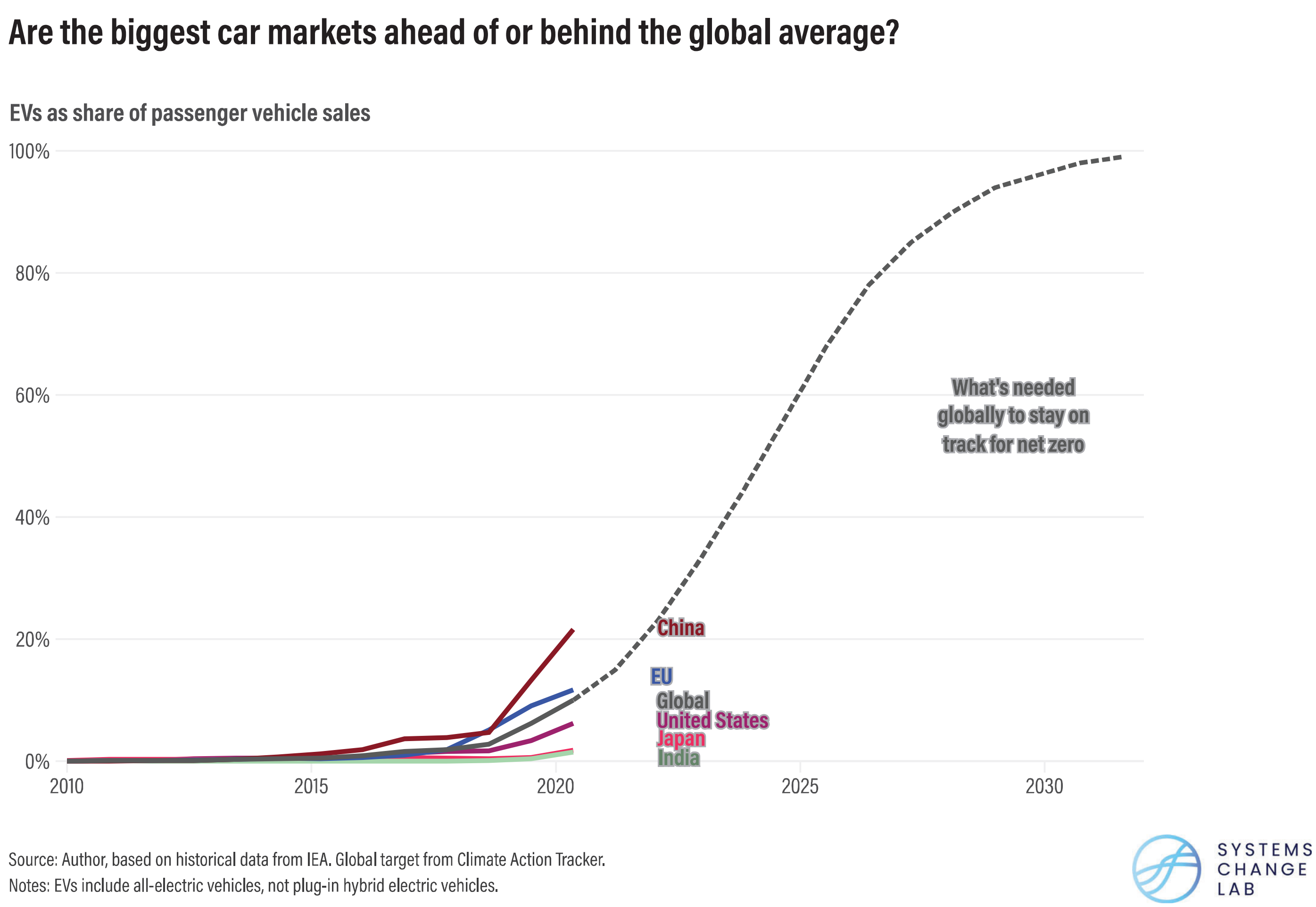
So far most of the EV leaders have been high-income countries, like in Scandinavia, or countries with a lot of market power, like China. Strong government policy and financial incentives from these countries paved the way for a dynamic EV industry to rise and helped costs to fall. Now as the economics of EVs become more favorable, other countries at lower income levels or in different national situations may be able to follow in the same footsteps or go even faster.

Parking spots reserved for EVs in Herzilya, Israel. In just two years, the country saw a significant increase in EV sales. Photo by Vered Barequet/Shutterstock.

How the Largest Car Markets Can Drive Industry Change

Helping the world transition to electric vehicles largely relies on the performance of the three biggest car markets — China, Europe and the United States — which are collectively responsible for 60% of all global car sales. All three markets have seen big upticks in EV sales in the past few years. China's EV sales share is currently double the global average. Europe's EV sales share is slightly above the global average. The United States' EV sales share is about one year behind the global average (in 2022 the U.S. was at 6.2% EV sales, which is exactly what the world was at in 2021). Sales in the U.S. are poised to grow quickly after the Inflation Reduction Act spurred $62 billion in EV investments during its first year.

Sales are still low in India and Japan, the fourth- and fifth-biggest car markets respectively. However, they are finally beginning to accelerate, and as recent sales data has shown, late-adopting countries often grow faster than the early adopters.



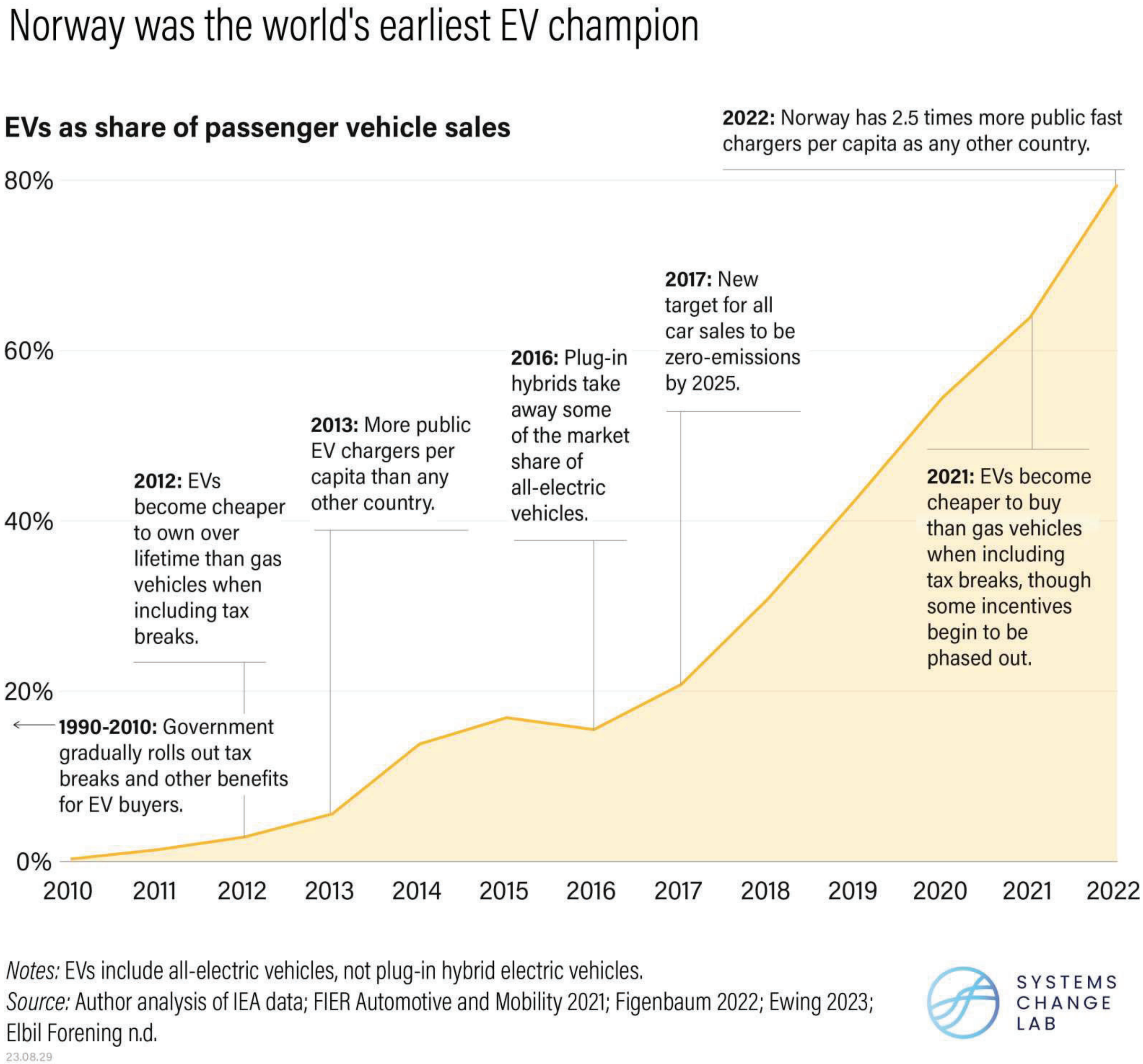
2 Countries Achieving Electric Vehicle Success

Let's dive deeper into Norway and China, two of the countries that have been most successful in scaling up EVs, to learn from their experiences.

1) Norway Is the Only Country Where the Majority of Car Sales are All-Electric

Norway is one of the coldest regions in the world and is crisscrossed by fjords that make some areas difficult to access. Given concerns that EV batteries don't run effectively in low temperatures and don't have as long a range as gasoline vehicles, one would expect that Norway would be one of the last regions to adopt EVs. To the contrary, Norway and its Scandinavian neighbors such as Iceland and Sweden are far and away the leaders in EV adoption. Eight out of 10 passenger car sales in Norway were all-electric vehicles in 2022, with 150,000 sold in total.

Norway is so far ahead of the pack because the government has deliberately and consistently promoted EVs, starting those efforts in 1990, long before the rest of the world. It has a target to phase out internal combustion engine vehicle sales by 2025, the earliest of any country.



There are three reasons why Norway's efforts to make EVs the default option for new car buyers have been successful:

First, government incentives have made EVs the best financial choice for consumers. Norwegians who buy all-electric vehicles do not have to pay high value-added taxes or registration taxes and receive other financial benefits as well. This eliminates a substantial portion of the cost of buying and owning an EV. These incentives were gradually rolled out in the 1990s and early 2000s, with support from multiple governments and all political parties. The government was originally trying to support a Norwegian EV brand called TH!NK. The company wasn't successful and most Norwegian cars are imported from abroad, but the government continued to promote EVs due to the environmental benefits.

Even with generous incentives, EVs didn't take off until the technology had advanced. The real turning point was around 2012, when the total cost of owning an EV over its lifetime (including the costs of purchasing, maintaining and charging the vehicle) became cheaper than the total cost of owning a traditional gas- or diesel-powered vehicle, when including all the tax breaks. By 2021, EVs were also on average 5,000 euros cheaper to purchase when including all the tax breaks.

Second, the government has invested heavily in EV chargers and as a result Norway has the most public fast chargers per capita of any country in the world. These can get an EV battery from zero to 80% in as little as 20 minutes. In addition, Norway has established a right to charge for people living in apartment buildings and provides grants for housing associations to install their own chargers.

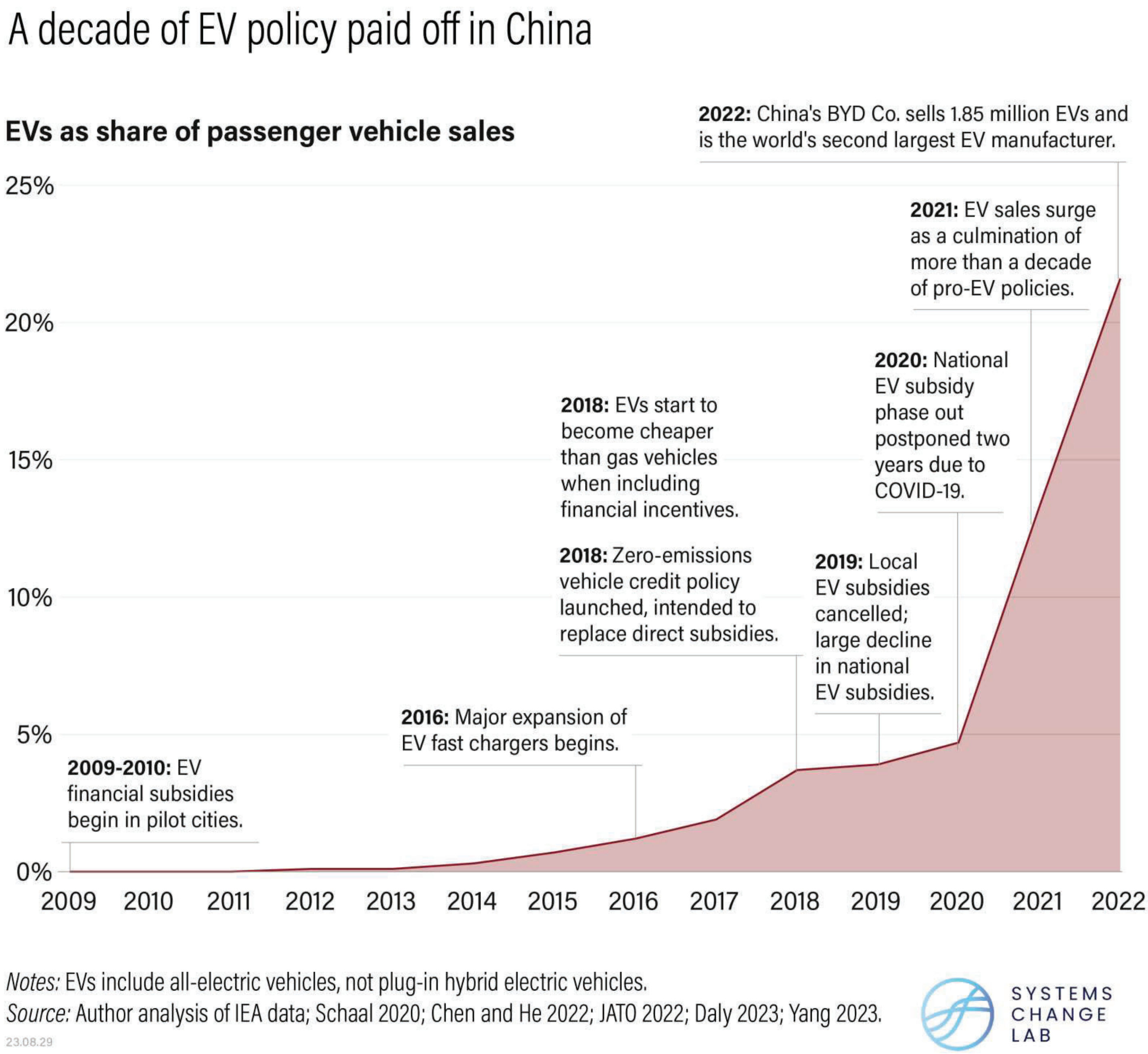
Third, Norway has also provided EV owners with some attractive perks, such as free parking in cities, exemptions or reductions in road tolls, access to priority bus lanes and reduced rates for EVs to be transported by ferry (ferries are frequently used given Norway's fjord-covered landscape).

Given the success of its EV policies, the government has started gradually rolling back EV incentives for luxury cars and some of the other perks for all EVs. Now that everyone in Norway is buying EVs, it no longer makes sense to allow all cars to have bus lane access and free parking. Plus, some of these policies may encourage people to choose car travel over public transit, which would increase emissions, so Norway is now more consciously considering how to promote other transport options besides private cars.

2) China Sold More EVs Last Year Than the Rest of the World Combined

China is by far the biggest player when it comes to EVs. In 2022, 22% of passenger vehicles sold in China were all-electric, which adds up to 4.4 million sales. That's higher than the 3 million EVs sold in the rest of the world combined. China's support for EVs has helped drive down battery costs and make EV adoption easier all over the world.

China, which was far behind other countries in the production of internal combustion engine vehicles, saw EVs as a strategic investment in a new area of automobile manufacturing where it could develop an edge if it started early enough. It was also interested in the role EVs could play in reducing air pollution and dependence on imported oil.



In 2009 and 2010, China first rolled out financial subsidies and tax breaks for both EV producers and consumers, starting with pilot cities around the country. Cities could customize the amount and type of EV subsidies to fit their needs and worked with local EV companies to help them grow. For example, Chinese EV company BYD started out with close ties to the city of Shenzhen and has since grown to be one of the biggest EV producers in the world. After the pilot cities programs, China continued to spend billions of dollars on various national and local subsidies and tax breaks. In 2018, China began a transition to a market-based zero-emissions vehicle credit system, adapted from California's zero-emissions vehicle mandate, to replace direct subsidies. The transition has been gradual, and some of the EV subsidies and tax breaks have been extended past their planned expiration date.

Overall, the industrial promotion policies have been effective. Today, eight out of the top 10 EV models sold in China are made by Chinese companies, and China has begun to export EVs globally. Chinese consumers can choose from nearly 300 EV models, more than anywhere else. Chinese companies have also done more than any other country to develop affordable EV models. In many other countries the focus has been on larger vehicles which require more expensive batteries, but in China, smaller vehicles are the norm. BYD recently launched an $11,000 EV hatchback, and the $4,500 Wuling Hongguang Mini EV has been one of the top sellers.

The retail price of many electric cars in China has fallen below that of comparable gas or diesel-powered vehicles, when including subsidies. And Tesla's entry into the Chinese market has spurred a price war that is pushing down EV costs further.

Another major factor that has encouraged uptake is that China has installed 760,000 public fast charging points and 1 million public slow charging points, which is more than the rest of the world combined. And like Norway, China has extended non-monetary benefits to EV drivers, mostly at the city level. For example, in the city of Beijing, car license plates are rationed and have a long wait time, but the process is essentially waived for EV buyers.

A large Tesla sign hangs above a showroom in Hong Kong. Tesla's entrance into China's electric car market has spurred a price war helping to drive down the costs of EVs. Photo by robertcicchetti/iStock.

Government Leadership Is Key for Faster EV Uptake

The experiences from Norway and China can provide lessons for other countries. Both countries had governments that made a deliberate choice to promote EVs, invested in public chargers and implemented policies to make EVs cost competitive. EV adoption grew rapidly once EVs were a better financial decision for prospective car buyers than traditional gas- or diesel-powered vehicles, especially when buyers were confident in the range of the vehicles and their ability to easily access public chargers.

Thanks to the policy pushes in countries like Norway and China, it won't take long for cost competitiveness to arrive for more countries, given the falling EV prices, but those governments should not sit back and wait for this to happen given the urgency of the climate crisis. Not every country is as wealthy as Norway or has the market power and government structure of China, but electric vehicles can be an economic and environmental win for a wide variety of developing countries.

So far, cost competitiveness has mostly been achieved through subsidies, but these can be quite expensive for government budgets and there are other options too. Policies mandating 100% EV sales are the single most effective policy to drive the transition. Currently, 16 countries, including Canada, Japan and the United Kingdom, have some form of policy mandating 100% EV sales in 2035 or earlier. More countries should create and enforce such policies. If the EU, U.S. and China all aligned their national regulation to aim for 100% EV sales by 2035, the scaling up of production would lower costs worldwide, bringing forward cost parity in other countries, such as India, by as much as three years. In addition, countries should increase the number of public chargers, and particularly the number of fast public chargers, in order to make EV ownership an easy choice.

The shift to EVs must be done equitably. Governments should incentivize carmakers to produce more affordable EV models. When subsidies are used, they should be targeted at low-income households, which in addition to being equitable is also more effective at increasing EV adoption, given that low-income households are more sensitive to price changes.

Rapidly increasing EV adoption to reach 75% to 95% of global passenger vehicle sales by 2030 will be challenging, but it is achievable if the world heeds these lessons and keeps up the current rapid pace of change.

Finally, it's important to note that increasing EV sales is only part of the story. To decarbonize road transportation, old gas- and diesel-powered vehicles will need to be retired rather than be sold to other drivers or to developing countries and the increasing popularity of large vehicles like SUVs will have to be reversed. What's more, the goal shouldn't be for everyone to own a car. Transforming the transport system to increase access to other forms of mobility can lower emissions, reduce automobile-related deaths, save time lost in traffic and limit ecosystem damages.

Data for all-electric vehicle sales in this article is from the International Energy Agency's Global EV Data Explorer, as of September 2023. Data is presented for both all-electric vehicles and plug-in hybrid; author split out the all-electric vehicles.

This article is the second in a series of deep-dive analyses from Systems Change Lab examining countries that are leaders in transformational change. Systems Change Lab is a collaborative initiative — which includes an open-sourced data platform — designed to spur action at the pace and scale needed to limit global warming to 1.5 degrees Celsius, halt biodiversity loss and build a just and equitable economy.

Relevant Work

CLIMATE

Are We on the Brink of an Electric Vehicle Boom? Only with More Action

Insights SEPTEMBER 16, 2021

CLIMATE

5 Shifts to Transform Transportation Systems and Meet Climate Goals

Insights MARCH 9, 2023

CLIMATE

EVs Could Create Thousands of Jobs in Michigan and Revitalize Its Auto Industry

Insights MAY 3, 2023

CITIES

Going Electric: How Ride-hailing Drivers Can Help Cities Speed Up EV Use

Insights NOVEMBER 9, 2021

Exhibit 9

Blogs

S-curves in the driving seat of the energy transition

Energy Transition Harry Benham 30 January 2023

Download Infographic Here

The energy transition may well be determined by the phenomenon of S-curves. This is because the future energy system will be characterised by manufacturing technology, not extractive fossil fuel projects.

The S-curve is a well-established phenomenon where a successful new technology reaches a certain catalytic tipping point (typically 5-10% market share), and then rapidly reaches a high market share (i.e. 50%+) within just a couple more years once past this tipping point.

curves, scalable learning-by-doing techniques based on thousands and thousands of repeated parts and assembly.

Extraction projects are almost the opposite: one-off large scale complex efforts that are difficult, potentially impossible, to replicate and improve.

The S-Curve of manufacturing represents the slow initial adoption of a new technology or innovation, followed by a period of rapid adoption and, later, a levelling-off as the technology or innovation becomes mature and reaches market domination (hence the 'S').

Many successful technologies tend to take-off spectacularly, on reaching a market share of 5-10%, to oust the incumbent technologies.

Behind every successful S-Curve there has to be a successful learning curve. In a virtuous cycle, the successful technology will get cheaper the more it gets deployed and will get more deployed the cheaper it gets.

When applied to our energy industry analysis, we find the following:

Solar panels, wind turbines, and lithium-ion batteries have all followed such learning curves.

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in the past two decades. And so their growth has followed an S-curve model.

And now that they are deployed at global scale, this theoretical insight has major real-world energy implications: wind and solar power generation is now 12% of the global total from less than 1% a decade ago, growing at 20% per year.

Thus S-Curves by their nature are disruptive and rapid. An energy transition driven by S-Curve technologies is unlikely to be smooth. As the adage goes: gradually, then suddenly.

This is even more important in the context of a primary energy system that is essentially flat, growing at a rate of about 1% per annum. When a new energy technology enters at a high rate of growth, the incumbent technology will eventually have to exit at a high rate too.

The benefits of S-Curve technologies are fairly obvious. Not only do they help sectors such as power and transport to align with the targets of the Paris Agreement, they also bring about major environmental and economic benefits to energy users.

As for S-Curves themselves, one of the key advantages of using them in energy forecasting is technology adoption and diffusion.

This is particularly useful in situations where the rate of adoption is influenced by a range of factors, such as the availability of financing, regulatory incentives, and consumer preferences.

As the energy system transitions towards deploying solar, wind, and electric vehicles (EVs) on a large scale, reducing its reliance on technologies extracting fossil fuels, the impact of learning rates and S-Curves will become significant tools to use, predict, and analyse the shape of future energy changes in various major sectors.

A good recent summary of such an impact in the energy industry is provided **here** by INET at Oxford University.

In addition, and highlighted below, we have several more detailed examples of the S-Curve effect in the energy transition covered by Carbon Tracker's analysis in recent notes.

In two papers we released in December 2022 and January 2023 as part of our automotive coverage, **Slipped Gear** and a joint **blog** with automotive think tank, **New Automotive**, we covered the rapid change of the global automotive industry structure, due to

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(BEVs) at industrial scale.

This sudden arrival is due to several factors, but two stand out: the scalability of BEV batteries driving down their costs by 90% over the past 15 years, and the recognition that transport stubbornly contributes 20% to global emissions. So just as BEVs become affordable, they also become a major policy tool to achieve Paris targets: hence they feature in many government policy targets, for example, the UK 2035 ICE ban, and the US Inflation Reduction Act.

We say *sudden arrival* because as recently as 2016, global sales of BEVs had failed to reach the one million mark, and were less than 1% of global sales,

In 2022, however, just six years later, we expect global sales to be over 10.3 million and have 13% market share, at a growth rate of 50% pa that looks set to continue. Assuming it does, then 2023 will show sales of about 14 million and reach a market share of close to 20%.

This high growth rate of BEVs would not be a major problem for incumbent automakers if all car sales were growing quickly: fossil-fuelled ones as well as BEVs. But they are not. Global car sales have been largely flat for the past decade.

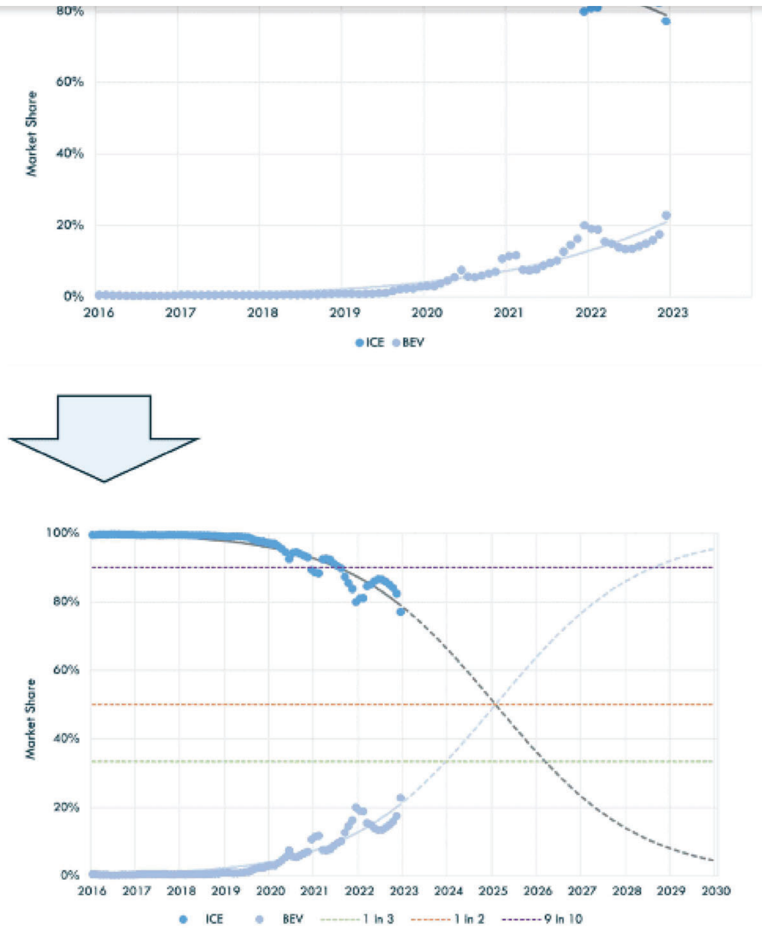
sales decreases the sales of any new fossil-fuel car: and that is what has happened in the global car market, at an increasingly rapid rate: the peak in sales of fossil fuel cars was likely 2016-17 globally. How fast sales decline from now on is therefore of huge importance to the industry.

In our blog we researched the UK car market in detail to see how the shape of new BEV sales followed this likely trend. The chart below shows a classic S-curve outcome, with actual sales up to 2022 in the top chart, and projected sales to 2030 in the bottom chart.

As noted in the blog post this means: "*In 2016, UK BEV sales were less than one in a 100; by the end of 2023, one in three new cars registered in the UK could be fully electric.*"

And the main finding this trajectory takes you to is that by 2030 sales of fossil cars in the UK could be a small minority of the total: less than 10%. If that sounds far-fetched consider that in the UK in 2017 pure diesel and petrol car sales were 98% of the market — today they are 50%.

Figure 1: UK New Vehicle Sales – BEV and ICE Market Share – Adoption S-Curves



Source: New AutoMotive, Carbon Tracker. Note: The individual data points show actual new sales market share. Sales are averaged over a 3-month rolling period. The S-Curves are plotted using a logistic function with the projection shown with a dashed line. 'ICE' is defined as all vehicles with an internal combustion engine, including hybrids.

In theory, incumbent fossil fuel OEMs (original engine manufacturers, companies like Ford, BMW, Toyota and so on), should be able to adapt to this new market terrain, and just electrify their best-selling brands.

But as the report Slipped Gear shows, they have been stalling in this mission for a variety of reasons, mainly:

- Prioritising Legacy Profits: Automotive OEMs hooked on ICE vehicle profits neglect improved emissions reduction and investment in BEV technology
- Poor signposting: Automotive OEMs have weak interim emissions targets, which are not aligned to meeting climate goals
- Lack of transparent financial alignment with the Paris Agreement – incumbent firms are reluctant to be transparent about their legacy fossil fuel vehicle liabilities and slow to embrace the new green revenues from BEVs

As a result, this has allowed the rapidly growing BEV market to be quickly flooded with new entrants who have no legacy fossil fuel vehicles or culture – most notably Tesla, but increasingly by new start-ups and Chinese firms venturing outside China, initially in JVs, and now also as stand-alone brands such as SAIC and BYD.

Meanwhile incumbents attempt to use policy tools to slow change: but as the S-curve logic applies, when the benefits of the learning curve of costs kick-in, and BEVs start to become ever cheaper, the change will likely be only one way, and very quick.

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petrol and diesel, in the past two years will only make this transition ever slicker.

What this means for incumbent automakers, and indeed the oil industry whose monopoly position on fuelling cars is now being superseded by electrons will be part of a Carbon Tracker Automotive blog series. At current rates of growth, for example, the global passenger car fleet could be 20% BEV by 2030, removing a whopping 4-6mb/d of oil demand.

Meanwhile recent company assessment of global lead automakers can be analysed in depth **here**, along with assessments of oil and gas and utility firms.

In the Energy Transition more generally, as noted, the power of S-curves goes well beyond BEVs. As we detailed in our last Energy Monitor issue in December 2022, **African Sun**, and in the 2021 report **The Sky's the Limit** the learning curves of utility scale solar PV panels has made solar electricity in many cases the cheapest in the world.

So much so it is estimated that 1,100GW of solar will have been installed by end 2022, including 30% pa growth last year of 258GW, maintaining the growth rate of the past 12 years since 2010 – a 20-fold increase overall. See **here.**

wind power accounted for over 12% of global electricity generation, growing together at 20% per annum. Only a decade ago the two technologies formed about 1% of global generation.

The power of S-curve growth means that wind and solar now account for over 75% of all annual growth in the power sector and will likely account for all of it in the next 2-3 years, forcing out fossil fuels at an increasing rate.

Solar and wind installed capacity of over 2,000GW in 2022 is higher than global coal capacity – and although generation will lag coal for a few years, with sustained high S-curve growth rates, this target will also likely soon be in reach.

In addition, as noted in our **report** on clean hydrogen for hard-to-abate sectors, innovations in electrolyser technologies are causing rapid price decreases and therefore a new S curve potentially for "green" hydrogen sourced from emission-free electricity. Heat pumps for electrified space heating are also starting to show signs of S curve characteristics at scale.

We have also delved into a major energy transition report reviewing 2022's high growth in renewable energies – again with S-curves being a major factor.

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(WEO) late last year. It is a (very) long detailed document, used by many energy stakeholders such as governments and international corporations.

In our summary review — **On Track for Paris? IEA lays out required pace of energy transition to keep 1.5°C in sight** we extracted the following key messages:

- *In its most recent World Energy Outlook, the IEA describes a rapidly changing energy landscape; the invasion of Ukraine has revealed the fragility of the fossil-fuel based energy system and hastened the energy transition.*
- *Electrification, which feeds off and into large-scale deployment of renewable technology, will be key to the shift to clean energy.*
- *With scenarios updated, the IEA sees peaks or plateaux for all fossil fuels, even with business as usual, before 2050.*
- *The IEA's 1.5°C scenario now includes a greater degree of temperature overshoot, and relies heavily on the rapid deployment of emissions mitigations technologies before 2050.*
- *A more credible – and cheaper – pathway to 1.5°C may be possible, with more trust in*

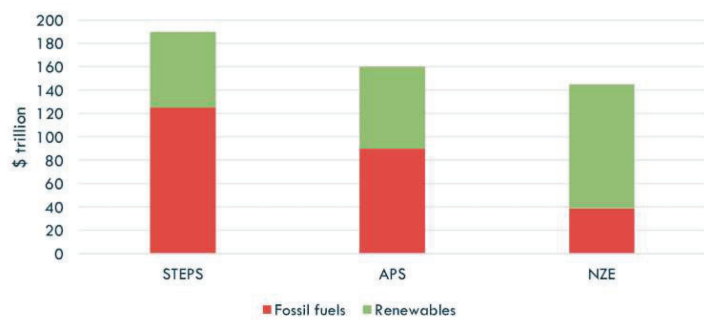
Carbon Tracker

production.

Again – the power of S-curves is clearly seen driving the energy transition.

Even venerable organisations such as the IEA may well get so much wrong by so little a mathematical error in predicting the rapid growth of manufacturing energy.

Figure 2: Total Energy Cost to 2050 by Scenario



Source: International Energy Agency, additional analysis by Carbon Tracker Initiative

Indeed, to confirm this rapid growth trend, other major analyst groups such as the UN sponsored **Inevitable Policy Response** forecasting unit have just released a new report on the **Race to the Top emerging between China, the EU and US** as they each aim to grasp the opportunities for re-building the global energy system using clean technologies compatible with global climate goals – and accelerate the shift.

energy system that produces over 35 billion tonnes of CO2 per annum, a very big and more efficient system needs to quickly step in to supersede it. This report shows how that could be done.

Yet, despite all this new energy at speed and scale, across several sectors, incumbent fossil fuel companies continue to increase their investment in out-dated energy production, and so rapidly increase their risk of stranding their uneconomic energy assets.

Paris Maligned?

Despite the rapid increase of energy alternatives in power and transport, and predictions of peak oil demand in the near-term, even in the most conservative scenarios, for example, the IEA's WEO STEPS, our *Paris Maligned* report highlights that major oil and gas companies are continuing to ever expand investment and production.

The report notes:

- Asset owners seeking 1.5°C-aligned portfolios cannot credibly own financial interests in companies that continue to invest in new conventional oil and gas projects. Alignment with Paris – whether 1.5°C or 'well below 2°C' –

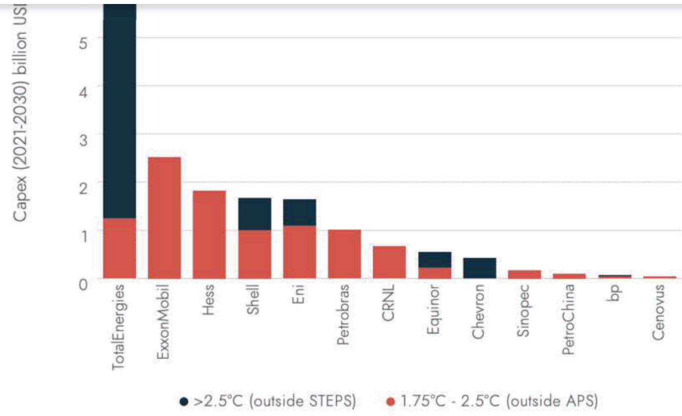
& gas companies are planning production increases.

- With Russia's invasion of Ukraine pushing commodity prices higher and incentivising new investment, investors looking to be Paris-aligned must continue to scrutinise company plans, as investment in new oil & gas projects that lock-in future emissions are incompatible with Paris.
- 62% of investments approved in 2021/Q1 2022 (or $103bn) were inconsistent with a Paris-aligned pathway (the IEA's 1.7°C Announced Pledges Scenario), including $58bn that was outside even a 2.5°C outcome.

This is not just bad planning, or bad environmental governance it is high risk economics with investor money, given the speed of new entrant alternative energy technologies.

Figure 3: Investments approved in 2021/early 2022 that are not Paris-aligned

Carbon Tracker Initiative



Source: IEA, Rystad Energy, CTI analysis

Drilling Down into oil and gas prices used in financial reporting

"Financial statements, like economic models, are only as good as the inputs to them."

In a comprehensive note published last year, **Still Flying Blind**, we highlighted how a large number of major oil and gas firms insulate themselves from the world at large in their opaque financial statements which still mostly put the risks of the energy transition and climate change at a distance from their own balance sheets.

Our new **Drilling Down** report looks into this in more detail for major UK and EU Oil and gas companies. We analysed the disclosures made by them, with particular attention to the projected oil prices that they use to test their productive assets for impairment.

around them fossil fuel companies are using nothing more subtle than assuming flat oil prices out into the distance as this report shows.

Compound the strategic risk of over-investment in fossil fuel projects with seemingly straightforward accounting rules that encourage it and you have the financial mechanics of how oil and gas companies allow seemingly irrational corporate investment decisions to be made.

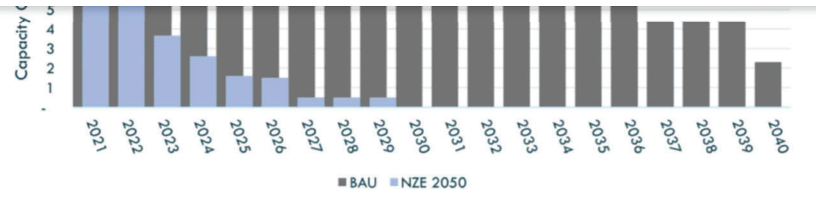
The bottom line is that most of the large oil and gas firms simply assume a comfortable floor of $50-60/bbl in real terms many decades out and therefore, all new corporate investment cases seem profitable. The world at large be damned.

Investors must beware these simple underlying assumptions of smooth invariable revenues, against true stress tests of corporate viability, such as the IEA's NZE prices of $25-35/bbl, and the likely non-linear changes we have mentioned earlier due to S-curve impacts of new technologies.

Corporate Profile – J Power in focus

Figure 4: Coal phase-out for J-Power wholly owned assets under NZE2050

Carbon Tracker

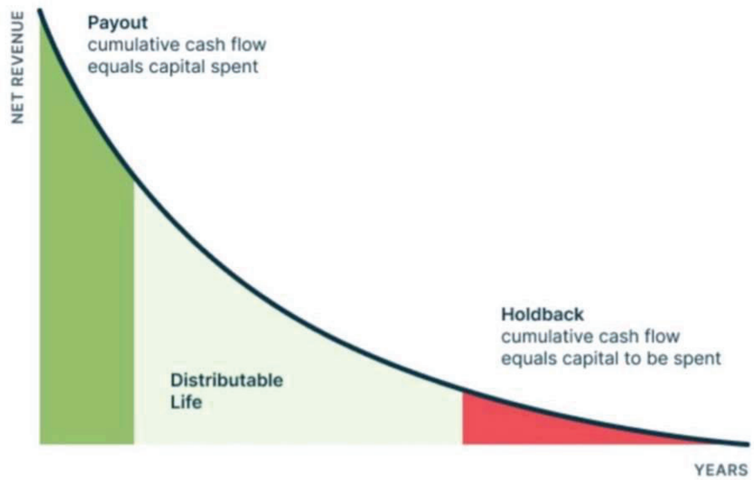


Source: Carbon Tracker Analysis

The conflicts of new and old energy in this transition is shown in microcosm in our corporate report on J-Power, a major Japanese utility firm which has a monopoly on grid connections between Japan's four major islands.

Despite much corporate marketing, this report shows how J-Power has limited ambition for renewables, is investing in coal and gas plants internationally, and is using carbon capture technologies to extend the life of its coal-fire based power plants. It's Net Zero 2050 ambitions therefore look undermined, symptomatic of current pledges more widely.

And finally our latest **report** on oil and gas decommissioning liabilities in the US shows how the fossil fuel industry, in trying to exit in a world of accelerating new energy alternatives, may be leaving behind major liabilities. With over two million abandoned oil and gas wells across the US there is growing concern about how these legacy assets can be effectively decommissioned safely and economically.



Source: Carbon Tracker analysis, A New Theory of ARO Creditor Rights

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Exhibit 10

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3 MIN READ

Data Point

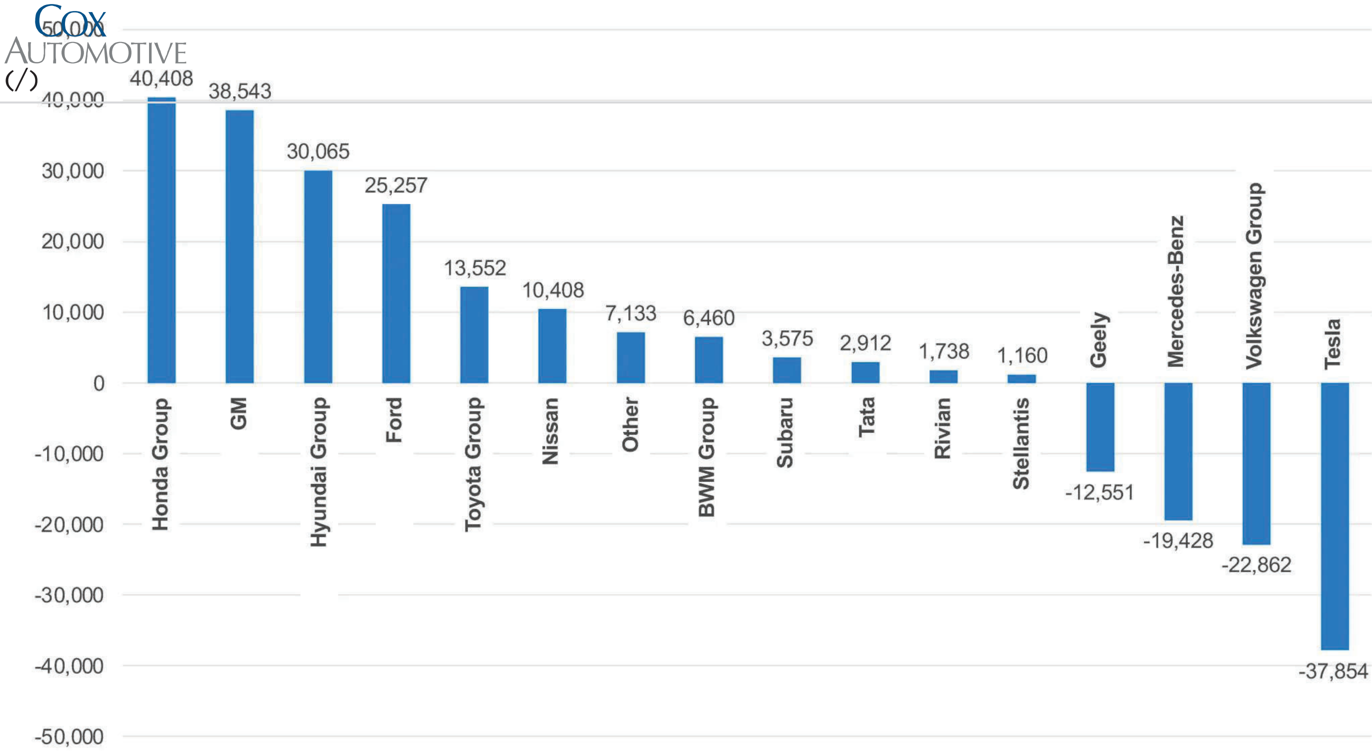
Electric Vehicle Sales Jump Higher in Q4, Pushing U.S. Sales to a Record 1.3 Million

Monday January 13, 2025

Sales of electric vehicles (EVs) in the U.S., according to the latest counts from Cox Automotive's Kelley Blue Book, jumped 15.2% year over year in the fourth quarter of 2024 to 365,824[1], setting a new volume record for any quarter. In 2024, full-year EV sales reached 1.3 million, an increase of 7.3% from the upwardly revised total in 2023. Sales of EVs in the U.S. benefitted from strong incentives from the automakers, excellent lease deals, and federal and state incentive programs.

The gains in 2024 were also supported by excellent new products, particularly from General Motors and Honda Motor Co., which together sold nearly 80,000 more EVs in 2024 than in 2023. Hyundai Motor Group and Ford Motor Company also notably increased EV sales last year. By volume, Tesla sales were estimated to be lower year over year by more than 37,000 units (roughly the volume GM added). VW and Mercedes-Benz also posted significantly lower volumes in 2024 compared to 2023.

Electric Vehicle Sales Volume Change by Automaker: 2024 vs 2023



(https://www.coxautoinc.com/wp-content/uploads/2025/01/Q4-2024-EV-sales-volume-chart-revised-01-30-25.jpg)

The EV market in the U.S., as it is in China and Europe, is hypercompetitive: Of the 68 mainstream EV models tracked by Kelley Blue Book, 24 models posted year-over-year sales increases; 17 models were all-new to the market; and 27 decreased in volume, including models being discontinued such as the Chevrolet Bolt and Mazda MX-30.

The Tesla Model Y and Model 3 continue to be best-selling electric vehicles in the U.S. by a long margin, but both aging models saw notable sales declines. Still, the Model Y and Model 3 accounted for more than 40% of all EVs sold last year. The Ford Mustang Mach-E was the best-selling EV not made by Tesla, followed by the Hyundai Ioniq 5. The Tesla Cybertruck came in at No. 5, just ahead of the Ford F-150 Lightning. The Honda Prologue, which had zero sales in 2023, was No. 7 on the best-selling list for 2024, marking up more than 33,000 sales in its first year.

List of Top 10 EV Models in the U.S.

1. Tesla Model Y

2. Tesla Model 3

3. Ford Mustang Mach-E

4. Hyundai Ioniq5

5. Tesla Cybertruck
6. Ford F-150 Lightning
7. Honda Prologue
8. Chevrolet Equinox
9. Cadillac Lyriq
10. Rivian R1S

Overall, EV sales in the U.S. continue to grow, with more than 2.5 million EVs sold in the past 48 months. In the latest analysis, sales in 2023 were revised upward to 1,212,758 units, a 49% gain from 2022. Sales in 2024 (1,301,411) were higher by 7.3% and accounted for 8.1% of total sales, up from 7.8% share in 2023. While the rate of growth has slowed, volume continues to expand. In the second half of 2024, more than 700,000 EVs were sold, accounting for 8.7% of total new-vehicle sales.

Cox Automotive expects further EV sales growth in 2025. With more than 15 new products scheduled to enter the market, improving charging infrastructure, and continued support (i.e., generous incentives) from the automakers, sales of EVs will likely account for close to 10% of total sales this year, according to the Cox Automotive Forecast (https://www.coxautoinc.com/news/cox-automotives-2025-outlook-market-growth-improving-affordability-and-higher-buyer-satisfaction-expected-in-year-ahead/).

While policy changes in Washington might slow the growth, those changes likely won't take effect for some time, and many buyers might jump in before changes are made. Cox Automotive is expecting 2025 to set another record for EV volume. In fact, in the year ahead, one out of every four vehicles sold will likely be electrified in some way – a hybrid, plug-in hybrid or pure EV. One thing is for certain: Each year, more electric vehicles with advanced battery technology are making their way onto America's roads.

---

[1]Kelley Blue Book counts exclude super exotics.

Download the Q4 2024 Kelley Blue Book EV Sales Report (https://www.coxautoinc.com/wp-content/uploads/2025/01/Q4-2024-Kelley-Blue-Book-EV-Sales-Report-revised.pdf)

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Exhibit 13

Have a question?

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ASK MIT CLIMATE

In the right circumstances, could a hybrid car be "cleaner" than an electric vehicle?

but it is possible for a

featuring guest expert Sergey Paltsev, Deputy Director of *hybrid vehicle to create even less climate pollution, depending how and where they're manufactured and driven.*

January 14, 2025

Electric vehicles (EVs), research has consistently shown, produce fewer climate-warming emissions compared to cars that burn gasoline or diesel. But could hybrid vehicles be a better deal for the climate than full EVs? “You can construct those cases and get that answer,” says Sergey Paltsev, deputy director of the MIT Center for Sustainability Science and Strategy and senior research scientist at the MIT Energy Initiative. However, it might require cherry-picking data to find a very specific set of circumstances.

There are two types of hybrid vehicles, both of which run on a mix of electricity from a battery (like an EV) and a gasoline engine (like an ordinary car). A traditional hybrid vehicle, like a Toyota Prius, carries a battery that recharges while the car’s engine runs. This energy is delivered to the wheels through electric motors, allowing the car to switch quickly between electric and gas power depending on driving conditions. A plug-in hybrid vehicle (PHEV), meanwhile, is essentially a full EV with a gas engine as a backup. This allows it to get by with a much smaller battery than a pure EV: when the battery runs out, the gas engine takes over.

the MIT Center for Sustainability Science and Strategy and Senior Research Scientist at the MIT Energy Initiative

Related MIT Groups

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MIT Climate Portal: "Are electric vehicles definitely better for the climate than gas-powered cars?"

MIT Climate Portal: "How much CO2 is emitted by manufacturing batteries?"

U.S. Department of Energy: "How do hybrid electric cars work?"

U.S. Department of Energy: "Emissions from electric vehicles"

MIT Trancik Lab: CarbonCounter (Interactive Tool)

No matter the vehicle, driving on gasoline virtually always does more to affect the climate than driving on battery power. That's partly because burning gasoline in an engine directly produces climate-warming carbon dioxide (CO_2). But it's also because electric motors are much more efficient than engines at turning energy into driving power. For example, consider an EV charged in West Virginia, where most electricity comes from burning coal—itself a major source of CO_2. This car *still* produces less CO_2 per mile driven than a gas-powered car, because it gets so much mileage out of every bit of electricity in its battery.[1]

So how could a hybrid, which uses gasoline at least part of the time, ever be cleaner than an EV? To know which vehicle is truly least damaging to the climate, you also need to factor in all the emissions created over the car's lifetime.[2] And that's where the math gets tricky.

If you look at a line graph of an EV's lifetime CO_2 emissions, you'll see there's a big bump at the beginning. That's because building EVs creates more emissions than building gasoline cars, due to the mining and manufacturing needed to make their large batteries. After this big initial bump, there's a gentle slant as the EV creates a modest amount of emissions every time it charges up, because electricity currently is not emissions-free.

Meanwhile, a gas car's graph would start with a smaller bump, but then slope dramatically upward as it spends

MIT Energy Initiative: "Insights Into Future Mobility" (Report)

Topics

CARS

its entire driving life—more than a decade on average—burning gasoline and releasing CO_2. After a few thousand miles of driving, the gas car's emissions overtake the EV's and keep rising.

Hybrids, both traditional and plug-in, fall in the middle. Because their batteries are smaller than an EV's, their graphs start with a medium-sized bump. This makes it possible to draw up scenarios where a hybrid is less climate-polluting than an EV. For example, a person who does most of their driving within a few miles of home could own a plug-in hybrid and rely on electric power nearly all the time. In this case, the PHEV is, in practice, a true EV, but with a smaller battery. With fewer manufacturing emissions, this hybrid would almost by definition be "cleaner" than a full EV—although that calculus could change quickly if the owner began to use their hybrid's gas engine more often.

However, Paltsev says, driving habits aren't the most important factor when comparing hybrids to EVs. The bigger questions are: How clean is your electricity, and how dirty is battery manufacturing?

Let's return to our EV charged in West Virginia. It drives cleaner than a gasoline car, but not a *lot* cleaner. In 2019, Paltsev worked on a study that concluded that, once you factor in manufacturing, this West Virginia EV will only *barely* be cleaner than a gasoline car. Here, a traditional hybrid would actually be 30% cleaner than a full EV.[1]

If you live somewhere that's highly reliant on coal power, then, an EV could be seen as a bet that the power mix will get cleaner over your car's lifetime. And, Paltsev points out, this would not be a crazy bet: the United States, like many other countries, is rapidly adding clean solar and wind power while phasing out coal. Already, most places are *not* like West Virginia, and we can expect EVs to be cleaner than hybrids and continue to get cleaner in the years to come.

Battery manufacturing is harder to evaluate. For one thing, Paltsev says, many estimates of the emissions created by battery manufacturing are based on data that goes back to the previous decade—and may be outdated for an industry changing so quickly. It's also not universally agreed what counts as manufacturing, and studies are not consistent. Any fair study of this question will have to include the emissions from mining the metals that go into a battery—but what about the emissions from building the mining equipment? "It really depends where you draw the boundaries for your comparison," he says.

Paltsev says a few studies, using high-end estimates for the amount of climate pollution created by battery manufacturing, have found plug-in hybrids to be cleaner than EVs. In his estimate, those figures are too high—perhaps double the likely emissions of today's cleanest EV battery production—but it's not surprising that researchers studying a hard question in a fast-changing environment can reach different answers.

Although Paltsev's research is clear that EVs are the best choice for the climate, he would never say they're the *only* good choice. Driving a hybrid can dramatically reduce climate pollution compared to owning a gasoline-only vehicle. If that's the right choice for some drivers, then he encourages them to make it. "Every ton of CO_2 that we can reduce matters," he says.

Thank you to many readers who sent in related questions, including David Byrne of Dublin, Ireland, Claire Kowalchik of Emmaus, Pennsylvania, Shreenivas Mate of Ventura, California, Sherry Morgan of South Deerfield, Massachusetts, Peter North of Woolwich, Maine, and Jimmy Voorhis of Boulder, Colorado.

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FOOTNOTES

[1] MIT Energy Initiative: Insights Into Future Mobility, November 2019.

[2] Argonne National Laboratory: "Cradle-to-grave lifecycle analysis of U.S. light-duty vehicle-fuel pathways: a greenhouse gas emissions and economic assessment of current (2020) and future (2030-2035) technologies," November 1, 2023.

Want to learn more?

Listen to this episode of MIT's "Today I Learned: Climate" podcast about electric vehicles.

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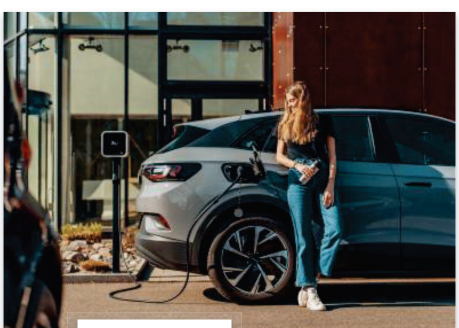

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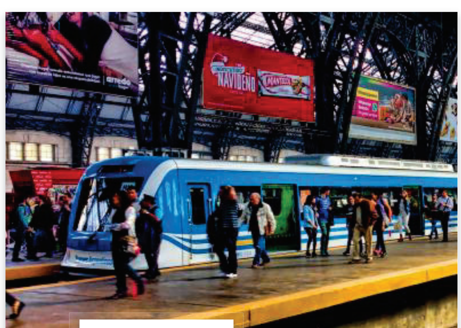
Electric Vehicles

Electric vehicles are a cleaner alternative



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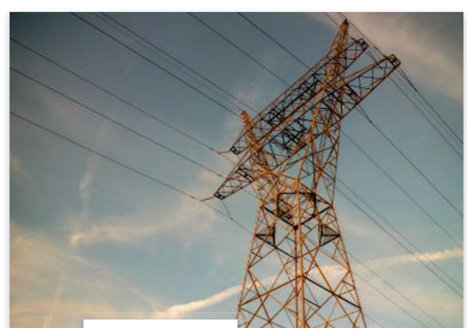

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The electric grid is a network of power

to gasoline- or diesel-powered cars and trucks—both in terms of harmful air pollution, and the greenhouse gas emissions that are causing climate change.

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Exhibit 17

To: **Liane M. Randolph**, Chair, California Air Resources Board
Honorable Board Members, California Air Resources Board

From: Steven S. Cliff, Ph.D., Executive Officer, California Air Resources Board

Date: September 25, 2024

Subject: California Truck Availability Analysis

I am writing to provide an update on the availability of medium- and heavy-duty vehicles in California for the 2024 model year (MY) and to respond to concerns raised at the May Board hearing. I am also including responses to ongoing questions regarding potential differences between zero-emission truck (ZET) pricing in the United States and in Europe.

On May 23, 2024, staff presented to the California Air Resources Board (CARB or Board) proposed amendments to the Advanced Clean Trucks (ACT) regulation. At the hearing, numerous upfitters and dealers spoke about their current inability to receive combustion products from manufacturers in California. They primarily attributed the issue of limited chassis availability to the ACT regulation. In response to these comments, the Board deferred its vote on the proposed ACT amendments to a future hearing and directed staff to work with industry to assess the situation further. This memo provides an update on the situation and staff's findings based on conversations with the affected parties.

Background

In California, the transportation sector alone accounts for 41% of total greenhouse gas emissions (50% when upstream emissions from fuel is included) and is a major contributor to oxides of nitrogen (NOx) and toxic diesel particulate matter (PM) emissions. Medium- and heavy-duty vehicles contribute a quarter of the transportation sector's greenhouse gas emissions and a third of the transportation sector's NOx emissions, a disproportionately high share considering these vehicles represent only about 1.8 million trucks of the 30 million registered vehicles in the state.

CARB has adopted several programs aimed at achieving California's criteria pollutant and greenhouse gas reduction goals, including regulating manufacturers under the ACT and HD Omnibus regulations and setting requirements for fleets in the Advanced Clean Fleets (ACF) and Clean Truck Check regulations. Actions toward reducing emissions have been taken at the federal level as well, most recently with the adoption of the Clean Trucks Plan and Phase 3 greenhouse gas emissions standards for heavy-duty (HD) vehicles.

The ACT regulation, adopted by CARB in June 2020, and approved by the Office of Administrative Law (OAL) in March 2021, reduces emissions beyond what can be achieved with internal combustion engines (ICE) and assists California in attaining the State's air quality and climate mitigation targets. The ACT regulation requires manufacturers of

Class 2b-8 vehicles to produce and deliver for sale an increasing percentage of zero-emission vehicles (ZEV) over time starting with the 2024 MY. The ACT regulation will ensure ZEVs are available for purchase and includes flexibility for manufacturers to strategically focus on vehicle models that are most suitable for electrification, but it does not require any specific fleets, dealers, or others to purchase these vehicles. The amendments proposed at the May hearing consist of generally minor, administrative changes that would address minor issues that have arisen through the rule's implementation, would ensure alignment with the original intent of the rule, and fulfill some of CARB's commitments in the Clean Truck Partnership (CTP) agreement.[1]

Announced in July 2023, the CTP is an agreement between CARB and the nation's leading truck manufacturers that advances the development of ZEVs for the trucking industry and provides flexibility for manufacturers to meet emissions requirements while reaching the state's climate and emission reduction goals. The agreement marks a commitment from the manufacturers to meet California's vehicle standards, including standards that will require manufacturers to only produce and sell ZEVs starting with the 2036 MY. As part of the CTP agreement, CARB agreed to initiate a rulemaking action in 2024 to include specific changes to the ACT regulation that are part of the amendments proposed to the Board in May.

The HD Omnibus regulation was adopted by CARB in September 2021 and approved by OAL in December 2021. The regulation primarily establishes more stringent exhaust emission standards for NOx and PM emissions for new on-road medium- and heavy-duty ICEs for sale in California starting with the 2024 MY. The regulation additionally revamped the HD in-use testing program, established powertrain certification test procedures for HD hybrid vehicles, implemented a new low-load test cycle, and increased the useful life and warranty periods for HD engines. The HD Omnibus regulation is expected to result in significant emission reductions from 2024 MY and newer engines sold in California.

One of the compliance flexibilities in the HD Omnibus regulation is the legacy engine provision that allows limited production of HD engines that meet the 2010 MY NOx and PM emissions standards, referred to as legacy engines. Legacy engine sales in California are only allowed if the manufacturer offsets any excess NOx and PM emissions deficits with HD combustion credits, performing emission reduction projects in disadvantaged communities in California, or with HD zero-emission (ZE) powertrain credits. The mechanism for generation and use of HD combustion credits and HD ZE powertrain credits is further described in the California Averaging, Banking and Trading provisions of the Omnibus regulation. Each manufacturer is limited on the number of legacy engines they can sell

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[1] California Air Resources Board, Clean Truck Partnership, 2023 (web link: *https://ww2.arb.ca.gov/sites/default/files/2023-07/Final%20Agreement%20between%20CARB%20and%20EMA%202023_06_27.pdf*, last accessed September 2024).

based on their total HD diesel engine production, also known as the legacy engine sales caps.

In February 2023, CARB staff became aware that while the technology for diesel-fueled HD Omnibus-compliant engines was available, some manufacturers did not intend to produce compliant engines for several categories of trucks for the 2024-2026 MY period. Given the impacts to fleets, additional flexibility was desired to enable a smoother transition to the HD Omnibus standards. Accordingly, in December 2023, CARB amended the legacy engine provisions in the HD Omnibus regulation to allow engine manufacturers to sell an increased number of legacy engines i.e., increased the legacy sales caps in the 2024 and 2025 MYs, as well as extend the provision to the 2026 MY so long as all excess emissions deficits are offset. This change to the legacy engine provisions was also part of the CTP agreement. The intent of the 2023 HD Omnibus amendments was to minimize HD product availability issues in California for the 2024-2026 MY transition period. The new legacy engine sales caps were developed in a collaborative manner with the Truck and Engine Manufacturers Association, its members, and the Ford Motor Company.

The ACF regulation, adopted by CARB in April 2022 and approved by OAL in October 2023, aims to accelerate the widespread adoption and usage of ZEVs in the medium- and heavy-duty truck sector, and light-duty vehicles used in mail and package delivery, to reduce harmful emissions generated from on-road mobile sources. The regulation requires drayage trucks, government fleets, and well capitalized businesses to phase-in increasing number of ZEVs and establishes a clear end date of new medium- and heavy-duty ICE vehicle sales in 2036 which creates a catalyst to accelerate development of a HD public infrastructure network.

Summary of Findings

Since the May hearing, staff met with representatives from all major HD truck and engine manufacturers, including Cummins, Daimler, Ford, GM, Hino, Isuzu, Navistar, Paccar, Stellantis, and Volvo/Mack. Each original equipment manufacturer (OEM) was presented with a consistent set of questions regarding the current availability status of the tractors and medium- and heavy-duty vehicles that they offer. Staff additionally met with several dealer, upfitter, and fleet representatives, some of which spoke at the May hearing, to hear their issues and insights from their perspectives.

This section compiles the information gathered from discussions with the affected parties regarding the current product shortage issues.

Which vehicles and engines are affected?

The shortage varies by vehicle type, but generally affects Class 4-8 diesel HD vehicles, with a prevalent impact on Class 6 and 7 vehicles (which typically use medium heavy-duty (MHD) engines). Each manufacturer is dealing with a unique situation, but the factors driving the availability issues, outlined in the following sections, appear to be broadly consistent amongst the manufacturers.

What is the impact of the Advanced Clean Trucks regulation?

The OEMs indicated that the product availability issues for the 2024 MY are not driven by the ACT regulation, as evidenced by the excess of ZEV credits available based on the ACT credit summary through the 2023 MY.[2] All of the regulated OEMs have ZEV products available for the market in the 2024 MY, and many have already sold ZEVs in previous years to build up an early credit bank. Most manufacturers have also indicated that they are open to purchasing ACT credits from other OEMs if the economics make sense but would ultimately prefer to sell ZEVs themselves. In addition, the lower-than-expected overall sales of 2024 MY engines are effectively decreasing each manufacturer's ZEV sales requirement under the ACT regulation as ZEV sales requirements are based on a percentage of total sales volumes.

Why are manufacturers requiring ZEV sales ratios?

Through discussions with manufacturers, dealers, and fleets, it appears numerous manufacturers have begun to inform their customers they will be applying future requirements to purchase ZEVs before they can acquire combustion vehicles to each of their dealer or upfitters regardless of the types of vehicles they sell as ZEVs. Some have expressed plans to begin implementing a rigid policy to require each dealer or upfitter to purchase a certain number of ZEVs from the manufacturer before they can get any ICEs whether or not the manufacturer offers ZEVs in the market segment the dealer specializes. For example, one dealer may focus on selling school buses which are already being electrified today while another may focus on specialized municipal equipment. In contrast to these manufacturer ratios, the ACT regulation includes flexibility for manufacturers to strategically focus on vehicle models that are most suitable for electrification, but it does not require any specific fleets, dealers, or others to purchase these vehicles.

The purpose for these ratios varies depends based on the manufacturer. Some are using these ratios in order to meet their percentage sales requirement under the ACT regulation and as a result are requiring a ratio of roughly 1 ZEV to 10 to 15 ICE vehicles, which essentially pushes the ACT regulation's requirement onto the dealership or fleet. In other cases, manufacturers are requiring ZEV sales in order to generate NOx credits as they did not plan to have an HD Omnibus-compliant engine and are instead setting ratios of 1 ZEV to 1 to 3 ICE vehicles in order to achieve compliance. These policies do not appear to be

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[2] California Air Resources Board, Advanced Clean Trucks Credit Summary Through the 2023 Model Year, 2024 (web link: *https://ww2.arb.ca.gov/resources/fact-sheets/ACT-Credits-Summary%202023*, last accessed September 2024).

causing acute product shortages today but will have an increasing impact in 2025 MY and beyond as more manufacturers implement ZEV ratios across their product portfolio.

Further, it appears that there is a discrepancy between what manufacturers are communicating as the main cause of the current product shortages to CARB staff versus to the dealers and fleets. Dealers and fleets conveyed that they recently heard from sales representatives from a number of manufacturers that the product shortage issues are primarily driven by the ACT regulation while referring to these ZEV ratios while other representatives from the same manufacturers have been specifically communicating to CARB staff that this is not the case for the 2024 MY. Staff believes that attributing the driving factor to the ACT regulation could be a sales strategy to continue ramping up ZEV sales and towards building a credit bank for the ACT requirements in the 2025 and 2026 MYs despite the current surplus of ACT credits. Nevertheless, the inconsistencies in communication have lead dealers and fleets to believe that the ACT regulation's requirements are leading to the product shortages in the medium- and heavy-duty space which, upon discussions with all affected parties, is not backed by the data available.

In summary, the manufacturers are well-situated to comply with the ACT regulation's requirements for the 2024 MY and there are more than enough available ACT credits that manufacturers could purchase, if necessary, to sell dealers what is needed. In anticipation of requirements in the upcoming MYs, some manufacturers are requiring dealers to sell ZEVs in order to receive combustion vehicles which affects the current acquisition issue to a small degree, but this is also a strategy that aligns with the ACT regulation's requirements. Lastly, while OEMs are largely informing dealers and fleets that the ACT regulation is placing limits on the number of ICE vehicles which can be delivered, they have alternatively confirmed with CARB staff that this is not the case for the 2024 MY, which is consistent with the current ACT credit surplus. This apparent contradiction appears to be the result of manufacturers needing to ensure their sales representatives and customers are continuing to make progress on increasing ZEV uptake to meet their upcoming ACT requirements in future years even if their current requirement for 2024 MY has been met.

What is the impact of the Heavy-Duty Engine and Vehicle Omnibus regulation?

Heavy-duty engine manufacturers are currently offering a mix of Omnibus-compliant and legacy engines for sale in California. CARB staff anticipates that the engine manufacturers would continue the same sales strategy for 2024-2026 MY period while they gradually phase-out their legacy engine sales due to Omnibus legacy engine sales caps. Several manufacturers have recently announced the introduction of new Omnibus-compliant engines. These include new HD engines by Volvo[3], Paccar[4] and Cummins[5] which can be used in class 8 vocational and tractor vehicles. CARB staff believes that manufacturers will continue to introduce additional Omnibus-compliant engines for various truck configurations in 2025 and 2026 MYs, thereby helping alleviate future product availability issues.

Based on conversations with the stakeholders, CARB staff believes that product availability issues in 2024 may be caused by limited supply of MHD engines made by a specific engine manufacturer, which is the dominant manufacturer in the MHD sector. The shortage concerns have been voiced primarily by the tow truck and municipal vehicle industries.

CARB staff has also discovered that while some engine manufacturers have limited their MHD legacy engine sales because of the legacy engine sales caps, there are at least two other engine manufacturers who have surplus legacy engines and have the capacity to sell additional MHD engines in California dealerships. At this stage, it is unclear if upfitters and secondary manufacturers have fully explored whether they can quickly switch to other engine platforms to produce tow trucks and municipal vehicles.

As indicated above, the 2023 HD Omnibus amendments were specifically designed last year to address product availability issues for the 2024-2026 MY period. It should also be emphasized that the CTP agreement explicitly specifies the legacy engine sales caps for various HD engine service classes for the 2024-2026 MY period. These sales caps were developed in a collaborative fashion between CARB and the CTP signatories. At the time, OEMs informed CARB that, to the best of their knowledge, the legacy engine sales caps would alleviate product availability issues for MHD engines.

Based on the information collected by CARB staff, the following factors appear to be contributing to the current product availability issues:

- The sales projections used by some OEMs at the time of CTP signing were inaccurate, underestimating the number of compliant engines they would sell. This has led to significantly fewer legacy engines being available.
- Several California-based companies have historically procured vehicles from out-of-state dealerships. Given the new California emissions requirements under the HD Omnibus regulation, out-of-state dealers have very limited or no allocations of

[3] Volvo Trucks, Volvo Trucks North America Announces Availability of CARB 2024 Omnibus Compliant Heavy-Duty Engine, 2024 (web link: *https://www.volvotrucks.us/news-and-stories/press-releases/2024/july/volvo-trucks-north-america-announces-availability-of-carb-2024-omnibus-compliant-heavy-duty-engine/* , last accessed September 2024)
[4] PACCAR, CARB MX 13, 2024 (web link: *https://paccarpowertrain.com/products/carb-mx-13/*, last accessed September 2024)
[5] Cummins, X15 N (2024), 2024 (web link: *https://www.cummins.com/engines/x15n-2024*, last accessed September 2024)

HD Omnibus-compliant engines. These California-based companies are now reaching out to California dealerships for Omnibus-compliant engines. However, California dealers may be prioritizing their existing and well-established customers and are only providing a limited number of engines to their new customers. Dealers ultimately determine how to distribute their allocation, which further affects the ability for some fleets to obtain HD engines

- Product offering by OEMs are based on internal business decisions. Given the legacy engine sales caps, companies have focused production efforts on platforms with the highest profit margins while eliminating low-margin products. It should be noted that even if additional MHD engines become available, they may or may not end up being used for tow truck or municipal applications

Given that CARB is a signatory to the CTP agreement, there is no mechanism for CARB to unilaterally change the legacy engine sales caps without breaching the partnership agreement. A collaborative solution between CARB and the CTP signatories would be needed to address any adjustments to legacy engine sales caps.

What is the impact of the Advanced Clean Fleets regulation?

At the May hearing, several representatives of tow truck fleets expressed concerns over the current infeasibility in acquiring and deploying ZEVs pursuant to the ACF regulation in their respective industry due to high costs and operational restrictions. However, the ACF regulation does not require tow trucks to be purchased as ZEVs until 2027 in addition to providing numerous safeguards if a ZEV is not available or does not meet a fleet’s needs.

Larger tow truck fleets may be affected by the ACF regulation if they have either $50 million or more in gross annual revenue, or that own, operate, or direct the operation of a total of 50 or more vehicles. Based on conversations with industry, only a handful of tow truck fleets are large enough to meet these thresholds, so the remainder of these smaller tow truck fleets are exempt from the ACF regulation. Under this regulation, larger fleets following the ZEV Milestones pathway have no requirement to purchase ZE tow trucks until 2027. This puts work trucks, including tow trucks, on a later schedule; however, some advanced ZEV purchases in this category would be appropriate as fleets progress towards the 2027 requirement. The ACF regulation also offers several exemptions and flexibilities to assist in the challenges that come with ZEV acquisition, including cases in which available ZEVs do not meet a fleet’s daily operational needs, and delays in infrastructure construction.

In summary, only a portion of tow truck fleets are affected by the ACF regulation, and the requirements on these vehicles acknowledge and reflect the challenges that could be applicable with electrifying tow trucks. In light of these facts, staff determined the ACF regulation is not having an impact on the availability of tow trucks currently.

What other factors are impacting the California market?

With the upcoming implementation of U.S. Environmental Protection Agency's HD emissions standards in the 2027 MY, almost all existing HD engine families will be phased out within the next two years at the national level. Given that California is ahead of the nation in terms of HD emissions requirements, we are seeing this phase-out happen sooner in California than elsewhere. Customers will eventually have to reevaluate their options for HD engines and choose new replacement products.

Other factors contributing to the overall product shortage situation, per the OEMs, include a nationwide downturn in the market, supply chain issues carrying over from previous years not caused by CARB regulations that are limiting the OEMs' ability to produce trucks, and manufacturers not being sufficiently prepared to comply with the HD Omnibus regulation. Additionally, some vehicle upfitters producing specialty vehicles, including tow trucks, have reached maximum production capacity thresholds nationwide and cannot increase production levels, which affects the manufacturers' ability to accept new orders. Finally, with the introduction of the federal Clean Trucks Plan,[6] the phase-out of all legacy engine productions will be implemented nationwide within the next two MYs. These additional factors have significant cumulative impacts on the current unavailability issues, and all vary by manufacturer.

Truck Price Comparison between California and Europe

At the May Board hearing, questions were raised regarding the growing differences between ZET pricing in the U.S. and in Europe as well as the reasons for it. To better understand the situation, Clean Truck and Bus Voucher Incentive Project (HVIP) staff undertook a preliminary assessment of pricing levels for a key category: ZE Class 8 tractors in the U.S./California and for the equivalent models (Class 5 Long Haul (LH)) in Europe.

Broadly, the same manufacturers operate in both the U.S. and Europe under a variety of brands:

- Daimler Truck is the parent company of Mercedes-Benz Trucks in Europe and Freightliner among other brands in the U.S.
- Traton is the parent company of MAN and Scania trucks in Europe and Navistar in the U.S.
- PACCAR is the parent company of DAF in Europe and Peterbilt and Kenworth in the U.S.
- Volvo Trucks operates in both Europe and the U.S., and owns Mack Trucks in the U.S.

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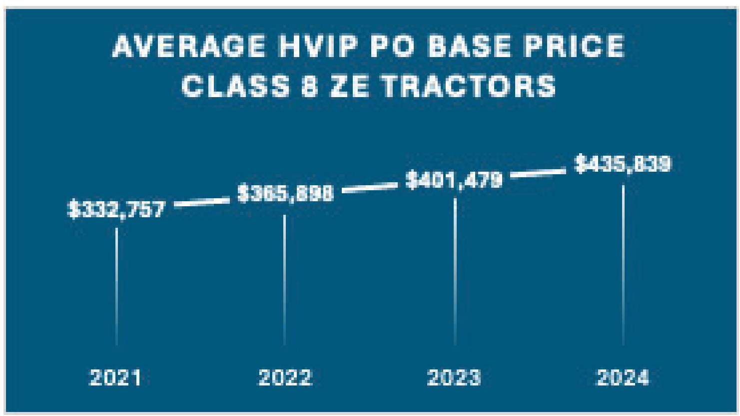
[6] U.S. EPA, Clean Trucks Plan, 2022 (web link: *https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-and-related-materials-control-air-pollution*, last accessed September 2024)

Pricing data in California have been pulled directly from purchase orders submitted as part of the HVIP voucher request process. Pricing in Europe has come from industry sources in the European Union (EU) and was compared for the period from 2021-22 against pricing seen in 2024.

Europe Zero-Emission Trucks have Lower Whole Vehicle Prices Compared to Equivalent California Zero-Emission Trucks

The preliminary findings from this research are revealing and are summarized as follows:

- The average California ZE Class 8 tractor in 2024 was priced at $435,839.
- The average European ZE tractor of similar capability to California. tractors (Class 5 LH in Europe) in 2024 were priced at $347,001.
- U.S. ZE tractors averaged $88,828 more to purchase than in Europe.



Europe Zero-Emission Trucks Have Lower Zero-Emission Powertrain Incremental Pricing Than in United States/California

There are differences between European and American tractor designs. To separate any price offset of the base tractor (known as a "glider") price from the powertrain (including batteries) price, HVIP examined the incremental pricing: the difference between the base diesel price in each region and the ZET price. While the equivalent trucks have detailed base tractor differences, the powertrains for ZETs are essentially the same in both regions and allow a direct "apples-to-apples" comparison. The findings were stark, as follows:

The incremental ZE powertrain price for California Class 8 ZETs in 2024 averages $279,937.

The incremental ZE powertrain price for European Class 5 LH ZETs averages $228,153.

EU incremental ZE powertrain price averages $51,784 lower than equivalent California incremental price even when accounting for lower base truck pricing in the EU. (European diesel trucks costing less than U.S. diesel trucks).

European Zero-Emission Truck Pricing is Going Down; U.S. Zero-Emission Truck Pricing is Going Up

- California zero-emission trucks (ZET) have <u>increased</u> in price by an average of $86,512 since 2021-22.
- European ZETs have <u>decreased</u> in price by an average of $12,641 in that same period.

There appear to be no clear reasons for this disparity between regions. Total ZET sales volumes are comparable between each region. Some European industry observers have noted that as battery prices are edging lower, generally vehicle makers in Europe have increased capability (increased battery size, range) while holding prices steady or lower. This is not the observed trend in California. There also appears to be some OEM price competition in Europe in advance of the Vehicle Energy Consumption Calculation Tool CO_2 model reporting deadline in 2025.

Next Steps

Staff intends to return to the Board at the upcoming October hearing to present their findings in addition to providing a final recommendation on the proposed amendments to the Advanced Clean Truck (ACT) regulation. While the proposed amendments are relatively minor and predominantly apply to compliance in the upcoming years, the changes are expected to provide manufacturers with more flexibility in complying with the ACT regulation as the market adjusts and potentially mitigate pressure on truck purchasers in future years, as explicitly expressed by many of the manufacturers.

The adoption of the ACT and Heavy-Duty Engine and Vehicle regulations are two of the largest actions taken by the Board in the pursuit of reducing criteria pollutant and greenhouse gas emissions in California and are critical in achieving the State's air quality and climate change goals. Subsequently, these regulations are significantly changing the current dynamics of the truck market in California and increasing the penetration of the first wave of ZE HD technology is expected to be difficult. However, measures have been taken through the Heavy-Duty Engine and Vehicle amendments, the proposed amendments to the ACT regulation, and other future actions to remedy unanticipated challenges that come with the changing market.

Exhibit 18

Zero-Emission Class 8 Truck Pricing Comparisons – EU & US

As part of CARB's efforts to support clean trucks in California, this fact sheet explores the differences between zero-emission truck (ZET) pricing in the European Union (EU) and the United States (US) and the reasons for it. To better understand the current market situation, these findings are based on a preliminary assessment of pricing focused on battery electric Class 8 truck in the US/California and equivalent models (Class 5 LH) in the EU.

The assessment's primary finding is that, based on the incremental price difference between zero-emission and diesel trucks, ZETs in the EU have a roughly $57,000 less incremental price difference than similar ZETs in the US.

Process Used

Pricing data in California was pulled directly from purchase orders submitted as part of the HVIP voucher request process. Pricing in the EU came from EU industry sources.

There are many differences between European and American truck designs and regulations that make direct comparisons on pricing difficult. The standard approach to address this is to determine "incremental pricing"–the difference between the base diesel truck price and the battery electric truck price. This roughly reveals the added price of the electric powertrain (including batteries).

This assessment determined incremental pricing by finding the difference between the base diesel truck price in each region and the base ZET price, using equivalent models. Diesel truck pricing is quite different in each region, but the battery electric powertrains are essentially the same. This enables a more direct "apples-to-apples" comparison.

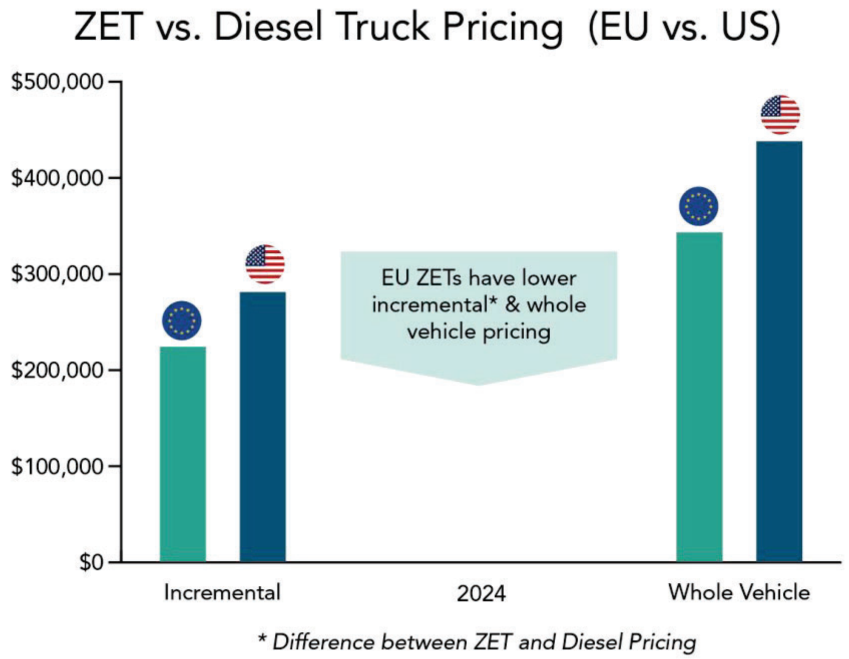
Findings

EU ZETs have lower incremental pricing than ZETs in the US/California.

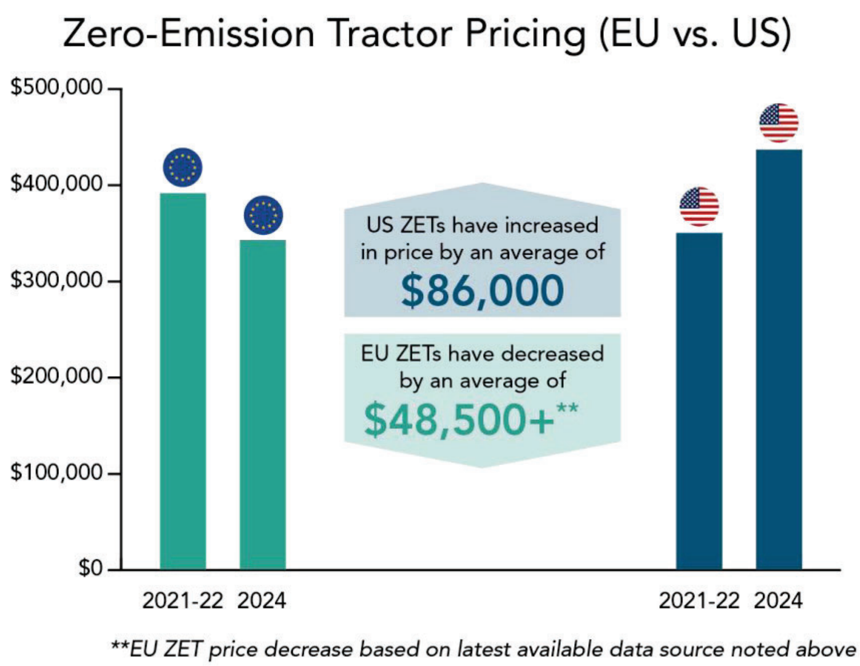
- The incremental ZE powertrain price for US/California Class 8 ZETs in 2024 averages $279,937.
- The incremental ZE powertrain price for European Class 5 LH ZETs averages roughly $223,000.
- **US incremental ZE powertrain price is around $57,000 more than EU incremental ZE powertrain price** even when accounting for lower base truck pricing in the EU.

EU ZETs have lower whole-vehicle prices compared to equivalent US/California ZETs.

- The average US/California zero-emission Class 8 truck in 2024 was priced at $435,839.
- The average EU zero-emission truck of similar capability to US trucks (Class 5 LH in Europe) in 2024 was priced at roughly $342,000.
- **US zero-emission trucks averaged nearly $94,000 more to purchase than in Europe.**



Total ZET sales volumes are roughly comparable between each region[iii]. Some European industry observers noted that as battery prices edge lower European vehicle makers have increased capability (increased battery size, range) while holding prices steady. Observers also note some OEM price competition in Europe in advance of the VECTO[iii] CO_2 model reporting deadline in 2025.



Aggregate HVIP Invoice Data by Year

HVIP Voucher Order Year	Average HVIP Purchase Order	Number of Orders	Average Diesel Equivalent Price	Average Incremental Cost
2021	$332,757	30	-	-
2022	$365,898	27	-	-
2023	$401,479	12	-	-
2024	$435,839	32	$155,902	$279,937

Truck Price Data Sources

- **US/California ZET Prices 2024 (Class 8 truck – day cab): $435,839**
  - Source: Purchase orders from HVIP voucher request documents; averaged across 32 orders
- **US/California ZET Prices 2021-22 (Class 8 truck – day cab): $349,328**
  - Source: Purchase orders from HVIP request documents 2021-2022; averaged across 57 orders
- **US Diesel Truck Prices (Class 8 truck - day cab): $155,902**
  - Source: Truckpaper.com retail sales site; based on retail prices for several hundred-day cab truck models that match models used for ZETs; prices averaged by OEM then roughly weighted by OEM market share
- **EU ZET Prices 2024 (Class 5 LH – day cab): $341,954**
  - Source: Nijenhuis Truck Solutions; average of the aggregated average price of multiple OEM models
- **EU ZET Prices 2021-22 (Class 5 LH – day cab): $390,550**
  - Source: Nijenhuis Truck Solutions; average of the aggregated average price of multiple OEM models
- **EU Diesel Truck Prices (Class 5 – LH – day cab): $118,858**
  - Sources: Truckpaper.com Global European retail sales site; average price of multiple OEM day cabs in models used for BETs; blended with Nijenhuis Truck Solutions aggregated price

*** Exchange rate between Euro and USD used for price conversions: 1 Euro = 1.07 USD

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[i] Zeroing in on Zero Emission Trucks, May 2024 Market Update, CALSTART; *https://issuu.com/calstart/docs/zio_zet_may_2024_market_update_final*

[ii] Race to Zero European Heavy-Duty Vehicle Market Development Quarterly, March 19, 2024, ICCT; *https://theicct.org/publication/race-to-zero-eu-hdv-market-development-q4-2023-mar24/#:~:text=Summary,and%200.9%25%20of%20heavy%20trucks*.

[iii] Vehicle Energy Consumption Calculation Tool (VECTO) – common method to measure and compare HD vehicle performance in the EU market; *https://www.infineuminsight.com/en-gb/articles/vecto-drives-efficiency-gains/*

Exhibit 19

Electric Vehicle Total Cost to Transport Analysis

May 2024

CHARGED LOGISTICS:

The cost of electric vehicle conversion for U.S. commercial fleets

EXECUTIVE SUMMARY

With evolving state and federal legal requirements, and potential mandates, aimed at converting commercial diesel vehicles to zero-emission vehicles (ZEV), Ryder customers frequently ask about the costs and benefits of incorporating electric vehicles (EV) into their fleets. As a result, Ryder conducted this analysis to determine the cost of EV conversion in today's market. In the analysis:

- Ryder analyzed the total cost to transport (TCT), in one-to-one comparisons, for transitioning Class 4 (light-duty), Class 6 (medium-duty), and Class 8 (heavy-duty) vehicles operating in California and Georgia from internal combustion engines (ICE) to EVs in today's market.
- Then, because most companies have more than one commercial vehicle, Ryder examined the TCT for transitioning a mixed fleet (light, medium, and heavy) of 25 ICE vehicles to EVs. The mix was based on the overall mix of commercial vehicles in the U.S. according to Polk Data Services.
- The analysis is based on representative network loads and routes from Ryder's dedicated fleet operations, which includes more than 13,000 commercial vehicles and professional drivers, as well as the impact of EV charging time and maximum payload to achieve equivalent delivery times.
- Our quantitative results show a relatively modest increase of up to 5% for light-duty EVs, and increases from 94% to 114% to convert heavy-duty trucks and from 56% to 67% to convert mixed fleets.
- Assuming that the price of goods would increase due to higher transportation costs, based on the cost impact to convert a mixed fleet from ICE to EV, we estimate these increases could cumulatively add approximately 0.5% to 1% to overall inflation.

INTRODUCTION

Ryder is at the forefront of identifying new technology for operational advancements and acts as an extended research and development arm for our suppliers and customers. Moreover, we are at the table with regulators, vehicle manufacturers, technology innovators, and industry peers as we discuss ways the industry can implement potential solutions. While Ryder is actively involved in the testing and successful deployment of EVs and charging infrastructure – as well as other alternative fuels – Ryder views the rapidly evolving transportation landscape through the lens of one of the longest-running and largest fleet owners in North America, with over 90 years of experience in truck transportation and nearly 250,000 commercial vehicles under management. With more than 41,000 commercial customers in its portfolio today, Ryder utilizes its expertise to implement logistics and transportation solutions for businesses across most industries.

With this in mind, using extensive Ryder historical data and current market prices for electric and ICE vehicles and charging infrastructure, Ryder examined the potential economic impacts of implementing an all-EV fleet. Ryder analyzed the impact in California and Georgia, as electricity, fuel, and labor costs range from some of the highest in the country to more modest. Ultimately, the analysis set out to understand the cost of electrifying a fleet and the potential impacts on businesses and consumers.

[1] Economics and Industry Data, American Trucking Associations (2022), https://www.trucking.org/economics-and-industry-data

TCT ANALYSIS: Objective and Variables

To understand the economic impacts of utilizing EVs in place of ICE vehicles, Ryder first examined the TCT for Class 4 light-duty transit vans, Class 6 medium-duty straight trucks, and Class 8 heavy-duty tractors.

Using quantitative data from representative network loads and routes from Ryder's dedicated transportation operating models, which include approximately 13,000 vehicles and professional drivers, the analysis factored in the cost of the vehicle, maintenance, drivers, range, payload, diesel fuel versus electricity, and the required EV charging time. It is important to note that the analysis assumes the accessibility and use of the fastest applicable commercial vehicle chargers – though this network infrastructure is not yet built out.

First, Ryder conducted a one-to-one analysis of a single vehicle (ICE vs. EV) in each of the light-, medium-, and heavy-duty classes using cost assumptions from California, where fuel, electricity, and labor are typically the highest in the nation, and Georgia, where cost assumptions are more favorable.

Then, as most companies have more than one vehicle, Ryder applied the individual costs to a fleet of 25 vehicles of mixed classes and types, and compared the cost of owning and operating that fleet in California and Georgia. The fleet mix is based on the overall mix of commercial vehicles in the U.S., according to third-party data, and includes 11 light-duty vans, four medium-duty straight trucks, and 10 heavy-duty tractors.

The analysis factors in a number of variables and other assumptions, including the average labor costs for California and Georgia. It also assumes fixed monthly tractor costs based on actual freight management system equipment pricing and lower EV maintenance costs, compared to ICE maintenance costs, due to fewer moving parts and no need to change oil or diesel exhaust fluid. The analysis estimates EV energy costs using current assessment models and fuel costs of $6.13 per gallon in California and $4.19 per gallon in Georgia. The cost of hardware, installation, and maintenance of EV chargers reflects actual infrastructure projects at current Ryder locations amortized over the life of the charger and multiple power units. The analysis estimates insurance and other general and administrative expenses (G&A) to be equal for one ICE unit and one EV unit.

CLASS 4
One-to-One Comparison

The Class 4 comparison assumes short-haul deliveries of about 80 miles, two trips per day, about 40,000 miles annually, and one local Class C driver per vehicle. The average payload for each is 2,500 pounds.

The first chart shows the comparison results for a single ICE transit van versus an EV transit van in California. The annual cost to convert to an EV is estimated at just under $5,000 or a 3% increase. While the cost of the vehicle is 71% more and labor is 19% more due to additional hours of service for EV charging time, fuel vs. energy and maintenance costs decrease 71% and 22% respectively, resulting in a relatively modest increase in TCT.

CALIFORNIA

	1 Driver - 1 Van		1 Driver - 1 Van			
	ICE VANS		EV VANS		VARIANCE	
Category	**Cost Detail**	**Amount**	**Cost Detail**	**Amount**	**Variance**	**% Change**
Labor Cost	1 driver, $23/hr @ 48 hours weekly	$62,192	1 driver, $23/hr @ 55 hours weekly	$74,032	$11,840	19%
Other Personnel Costs	PTO, Payroll Tax, Workers Comp	$30,441	PTO, Payroll Tax, Workers Comp	$33,115	$2,674	9%
Equipment Cost*	1 van, $1,030/month per unit	$12,360	1 van, $1,766/month per unit	$21,192	$8,832	71%
Equipment Maintenance Cost*	$0.09/mile	$3,805	$0.07/mile	$2,959	$(846)	(22%)
Fuel vs. Energy Cost	$0.67/mile fuel cost, 9.1 MPG	$28,479	$0.19/mile energy cost	$8,158	$(20,321)	(71%)
EV Charger Cost	N/A	$ –	$124k hardware, installation, maintenance	$2,756	$2,756	–
Other Operating Costs	1 van, insurance, G&A, CVCs, etc.	$34,046	1 van, insurance, G&A, CVCs, etc.	$34,046	$ –	0%
Total	**Annual TCT**	**$171,323**	**Annual TCT**	**$176,258**	**$4,935**	**3%**

3% TOTAL COST INCREASE

The second chart shows the comparison results in Georgia in which the TCT for an ICE vehicle and is estimated to have a variance of nearly $8,000 or an increase of approximately 5%. The variance in Georgia is greater than California due to the difference between gas and energy costs in each state.

GEORGIA

	1 Driver - 1 Van		1 Driver - 1 Van			
	ICE VANS		EV VANS		VARIANCE	
Category	**Cost Detail**	**Amount**	**Cost Detail**	**Amount**	**Variance**	**% Change**
Labor Cost	1 driver, $22/hr @ 48 hours weekly	$58,535	1 driver, $22/hr @ 55 hours weekly	$70,071	$11,536	20%
Other Personnel Costs	PTO, Payroll Tax, Workers Comp	$29,616	PTO, Payroll Tax, Workers Comp	$32,220	$2,604	9%
Equipment Cost*	1 van, $1,030/month per unit	$12,360	1 van, $1,766/month per unit	$21,192	$8,832	71%
Equipment Maintenance Cost*	$0.09/mile	$3,805	$0.07/mile	$2,959	$(846)	(22%)
Fuel vs. Energy Cost	$0.44/mile fuel cost, 9.1 MPG	$18,649	$0.04/mile energy cost	$1,694	$(16,955)	(91%)
EV Charger Cost	N/A	$ –	$124k hardware, installation, maintenance	$2,756	$2,756	–
Other Operating Costs	1 van, insurance, G&A, CVCs, etc.	$33,075	1 van, Insurance, G&A, CVCs, etc.	$33,075	$ –	0%
Total	**Annual TCT**	**$156,040**	**Annual TCT**	**$163,967**	**$7,927**	**5%**

5% TOTAL COST INCREASE

* Equipment and maintenance costs are averages

CLASS 6
One-to-One Comparison

The Class 6 comparison assumes short to medium hauls from 100 to 230 miles, one to two trips per day, about 55,000 miles annually, and one local Class B driver per vehicle. The average payload is 11,000 pounds.

The first chart below shows the comparison results for a single ICE straight truck and an equivalent EV in California. The annual TCT to convert to an EV is approximately $48,000 or nearly 22% higher. The cost of the vehicle increases 216%, which is only partially offset by a 57% savings in fuel and energy costs and 22% savings on maintenance.

CALIFORNIA

	1 Driver - 1 Truck		1 Driver - 1 Truck			
	ICE TRUCKS		EV TRUCKS		VARIANCE	
Category	**Cost Detail**	**Amount**	**Cost Detail**	**Amount**	**Variance**	**% Change**
Labor Cost	1 driver, $27/hr @ 48 hours weekly	$73,008	1 driver, $27/hr @ 51 hours weekly	$78,589	$5,581	8%
Other Personnel Costs	PTO, Payroll Tax, Workers Comp	$32,884	PTO, Payroll Tax, Workers Comp	$34,144	$1,260	4%
Equipment Cost*	1 truck, $2,364/month per unit	$28,366	1 truck, $7,466/month per unit	$89,592	$61,226	216%
Equipment Maintenance Cost*	$0.09/mile	$5,171	$0.07/mile	$4,022	$(1,149)	(22%)
Fuel vs. Energy Cost	$0.67/mile fuel cost, 9.1 MPG	$38,707	$0.29/mile energy cost	$16,700	$(22,007)	(57%)
EV Charger Cost	N/A	$ –	$186k hardware, installation, maintenance	$2,657	$2,657	–
Other Operating Costs	1 truck, insurance, G&A, CVCs, etc.	$42,411	1 truck, insurance, G&A, CVCs, etc.	$42,411	$ –	0%
Total	**Annual TCT**	**$220,547**	**Annual TCT**	**$268,115**	**$47,568**	**22%**

22% TOTAL COST INCREASE

The second chart shows the comparison results in Georgia, where the annual TCT convert to an EV is estimated to increase nearly $54,000 or almost 28%. As in the Class 4 comparison, the variance in Georgia is greater than California due to the difference between gas and energy costs in each state. Once again, the variance in Georgia is greater than California due to the difference between gas and energy costs in each state.

GEORGIA

	1 Driver - 1 Truck		1 Driver - 1 Truck			
	ICE TRUCKS		EV TRUCKS		VARIANCE	
Category	**Cost Detail**	**Amount**	**Cost Detail**	**Amount**	**Variance**	**% Change**
Labor Cost	1 driver, $24/hr @ 48 hours weekly	$63,625	1 driver, $24/hr @ 51 hours weekly	$68,349	$4,724	7%
Other Personnel Costs	PTO, Payroll Tax, Workers Comp	$30,765	PTO, Payroll Tax, Workers Comp	$31,831	$1,066	3%
Equipment Cost*	1 truck, $2,364/month per unit	$28,366	1 truck, $7,466/month per unit	$89,592	$61,226	216%
Equipment Maintenance Cost*	$0.09/mile	$5,171	$0.07/mile	$4,022	$(1,149)	(22%)
Fuel vs. Energy Cost	$0.44/mile fuel cost, 9.1 MPG	$25,346	$0.18/mile energy cost	$10,236	$(15,110)	(60%)
EV Charger Cost	N/A	$ –	$186k hardware, installation, maintenance	$2,657	$2,657	–
Other Operating Costs	1 truck, insurance, G&A, CVCs, etc.	$40,494	1 truck, Insurance, G&A, CVCs, etc.	$40,494	$ –	0%
Total	**Annual TCT**	**$193,767**	**Annual TCT**	**$247,181**	**$53,414**	**28%**

28% TOTAL COST INCREASE

* Equipment and maintenance costs are averages

CLASS 8

One-to-One Comparison

The Class 8 comparison assumes hauls ranging from 100 to 500 miles, one to two trips per day, about 109,000 miles annually, and 1.2 local Class A drivers per diesel vehicle (typical for an ICE unit in Ryder's dedication transportation operations). The average payload in this scenario is 29,000 pounds for an ICE unit. At this time, the maximum payload for an EV is approximately 22,000 pounds. Given the payload differences between ICE and EV heavy-duty commercial vehicles, as well as accounting for EV charging time and equivalent delivery times, Ryder estimates that nearly two EVs and more than two drivers are needed to equal the output of one ICE vehicle.

The first chart shows the comparison results for a single ICE heavy-duty tractor and equivalent EV in California. Due to the increased number of tractors and drivers needed, the annual TCT to convert to EVs is nearly double, with a variance of $314,000 or 94%. The cost of the vehicles is the largest contributor at more than 500%, followed by operating costs at 87%, labor costs at 76%, and other personnel costs at 74%. Fuel and energy savings are 52%.

CALIFORNIA

	ICE TRUCKS (1.2 Drivers - 1 Tractor)		EV TRUCKS (2.07 Drivers - 1.87 Tractors)		VARIANCE	
Category	**Cost Detail**	**Amount**	**Cost Detail**	**Amount**	**Variance**	**% Change**
Labor Cost	1.2 drivers, $29/hr, ~58 hours/week	$93,285	2.07 drivers, $30/hr, ~97 hours/week	$164,151	$70,866	76%
Other Personnel Costs	PTO, Payroll Tax, Workers Comp	$40,742	PTO, Payroll Tax, Workers Comp	$70,955	$30,213	74%
Equipment Cost*	1 tractor, $3,444/month per unit	$41,328	1.87 tractors, $11,091/month per unit	$248,438	$207,110	501%
Equipment Maintenance Cost*	$0.065/mile	$7,097	$0.06/mile	$8,734	$1,637	23%
Fuel vs. Energy Cost	$0.89/mile fuel cost, 6.9 MPG	$96,997	$0.32/mile energy cost	$46,126	$(50,871)	(52%)
EV Charger Cost	N/A	$ –	$186k hardware, installation, maintenance	$8,267	$8,267	–
Other Operating Costs	1 tractor, insurance, G&A, CVCs, etc.	$54,665	1.87 tractors, insurance, G&A, CVCs, etc.	$102,041	$47,376	87%
Total	**Annual TCT**	**$334,114**	**Annual TCT**	**$648,712**	**$314,598**	**94%**

94% TOTAL COST INCREASE

The second chart shows the comparison results in Georgia in which the TCT for an ICE vehicle versus an EV shows a variance of more than $330,000 or just under 114%. Here again, the variance in Georgia is greater than California due to the difference between gas and energy costs in each state.

GEORGIA

	ICE TRUCKS (1.2 Drivers - 1 Tractor)		EV TRUCKS (2.07 Drivers - 1.87 Tractors)		VARIANCE	
Category	**Cost Detail**	**Amount**	**Cost Detail**	**Amount**	**Variance**	**% Change**
Labor Cost	1.2 drivers, $27/hr, ~58 hours/week	$87,090	2.07 drivers, $30/hr, ~97 hours/week	$156,179	$69,089	79%
Other Personnel Costs	PTO, Payroll Tax, Workers Comp	$39,343	PTO, Payroll Tax, Workers Comp	$69,155	$29,812	76%
Equipment Cost*	1 tractor, $3,444/month per unit	$41,328	1.87 tractors, $11,091/month per unit	$248,438	$207,110	501%
Equipment Maintenance Cost*	$0.065/mile	$7,097	$0.06/mile	$8,734	$1,637	23%
Fuel vs. Energy Cost	$0.58/mile fuel cost, 6.9 MPG	$63,515	$0.23/mile energy cost	$33,091	$(30,424)	(48%)
EV Charger Cost	N/A	$ –	$186k hardware, installation, maintenance	$8,267	$8,267	–
Other Operating Costs	1 tractor, insurance, G&A, CVCs, etc.	$52,808	1.87 tractors, insurance, G&A, CVCs, etc.	$98,574	$45,766	87%
Total	**Annual TCT**	**$291,181**	**Annual TCT**	**$622,438**	**$331,257**	**114%**

* Equipment and maintenance costs are averages

114% TOTAL COST INCREASE

Mixed Fleet Comparison

Ryder applied the TCT for individual vehicles (as outlined previously) to a fleet of 25 commercial vehicles of mixed classes and types in California and Georgia. The mix of the 25 units is a representative sample of the fleet mix in the U.S. today according to Polk Data, which is approximately 43% Class 3-4 (light-duty) vehicles, 17% Class 5-6 (medium-duty) vehicles, and 40% Class 7-8 (heavy-duty) vehicles.

For light- and medium-duty vehicles, the analysis estimates one driver per vehicle for both ICE and EV. For heavy-duty vehicles, as found in the one-to-one comparisons, it is estimated that a company would need nearly two EV tractors and more than two drivers to haul the same load on the same route as one ICE vehicle. In this scenario, a company converting 10 ICE tractors, is estimated to need almost 19 EV tractors and 21 total drivers for the same level of service. This is estimated to increase the number of vehicles from 25 to 34.

Therefore, to convert a mixed fleet of vehicles in California from ICE to EV, the annual TCT is estimated to be nearly $3.4 million or a 56% increase. To convert that same size fleet in Georgia, the TCT is estimated to be more than $3.7 million or a 67% increase.

CALIFORNIA

	ICE TRUCKS			EV TRUCKS			TOTAL COST IMPACT	
TRUCK TYPE	TOTAL ICE UNITS REQURIED	TOTAL DRIVERS REQUIRED	ICE TCT	TOTAL EV UNITS REQUIRED	TOTAL DRIVERS REQUIRED	EV TCT	COST IMPACT	% IMPACT
Transit Van*	11	11	$1,884,560	11	11	$1,938,845	$(54,284)	3
Straight Truck*	4	4	$882,286	4	4	$1,072,459	$(190,173)	22
Tractor**	10	12	$3,341,132	18.7	20.7	$6,487,119	$(3,145,987)	94
Total	**25**	**27**	**$6,107,878**	**33.7**	**35.7**	**$9,498,423**	**$(3,390,545)**	**56**

56% TOTAL COST INCREASE

* Assumes 1 truck and 1 driver for ICE and EV transit van and straight truck
** Assumes 1.2 drivers and 1 tractor for ICE and 2.07 drivers and 1.87 tractors for EV

GEORGIA

	ICE TRUCKS			EV TRUCKS			TOTAL COST IMPACT	
TRUCK TYPE	TOTAL ICE UNITS REQURIED	TOTAL DRIVERS REQUIRED	ICE TCT	TOTAL EV UNITS REQUIRED	TOTAL DRIVERS REQUIRED	EV TCT	COST IMPACT	% IMPACT
Transit Van*	11	11	$1,716,434	11	11	$1,803,643	$(87,208)	5
Straight Truck*	4	4	$775,070	4	4	$988,724	$(213,654)	28
Tractor**	10	12	$2,911,808	18.7	20.7	$6,224,393	$(3,312,585)	114
Total	**25**	**27**	**$5,403,312**	**33.7**	**35.7**	**$9,016,760**	**$(3,613,447)**	**67**

67% TOTAL COST INCREASE

* Assumes 1 truck and 1 driver for ICE and EV transit van and straight truck
** Assumes 1.2 drivers and 1 tractor for ICE and 2.07 drivers and 1.87 tractors for EV

TCT IMPACT ON BUSINESSES AND CONSUMERS

According to the American Trucking Associations, approximately 72% of goods are transported by trucks in the U.S. today. Ryder's analysis estimates cost increases of 94% to 114% to convert heavy-duty trucks to EVs and 56% to 67% to convert mixed fleets of 25 vehicles, depending on the geographic region. If businesses pass the increased cost of transportation onto consumers through higher prices, based on the average cost impact to convert mixed fleets, Ryder estimates that such increased costs could cumulatively add approximately 0.5% to 1% to overall inflation.[2]

INDUSTRY VARIABLES TO CONSIDER

There has been an increased focus on the development of commercial EVs over the past decade. That said, the commercial EV market is still nascent, and there are ongoing challenges such as infrastructure development, battery technology improvements, and cost considerations that continue to hinder adoption.

While this analysis centers on the TCT to convert a fleet in today's landscape, Ryder and the entire industry are considering additional major variables in the adoption of commercial EVs. Two of those variables are EV availability and charging infrastructure.

EV Vehicle Availability

Today, there are 16.4 million Class 3-8 commercial vehicles in operation in the U.S.; of this number only an estimated 18,000 EVs are currently deployed[3]. Additionally, production estimates continue to be volatile in part due to the changing regulatory landscape. Therefore, if companies are required to convert to EVs in the near future, availability and production of EVs may be far less than the vehicles needed to run America's supply chains.

Charging Infrastructure

The Clean Freight Coalition (CFC), an alliance of truck transportation stakeholders, has stated that there is no network in the U.S. where over-the-road professional truck drivers can stop for legally mandated rest breaks and charge a vehicle battery at the same time. According to a report released by the CFC, preparing today's commercial vehicle fleet for electrification would require an investment of nearly $1 trillion in charging infrastructure and electric service upgrades[4].

Additionally, the International Council on Clean Transportation estimates that nearly 700,000 chargers will be needed nationwide to accommodate the one million Class 4, 6, and 8 EVs anticipated to be deployed by 2030, which will consume 140,000 megawatts of electricity every day, equivalent to the daily energy needs of nearly 5 million American homes[5]. Along with these above findings, the Joint Office of Energy and Transportation recently released a zero-emission freight corridor strategy that would not achieve a national charging network in the U.S. until between 2035 and 2040.

[2]Estimated impact on inflation based on Consumer Price Index (CPI) data for all urban consumers from the U.S. Bureau of Labor Statistics assuming transportation costs are 2-4% of certain CPI expenditure categories. See Consumer Price Index data, U.S. Bureau of Labor Statistics (as of February 2024), available at https://www.bls.gov/cpi/. See also F. Curtis Barry & Company, https://www.fcbco.com/articles-and-whitepapers/articles/bid/129441/rising-transportation-costs-and-what-to-do-about-them ("Inbound freight costs for domestically sourced product typically range from 2%-4% of gross sales")., [3]CALSTART report Zeroing in on Zero-Emission Trucks January 2024, [4]CFC Whitepaper: Forecasting a Realistic Electricity Infrastructure Buildout for Medium- & Heavy-Duty Battery Electric Vehicles, [5]The International Council on Clean Transportation – theicct.org

It must be noted, the American Trucking Associations opposes the recently announced EPA emission standard for heavy-duty trucks, saying it's entirely unachievable given the lack of charging infrastructure and restrictions on the power grid.

With more than 80% of U.S. communities relying exclusively on trucking for goods[6], charging infrastructure would need to be in place for the successful conversion of fleets from ICE to EV.

CONCLUSION

Ryder's analysis underscores the reasons EV adoption for commercial vehicles remains in its infancy. In addition to the limited support infrastructure and EV availability, the business case for converting to EV for most payload and mileage applications, is extremely challenging.

While Ryder's analysis estimated the one-to-one conversion to EV for light-duty vehicles to be a relatively modest up to 5% increase in cost – and a good introduction to EV adoption – the one-to-one conversion for medium- and heavy-duty vehicles is estimated to be up to nearly 114% more costly. When expanding the analysis to a mixed fleet, Ryder estimated it can cost 56% more to convert a fleet to EV in California, where fuel and energy costs are typically higher than other states. The cost to convert a fleet is up to 67% more in Georgia, which shows lower fuel and energy costs do not provide the same offsets to the substantially higher EV equipment, operating, and labor costs.

Furthermore, mandating an EV transition at this time may lead to disruptions in our nation's supply chains as well as crippling inflationary pressures on all products moved by trucks. Ryder's analysis shows that if EVs are mandated by law, or encouraged by implementing a tax or fee on ICE vehicles to tilt the economics in favor of EVs, the resulting transportation cost increases could cumulatively add approximately 0.5% to 1% to overall inflation.

Today, Ryder helps customers successfully introduce EVs into their fleets in cases in which the customers' transportation needs align with the technology's current capabilities and available infrastructure. Ryder stands ready to help lead our customers through any energy transition in the commercial transportation industry. However, the technology needed to implement a transition must be available, reliable, and cost competitive with current vehicle technology alternatives.

Now is the time for all stakeholders to come together to examine the big picture. It will take regulators, vehicle manufacturers, technology innovators, and other transportation companies working together to affect real change. This includes a focus on expanding EV payload and range to match ICE vehicles, while keeping the cost of EVs comparable to provide an economic advantage. We must also pursue other alternative fuel technologies—natural gas, hydrogen, hybrids, and carbon capture.

The key to successfully transitioning to a zero-emission future is to find a balance between encouraging innovation and safeguarding the interests of businesses, consumers, and the environment.

[6] ATRI

ABOUT RYDER

Ryder System, Inc. (NYSE: R) is a fully integrated port-to-door logistics and transportation company. It provides supply chain, dedicated transportation, and fleet management solutions, including warehousing and distribution, contract manufacturing and packaging, e-commerce fulfillment, last-mile delivery, managed transportation, professional drivers, freight brokerage, nearshoring solutions, full-service leasing, maintenance, commercial truck rental, and used vehicle sales to some of the world's most-recognized brands. Ryder provides services throughout the United States, Mexico, and Canada. In addition, Ryder manages nearly 250,000 commercial vehicles, services fleets at 760 maintenance locations, and operates nearly 300 warehouses encompassing more than 100 million square feet. Ryder is regularly recognized for its industry-leading practices; technology-driven innovations; corporate responsibility; environmental management; safety, health and security programs; military veteran recruitment initiatives; and the hiring of a diverse workforce. www.ryder.com

Note Regarding Forward-Looking Statements: Certain statements and information included in this news release are "forward-looking statements" within the meaning of the Federal Private Securities Litigation Reform Act of 1995. These forward-looking statements, including our expectations with respect costs of EVs, including related costs of maintenance, charging infrastructure, labor, and insurance, as well as our expectations related to the impact of converting fleets to EVs on supply chains and inflation, are based on our current plans and expectations and are subject to risks, uncertainties and assumptions. Accordingly, these forward-looking statements should be evaluated with consideration given to the many risks and uncertainties that could cause actual results and events to differ materially from those in the forward-looking statements including those risks set forth in our periodic filings with the Securities and Exchange Commission. New risks emerge from time to time. It is not possible for management to predict all such risk factors or to assess the impact of such risks on our business. Accordingly, we undertake no obligation to publicly update or revise any forward-looking statements, whether as a result of new information, future events, or otherwise.

Ryder® Ever better.™

Exhibit 20

Renewable Diesel – A Catalyst for Decarbonization

April 2024

Prepared by the American Transportation Research Institute

American Transportation Research Institute

Renewable Diesel – A Catalyst for Decarbonization

April 2024

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LIST OF ACRONYMS

ACF	Advanced Clean Fleets
ACT	Advanced Clean Trucks
ANL	Argonne National Laboratory
ASTM	American Society for Testing Materials
ATRI	American Transportation Research Institute
B20	Blend of diesel with 6 percent to 20 percent biodiesel
B5	Blend of diesel with up to 5 percent biodiesel
BEV	Battery Electric Vehicle
CARB	California Air Resources Board
CO_2	Carbon Dioxide
DOE	Department of Energy
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EU	European Union
FAAE	Fatty Acid Alkyl Esters
FAME	Fatty Acid Methyl Esters
FCEV	Hydrogen-Fuel-Cell Electric Vehicles
FHWA	Federal Highway Administration
GHG	Greenhouse Gases
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
IATA	International Air Transport Association
ICCT	International Council on Clean Transportation
ICE	Internal Combustion Engine
ICE RD	Internal Combustion Engine using Renewable Diesel
IEDO	Industrial Efficiency and Decarbonization Office
IRA	Inflation Reduction Act
IRS	Internal Revenue Service
LCFS	Low Carbon Fuel Standards
MHDV	Medium- and Heavy-Duty Vehicles

NO_x	**Oxides of Nitrogen**
OPEC	**Organization of Petroleum Exporting Countries**
PACE	**Partnership in Assisting Community Expansion**
PM	**Particulate Matter**
PROTECT	**Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation**
PUC	**Public Utilities Commissions**
RD	**Renewable Diesel**
RED	**Renewable Energy Directive**
RFNBO	**Renewable Fuels of Non-Biological Origin**
RFS2	**Renewable Fuel Standard**
RVO	**Renewable Volume Obligations**
SAF	**Sustainable Aviation Fuel**
TCO	**Total Cost of Ownership**
UCO	**Used Cooking Oil**
ULSD	**Ultra-Low Sulfur Diesel**
ZEV	**Zero-Emission Vehicle**

INTRODUCTION

In May 2022 the American Transportation Research Institute (ATRI) published research that compared the life-cycle carbon dioxide (CO_2) emissions of petroleum diesel fueled trucks to alternative fueled trucks.[1] Using the GREET model, which was developed by the U.S. Department of Energy's (DOE) Argonne National Laboratory (ANL), ATRI's analysis measured CO_2 emission decreases that could be achieved through the use of alternative energy sources.[2] These findings included a potential 30.0 percent decrease in life-cycle CO_2 per truck through the use of battery electric vehicle (BEV) trucks and a 67.3 percent decrease through the use of renewable diesel (RD) in existing Class 8 trucks.

A second ATRI study, published in December 2022, looked at the technical and electric infrastructure-related challenges of shifting to BEV trucks.[3] The report identified substantial barriers to implementation including:

- Insufficient electricity generation, transmission and distribution in the U.S.;
- The need for a widely accessible truck charging network; and
- Complications related to the mining and processing of battery materials.

The following RD research is an extension of the previous ATRI reports, taking a more robust look at the factors and benefits of using RD as an alternative to BEV. This report assesses:

- RD as an alternative to both traditional diesel and BEV trucks;
- RD's implications from environmental, operational and financial perspectives; and
- Processes and policies for potentially increasing the use of RD in the trucking industry.

Diesel Fuel Definitions

Diesel is the primary fuel used by heavy-duty trucks in the U.S. Most diesel fuel is sourced from petroleum, though non-petroleum feedstocks can be used to produce fuel that meets diesel standards.

Petroleum Diesel. Petroleum diesel is a fuel derived from crude oil which is comprised of hydrocarbons.[4] Crude oil and its derivatives are referred to as fossil fuels since they were "primarily formed from plants and organisms that lived millions of years ago."[5] When burned,

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[1] Jeffrey Short and Danielle Crownover, *Understanding the CO2 Impacts of Zero-Emission Trucks: A Comparative Life-Cycle Analysis of Battery Electric*, *Hydrogen Fuel Cell and Traditional Diesel Trucks*, American Transportation Research Institute (May 2022), https://truckingresearch.org/2022/05/understanding-the-co2-impacts-of-zero-emission-trucks/

[2] The GREET Model's full title is "The Greenhouse gases, Regulated Emissions, and Energy use in Technologies" Model. It is described by the DOE as "a one-of-a-kind analytical tool that simulates the energy use and emissions output of various vehicle and fuel combinations." The model is housed within DOE's Office of Energy Efficiency and Renewable Energy and is provided to the public through the Argonne National Laboratory.

[3] Jeffery Short, Alexandra Shirk, and Alexa Pupillo, *Charging Infrastructure Challenges for the U.S. Electric Vehicle Fleet*, American Transportation Research Institute (December 2022), https://truckingresearch.org/2022/12/charging-infrastructure-challenges-for-the-u-s-electric-vehicle-fleet-december-2022-full-report/.

[4] U.S. Energy Information Administration, "Oil and petroleum products explained" (updated on June 12, 2023), https://www.eia.gov/energyexplained/oil-and-petroleum-products/.; and U.S. Energy Information Administration, "Diesel fuel explained" (updated on December 22, 2023), https://www.eia.gov/energyexplained/diesel-fuel/.

[5] Federal Energy Regulatory Commission, *Energy Primer: A Handbook for Energy Market Basics* (April 2020), Staff Report, https://www.ferc.gov/sites/default/files/2020-06/energy-primer-2020.pdf.

these fuels release CO_2 into the atmosphere that had been previously stored underground for millennia. Adding this CO_2 to the atmosphere further traps heat from the sun and increases average temperatures on the planet.[6]

Petroleum diesel in the U.S. is required to meet technical standards in specific applications and regions.

- ASTM D975: This is the key diesel fuel grade standard; it is met through a series of required test outcomes (e.g. flash point, viscosity, lubricity).[7]
- Ultra-Low-Sulfur Diesel (ULSD): Diesel with a sulfur content of 15 ppm or less. The U.S. Environmental Protection Agency (EPA) requires all highway diesel fuel supplied and used by highway vehicles to be ULSD.[8]
- CARB Diesel: A specific grade of diesel required by the California Air Resources Board (CARB).[9] CARB diesel requires lower aromatics than ULSD to reduce emissions such as oxides of nitrogen (NO_x) in older vehicles.[10]

Two Biofuels for Trucking: Biodiesel and Renewable Diesel. Biofuels, which are not fossil fuels, represent an alternative and/or supplement to petroleum diesel. Biofuels are made from plant- and animal-based products and waste streams that are converted into a useable fuel and are considered renewable since they are derived from organic material that can be grown.[11] Unlike petroleum diesel, biofuels are not fossil fuels. That is because the organic materials used to make renewable diesel – such as soybean oil – remove carbon from the air when growing, and then release carbon when the organic material is processed, combusted or decomposed.

The two most common biofuels used by the trucking industry are described below.

- *Biodiesel.* A biofuel that consists of fatty acid methyl esters (FAME) that is chemically different from petroleum diesel.[12] Biodiesel is typically blended with petroleum diesel to form B5 (up to 5% biodiesel) or B20 (6% to 20% biodiesel); higher concentrations can have negative impacts on engine components.[13] Biodiesel is produced through

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[6] National Aeronautics and Space Administration, "Vital Signs of the Planet: Carbon Dioxide" (accessed February 7, 2024), https://climate.nasa.gov/vital-signs/carbon-dioxide/.
[7] 1. Robin Fulk, "What you Need to Know about ASTM D975," Polaris Laboratories (February 2018), https://polarislabs.com/decoding-astm-d975/
[8] U.S. Environmental Protection Agency, "Diesel Fuel Standards and Rulemakings" (updated on August 18, 2023), https://www.epa.gov/diesel-fuel-standards/diesel-fuel-standards-and-rulemakings#
[9] McKinsey & Company, "CARB Diesel" (accessed February 2024), https://www.mckinseyenergyinsights.com/resources/refinery-reference-desk/carb-diesel/#
[10] Maryam Hajbabaei et al., "Assessment of the emissions from the use of California Air Resources Board qualified diesel fuels in comparison with Federal diesel fuels," *International Journal of Engine Research* 14, no. 2 (June 2012), https://journals.sagepub.com/doi/10.1177/1468087412446883?icid=int.sj-full-text.similar-articles.2.
[11] Philipp Cavelius et al., "The potential of biofuels from first to fourth generation," *PLoS Biology* (30), no. 3 (March 2023), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10063169/#.
[12] Biodiesel meets the ASTM D6751 standard.
[13] Alternative Fuels Data Center, "Biodiesel Blends" (accessed on February 12, 2024), U.S Department of Energy, https://afdc.energy.gov/fuels/biodiesel_blends.html.; Possible engine Issues include: "operational problems associated with oxidative stability, engine oil dilution, formation of deposits in fuel injection systems, compatibility with some materials, and low-temperature operability." as discussed in: A.D. Bugarski, J.A. Hummer, and S.E. Vanderslice, "Effects of FAME biodiesel and HVORD on emissions from an older-technology diesel engine," *Mining Engineering* 69, no. 12 (December 2017), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5769955/#.

transesterification, where alcohol is combined with either vegetable oil or animal fat to form fatty acid alkyl esters (FAAE) and glycerol.[14] The FAAE is further processed to produce biodiesel and the leftover glycerol can be used to make soap. At the end of this process the biodiesel still includes oxygen which decreases its energy volume, leads to corrosion in engines, and has a higher cloud-point than traditional diesel.[15]

- *Renewable Diesel.* RD, which is the focus of this report, is a fuel that is produced to be "chemically identical" to petroleum diesel; thus, RD can be mixed with petroleum diesel in any amount or used as a standalone, drop-in fuel in a traditional diesel truck without consequences.[16] There are several methods for producing RD, with the most common being hydrotreating. In the hydrotreating process, lipids from feedstocks of vegetable or animal products, or waste are reacted with hydrogen under high temperature and pressure to remove water and oxygen.[17] Other steps are then taken to separate out the final RD product.

Diesel Fuel Use in Trucking

The transportation sector is the end-user for nearly all petroleum diesel consumed in the U.S. Across the sector, which includes trucks, buses, rail and maritime, more than 46.4 billion gallons were consumed in 2023 (including biodiesel and renewable diesel blended into petroleum diesel).[18] ATRI estimates that, in 2023, the trucking industry consumed most of this diesel (77.8%); annual consumption estimates are shown in Figure 1.[19]

It should be noted that the numbers in the data sources used by ATRI often have many decimal places. While ATRI uses the complete decimal figures in its research calculations, the ATRI report tables often show outputs rounded to the nearest meaningful decimal place for formatting and presentation purposes. As a result, the numbers in the tables periodically do not add up due to rounding. Tables where numeric rounding occurs are marked in the report with an asterisk (*).

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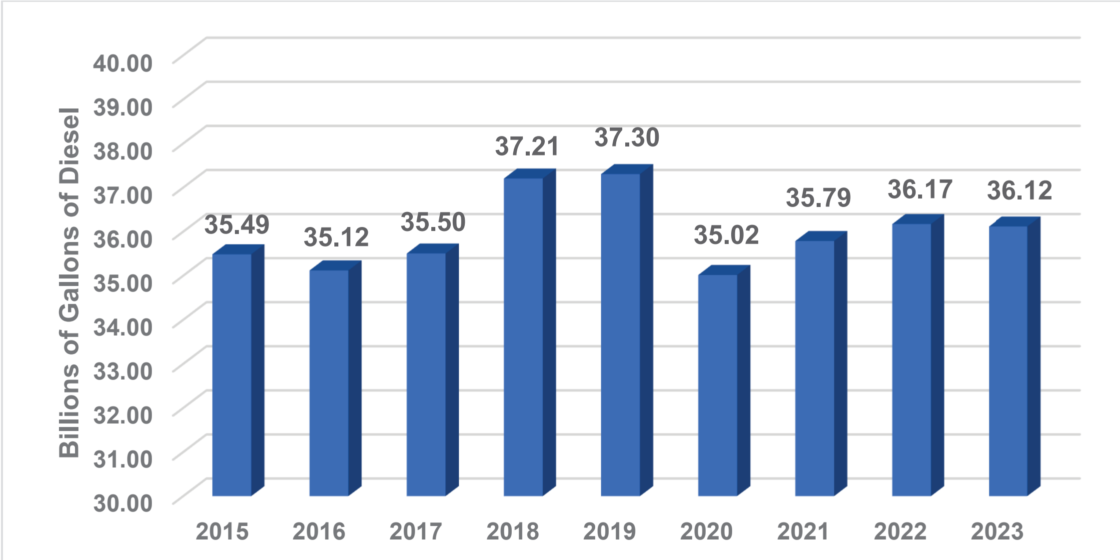
[14] Venkatesh Mandari and Santhosh Kumar Devarai, "Biodiesel Production Using Homogeneous, Heterogeneous, and Enzyme Catalysts via Transesterification and Esterification Reactions: a Critical Review," *BioEnergy Research* 15, no. 2 (September 2021), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8476987/.
[15] Maria Gerveni and Scott Irwin, "Biodiesel and Renewable Diesel: What's the Difference?," *farmdoc daily* 3, no. 22 (February 8, 2023), University of Illinois, https://farmdocdaily.illinois.edu/2023/02/biodiesel-and-renewable-diesel-whats-the-difference.html.
[16] State of Oregon Department of Environmental Quality, *Renewable Diesel 101* (accessed March 2024), https://www.oregon.gov/deq/FilterDocs/cfpdieselfaq.pdf; Alternative Fuels Data Center, "Renewable Diesel" (accessed on March 19, 2024), U.S. Department of Energy, https://afdc.energy.gov/fuels/renewable_diesel.html#:.
[17]Ibid.
[18] U.S. Energy Information Administration, *January 2024: Monthly Energy Review* (January 29, 2024), "Table 3.7c Petroleum Consumption: Transportation and Electric Power Sectors," https://www.eia.gov/totalenergy/data/monthly/archive/00352401.pdf.
[19] Ibid.; and
Oak Ridge National Laboratory, *Transportation Energy Book: Edition 40* (May 2023), "Table 2.7 Domestic Consumption of Transportation Energy by Mode and Fuel Type, 2019," https://tedb.ornl.gov/wp-content/uploads/2022/03/TEDB_Ed_40.pdf.; and
Federal Highway Administration, "Highway Statistics Series 2022" (accessed on February 2024), U.S. Department of Transportation, https://www.fhwa.dot.gov/policyinformation/statistics.cfm.

Figure 1: Annual U.S. Consumption of Diesel Fuel by Large Trucks*

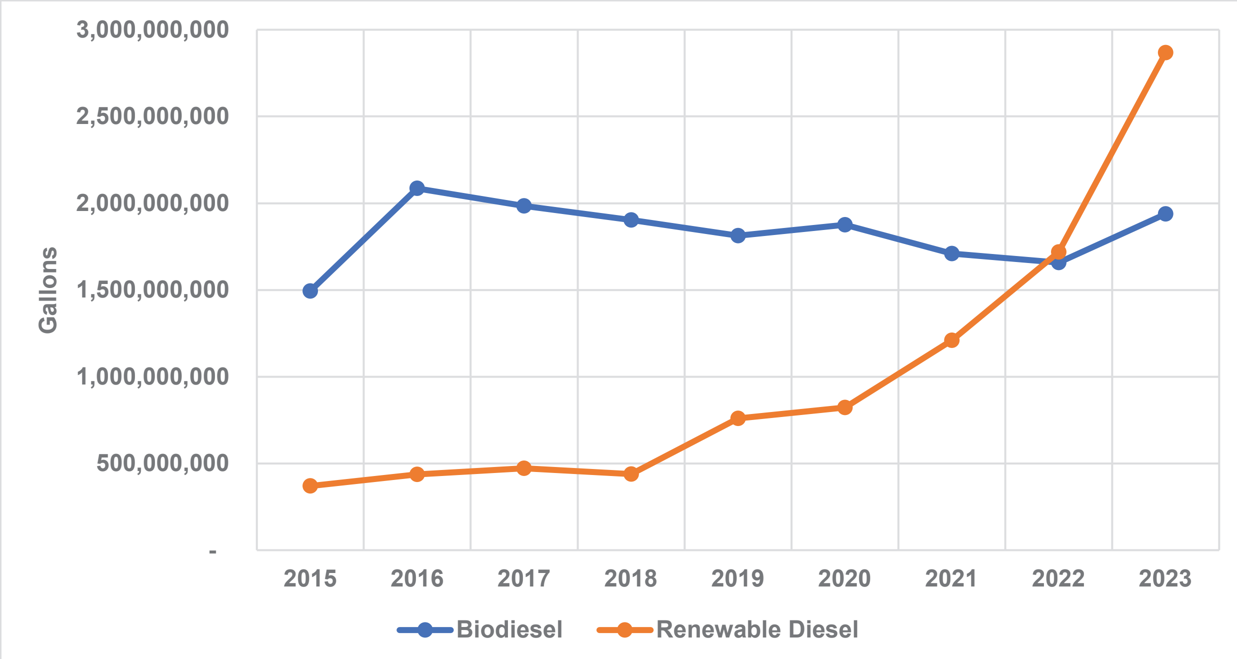


This report, however, focuses on petroleum diesel and RD use specifically by heavy-duty tractors. ATRI utilized the Federal Highway Administration (FHWA) Highway Statistics series to identify diesel consumption by this group. The statistics show that the nation's 3.25 million registered combination trucks consumed 28 billion gallons of diesel in 2022.[20]

Biodiesel, which is primarily blended with petroleum diesel but is not chemically identical to petroleum diesel, has historically been the most widely consumed biofuel for use in trucking. However, as shown in Figure 2, RD consumption has surpassed biodiesel in recent years as domestic production capacity has grown and incentives for production have been put in place.[21]

[20] Federal Highway Administration, Highway Statistics Series 2022 (accessed March 2024), U.S. Department of Transportation, https://www.fhwa.dot.gov/policyinformation/statistics.cfm. Table VM-1 indicates that 3,249,824 combination trucks consumed 28.218 billion gallons of diesel fuel at 6.9 mpg to drive 195.389 billion miles.
[21] U.S. Energy Information Administration, *March 2024: Monthly Energy Review* (April 05, 2024), p. 194-195, https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf.

Figure 2: Annual U.S. Consumption of Biodiesel and Renewable Diesel



As indicated in Figure 2, in 2023 RD consumption levels reached 2.868 billion gallons annually in the U.S. This represents a 66.9 percent increase from consumption in 2022, which was 1.718 billion gallons. In 2022 CARB reported that 73 percent of RD consumed in the U.S. was sold in California and received credits through its Low Carbon Fuel Standard (LCFS) regulatory program.[22]

It is estimated that global consumption of RD in 2023 was 3.69 billion gallons; thus the U.S. consumed more than 77 percent of the global supply last year.[23] Additionally, it is estimated that 14 percent of U.S. RD consumption is imported.[24]

In summary:

- More than 35 billion gallons of petroleum diesel are consumed annually by the U.S. trucking industry; 28 billion gallons are consumed by the nation's 3.25 million combination trucks.
- Consumption of RD – which is molecularly identical to petroleum diesel and can be used as a stand-alone drop-in fuel – has risen to nearly 3 billion gallons in 2023, up more than 500 percent from 2018.[25]

[22] California Air Resources Board, "LCFS Data Dashboard" (accessed on February 7, 2024), https://ww2.arb.ca.gov/resources/documents/lcfs-data-dashboard.
[23] Businesswire, "Renewable Diesel Market Expected to Produce 3.70 Billion Gallons by 2023, with a Staggering 19.12% CAGR - ResearchAndMarkets.com" (October 23, 2023), https://www.businesswire.com/news/home/20231023310746/en/Renewable-Diesel-Market-Expected-to-Produce-3.70-Billion-Gallons-by-2023-with-a-Staggering-19.12-CAGR---ResearchAndMarkets.com.
[24] U.S. Energy Information Administration, "March 2024 Monthly Energy Review" (March 2024), https://www.eia.gov/totalenergy/data/monthly/.
[25] U.S. Energy Information Administration, "January 2024: Monthly Energy Review" (January 2024), "Table 10.4a Biodiesel Overview" and "Table 10.4b Renewable Diesel Fuel Overview,"

- RD consumption in the U.S. now exceeds biodiesel consumption by 32.3 percent.
- California renewable diesel sales account for 73 percent of RD sold in the U.S.

RD Feedstocks and Production

RD production is "categorized as first to fourth generation fuel, depending on feedstock."[26] These categories vary slightly across several scientific sources, but they generally follow the guidelines below.[27]

> *First generation* RD is sourced from food-based products. Examples for renewable diesel production include soybean oil and distillers corn oil. These feedstocks can be referred to as "edible biomass."[28] Some argue that first generation biofuels directly compete with edible food supplies, and thus have the potential to create inflationary effects.
>
> *Second generation* RD is derived from waste products that are not direct sources of food. These may include organic waste materials, agricultural residues and wood materials. One common second generation biofuel is used cooking oil (UCO). Generally, second generation feedstocks can be referred to as "non-edible biomass."[29]
>
> *Third generation* RD is derived from "microalgae and cyanobacteria biomass," which can be used to naturally generate alcohols and lipids."[30] This approach is currently in the research stage. Third generation feedstocks can be referred to as "algal biomass."[31]
>
> *Fourth generation* RD, which is also in the research stage, "encompasses the use of genetic engineering to increase desired traits of organisms used in biofuel production."[32]

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https://www.eia.gov/totalenergy/data/monthly/archive/00352401.pdf.; 2023 annual consumption figures are ATRI estimates based on monthly consumptions for first 11 months of 2023;
U.S. Energy Information Administration, "In 2023, U.S. renewable diesel production capacity surpassed biodiesel production capacity" (September 5, 2023), https://www.eia.gov/todayinenergy/detail.php?id=60281#:.

[26] Philipp Cavelius et al., "The potential of biofuels from first to fourth generation," *PLoS Biology* 30, no. 3 (March 2023), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10063169/#.

[27] Ibid. and;
U.S. Environmental Protection Agency, "Economics of Biofuels" (accessed February 2024), https://www.epa.gov/environmental-economics/economics-biofuels#:. ; and
European Technology and Innovation Platform Bioenergy, "Sustainable Feedstocks for Advanced Biofuels and Intermediate Bioenergy Carriers Production in Europe" (accessed on February 19, 2024), https://www.etipbioenergy.eu/value-chains/feedstocks/biofuels-feedstocks-an-overview#.

[28] Hayder A. Alalwan, Alaa H. Alminshid, and Haydar A.S. Aljaafari, "Promising evolution of biofuel generations. Subject review," *Renewable Energy Focus* 28 (2019), https://www.sciencedirect.com/science/article/abs/pii/S1755008418303259.

[29] Ibid.

[30] Philipp Cavelius et al., "The potential of biofuels from first to fourth generation," *PLoS Biology* 30, no. 3 (March 2023), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10063169/#.

[31] Hayder A. Alalwan, Alaa H. Alminshid, and Haydar A.S. Aljaafari, "Promising evolution of biofuel generations. Subject review," *Renewable Energy Focus* 28 (2019), https://www.sciencedirect.com/science/article/abs/pii/S1755008418303259.

[32] Philipp Cavelius et al., "The potential of biofuels from first to fourth generation," *PLoS Biology* 30, no. 3 (March 2023), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC10063169/#.

Present-day commercially available RD is made from feedstocks and processes that are limited to first and second generation. Table 1 lists common types of oils and fats that are used for making renewable diesel.[33]

Table 1: Feedstock Types Used for Renewable Diesel Production

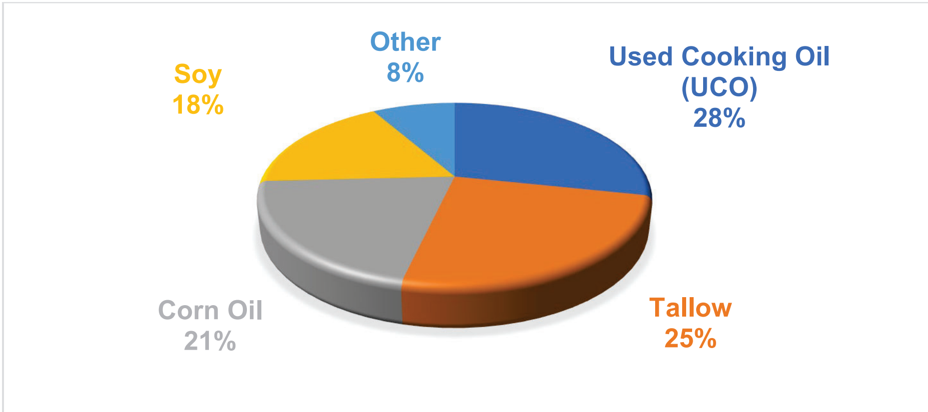
Type	Oil/Fat Group
Canola Oil	Vegetable Oil
Distillers Corn Oil	Vegetable Oil
Cottonseed Oil	Vegetable Oil
Palm Oil	Vegetable Oil
Soybean Oil	Vegetable Oil
Poultry Fat	Animal Fat
Tallow (Beef)	Animal Fat
White Grease (Pork)	Animal Fat
Yellow Grease	Waste Fats & Oils
Used Cooking Oil (UCO)	Waste Fats & Oils

A general benchmark of 8.5 pounds of feedstock material per one gallon of renewable diesel is used by renewable diesel producers to estimate total feedstock needs, though this figure may vary depending on feedstock type and condition.[34]

As discussed earlier, the majority of renewable diesel consumed in the U.S. is purchased in California. As part of its LCFS program, CARB tracks the feedstocks that are used in RD sold through the California program. The feedstocks associated with 2022 RD sold in California are shown in Figure 3.[35]

[33] Maria Gerveni, Scott Irwin, and Todd Hubbs, "Renewable Diesel Feedstock Trends over 2011-2022," *farmdoc daily* 13, no. 231 (December 20, 2023), University of Illinois, https://farmdocdaily.illinois.edu/2023/12/renewable-diesel-feedstock-trends-over-2011-2022.html.
[34] Ibid.
[35] California Air Resources Board, "LCFS Data Dashboard" (accessed February 7, 2024), https://ww2.arb.ca.gov/resources/documents/lcfs-data-dashboard.

Figure 3: California RD Feedstocks 2022*



A 2023 McKinsey study identified the top states that produce first generation feedstocks that could be converted to RD. These are shown in Table 2.[36]

Table 2: Top Feedstock States by Feedstock Type

	Minnesota	Nebraska	Iowa	Indiana	Illinois
Soybean Oil	■	■	■	■	■
Distillers Corn Oil	■	■	■	■	■
Canola	■				
White Grease (Pork)	■		■	■	■
Tallow (Beef)		■			

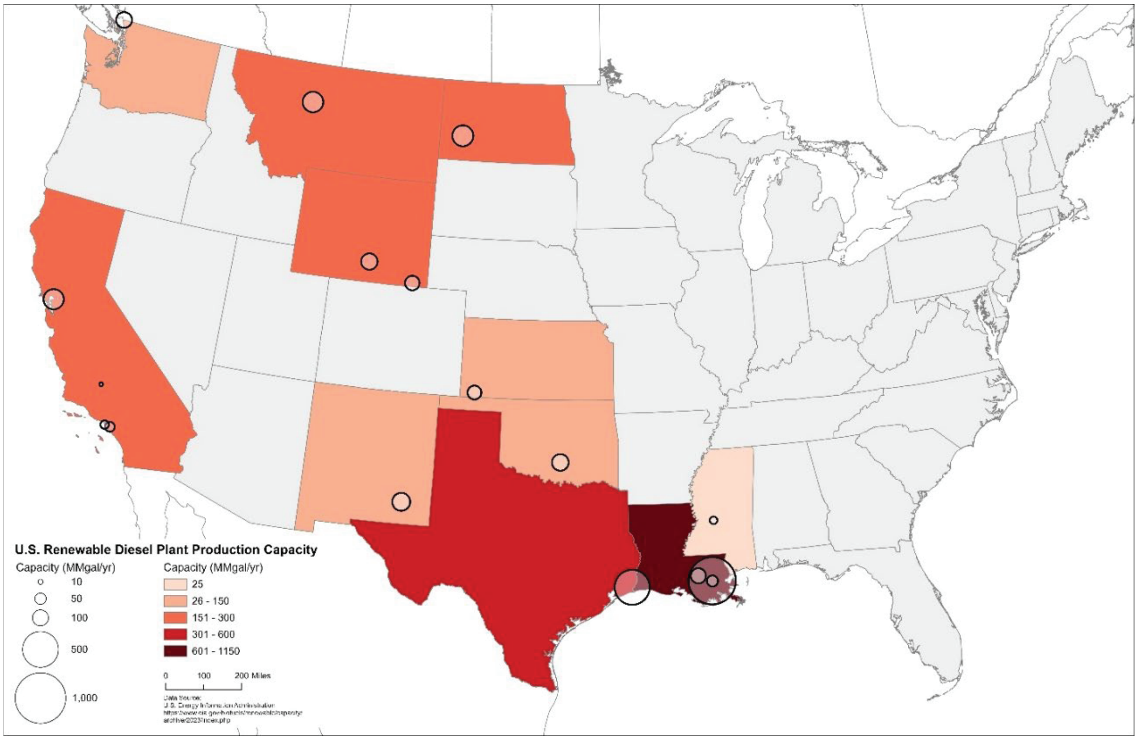
Additionally, the study indicates that all major cities in the United States are key sources of UCO.

At the beginning of 2023 the U.S. had 17 RD plants in 11 states with a production capacity of 3 billion gallons per year. The location and size of these plants are shown in Figure 4.[37]

[36] Tim Fitzgibbon, Khush Nariman, and Brian Roth, "Converting refineries to renewable fuels: No simple switch," McKinsey (June 21, 2023), https://www.mckinsey.com/industries/oil-and-gas/our-insights/converting-refineries-to-renewable-fuels-no-simple-switch.

[37] U.S. Energy Information Administration, "U.S. Renewable Diesel Fuel and Other Biofuels Plant Production Capacity" (accessed February 2024), https://www.eia.gov/biofuels/renewable/capacity/.; Note from EIA on the data: "Renewable Diesel Fuel and Other Biofuels Production Capacity [figures are] intended to measure estimated gallons of renewable diesel fuel, renewable heating oil, renewable jet fuel, renewable naphtha and gasoline, and other biofuels (excluding fuel ethanol and biodiesel) and biointermediates that a plant is capable of producing."

Figure 4: Location and Capacity of U.S. RD Production Facilities



U.S. production capacity of RD increased nearly 280 percent in the two years from January 2021 – when there were only six plants in the U.S. – to January 2023.[38] Additionally, the U.S. Energy Information Administration (EIA) forecasts that domestic capacity will again more than double between the end of 2022 and the end of 2025, from 2.6 billion gallons per year to 5.9 billion gallons per year.[39]

A University of Illinois RD forecast found similar capacity increases – with production capacity reaching 7.4 billion gallons per year after 2025.[40] This forecast was, in part, based on planned expansion of six facilities shown in Figure 4.

Additionally, the University of Illinois forecast includes new RD capacity through conversion from existing petroleum refineries or construction of entirely new facilities in the states shown in Table 3.

[38] U.S. Energy Information Administration, "U.S. Renewable Diesel Fuel and Other Biofuels Plant Production Capacity Archives" (September 3, 2021), https://www.eia.gov/biofuels/renewable/capacity/archive/2021/index.php.
[39] U.S Energy Information Administration, "Domestic renewable diesel capacity could more than double through 2025" (February 2, 2023), https://www.eia.gov/todayinenergy/detail.php?id=55399.
[40] Maria Gerveni, Scott Irwin, and Todd Hubbs, "Overview of the Production Capacity of U.S. Renewable Diesel Plants for 2023 and Beyond," *farmdoc daily* 13, no. 57 (March 29, 2023), University of Illinois, https://farmdocdaily.illinois.edu/2023/03/overview-of-the-production-capacity-of-u-s-renewable-diesel-plants-for-2023-and-beyond.html.

Table 3: Planned RD Capacity Increases 2023 and Beyond*

State	New Locations	Additional Annual Capacity (Millions of Gallons)
California	3	1,040
Louisiana	6	986
Oregon	1	575
Alabama	1	200
Kansas	1	150
Texas	1	125
Nebraska	1	80
Nevada	1	44
Iowa	1	36
Indiana	1	31
Total	**17**	**3,267**

In summary:

- Used cooking oil (UCO), tallow and corn oil are the top three feedstocks for California RD.
- RD production capacity increased nearly 280 percent in the last two years.
- Many Midwest states are key producers of RD feedstock; RD production capacity is increasing, but not necessarily near feedstock sources.

Incentive Programs for RD

The increase in production and consumption of RD has been influenced by incentive programs. These programs are often designed to encourage production and decrease the cost of RD to consumers with an end goal of decreasing CO_2 emissions.

Appendix A of this report contains a list of federal and state programs that seek to increase the use of RD. These programs include research into developing new or better feedstocks. Several highlights from these programs are described below.

Federal Incentives**.** Federal incentives like the Biodiesel Income Tax Credit and the Renewable Fuel Standard (RFS2) have helped to accelerate interest in biodiesel and renewable diesel.

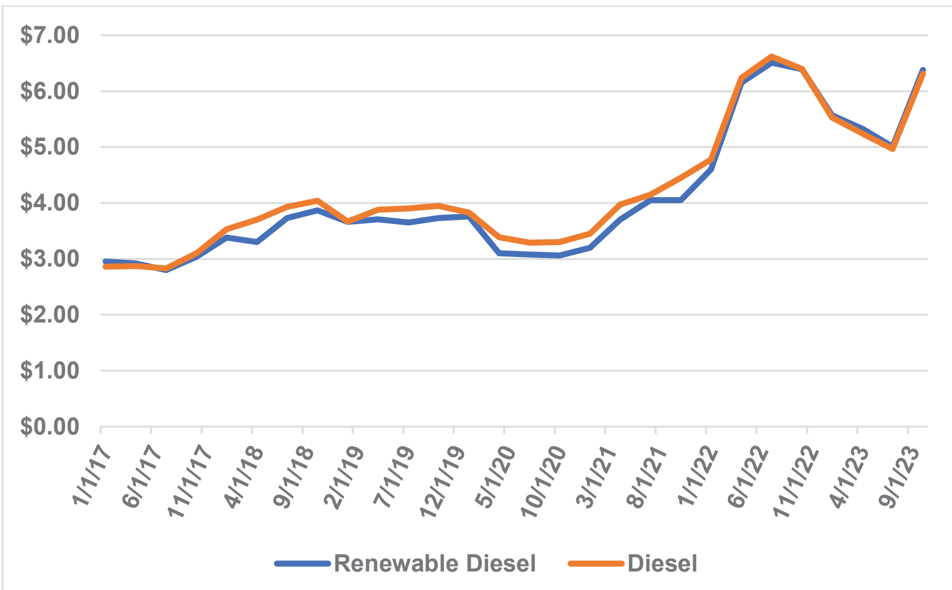
> The *Biodiesel Income Tax Credit* allows fuel producers to receive a tax credit of $1 per gallon of biofuel (including renewable diesel) that is delivered to on-road vehicles. This tax credit, which was enacted in 2004, was recently extended by the Inflation Reduction Act (IRA) to run through the end of 2024.[41]

[41] Alternative Fuels Data Center, “Biodiesel Income Tax Credit” (accessed February 2024), U.S. Department of Energy, https://afdc.energy.gov/laws/396.; Inflation Reduction Act Tracker, "IRA SECTION 13201 – Tax Credits for Biodiesel, Renewable Diesel, and Alternative Fuels," Sabin Center for Climate Change Law, Environmental Defense

The *RFS2* is a national program overseen by the U.S. EPA that requires Renewable Volume Obligations (RVO) on transportation fuel producers and importers.[42] Through this program, companies supplying fuel are mandated to meet a certain level of greenhouse gas (GHG) content across their products; production of RD helps producers meet their obligation.[43]

State Incentives. CARB motivates RD use through its LCFS program, by incentivizing producers to sell RD in the state. The LCFS is designed to reduce GHG emissions through a credit marketplace that penalizes sales of higher-carbon fuels such as petroleum diesel, and rewards sales of low-carbon alternatives. As a result, the price of RD in California has been very close to the price of petroleum diesel that is sold in the state (Figure 5).[44]

Figure 5: Average Price of Diesel and RD in California, 2017-2023



Competition for Incentives. The term sustainable aviation fuel (SAF) refers to biofuels that could partially or entirely replace traditional petroleum-based jet fuel. [45] SAF could potentially reduce aviation emissions. The ASTM standard for SAF differs from traditional jet fuel. Today's SAF cannot be used as a stand-alone drop-in aviation fuel and should only be mixed with jet fuel at

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Fund (accessed on February 21, 2024), https://iratracker.org/programs/ira-section-13201-tax-credits-for-biodiesel-renewable-diesel-and-alternate-fuels/.

[42] Alternative Fuels Data Center, "Renewable Fuel Standard" (accessed February 2024), U.S. Department of Energy, https://afdc.energy.gov/laws/RFS.

[43] Phillip Herring and Melvin Lee, "Feature: US RINs complex under pressure while renewable diesel helps RVO mandates," S&P Global (November 20, 2023), https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/agriculture/112023-us-rins-complex-under-pressure-while-renewable-diesel-helps-rvo-mandates.

[44] Alternative Fuels Data Center, "Fuel Prices: Alternative Fuel Price Report" (accessed March 2024), U.S. Department of Energy, https://afdc.energy.gov/fuels/prices.html.

[45] Alternative Fuels Data Center, "Sustainable Aviation Fuel," U.S. Department of Energy (accessed March 2024), https://afdc.energy.gov/fuels/sustainable_aviation_fuel.html.

blend levels of up to 10 percent or 50 percent depending upon the production process and feedstock.[46]

Many in the aviation industry believe that drop-in SAF is a necessity for aviation decarbonization. The International Air Transport Association (IATA), for instance, states that "the 'drop-in' condition is a major requirement for the aviation industry. Any SAF that doesn't meet this condition could present safety issues associated with risks of mishandling and would require a parallel infrastructure to be implemented in all connected airports, creating unnecessary risks and costs."[47]

Under the IRA, SAF producers receive a credit of $1.25 per gallon produced whereas RD receives a credit of $1.00 per gallon.[48] According to analysis by LMC International, as SAF and RD are fundamentally in competition over some feedstocks, higher credits could incentivize investment in SAF over RD.[49] Likewise, the research asserts that production of SAF is less environmentally beneficial when compared with RD.

Several feedstock pathways for SAF have been identified. While these include feedstocks that could compete with RD (e.g. vegetable oils and animal fats) they also included ethanol feedstocks such as sugarcane and sugar beets, which are not feedstocks for RD.[50]

In summary:

- There are two key federal programs that act to increase RD production – one is a tax credit and the other is a renewable fuels production requirement.
- The California market for RD has relative price parity with petroleum diesel in part due to its LCFS subsidy program.
- In the future, SAF production may compete with RD production to some degree, but SAF is not currently a stand-alone drop-in fuel, is more difficult to produce and has many feedstocks that do not compete with RD.

Environmental Regulations and RD

Globally, governments have acted in different ways to decrease CO_2 emissions from heavy-duty trucks. RD's role in decarbonization, however, is seen differently by two key global players in the decarbonization effort – California/CARB and the European Union (EU).

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[46] International Air Transport Association, "Fact Sheet 2 - Sustainable Aviation Fuel: Technical Certification," (undated), https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/saf-technical-certifications.pdf.
[47] Ibid.
[48] Internal Revenue Service, "Sustainable Aviation Fuel Credit" (accessed March 2024), https://www.irs.gov/credits-deductions/businesses/sustainable-aviation-fuel-credit; Alternative Fuels Data Center, "Biofuel Income Tax Credit," U.S. Department of Energy (accessed March 2024), https://afdc.energy.gov/laws/396.
[49] LMC International, Comparative Economic Analysis of Renewable Jet Fuel and Renewable Diesel (September 2021), for National Association of Truck Stop Owners, https://www.natso.com/resources/resources/view/document/873.
[50] International Air Transport Association, "Fact Sheet 2 - Sustainable Aviation Fuel: Technical Certification," (undated), https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/saf-technical-certifications.pdf.

Though California/CARB does currently support the use of RD in meeting state decarbonization goals through programs like the LCFS, their current long-term regulatory focus for heavy-duty trucks is zero tailpipe emissions. To-date, this means limiting the trucking industry's long-term decarbonization tools to BEV or hydrogen fuel-cell electric vehicles (FCEV).

CARB's Advanced Clean Trucks (ACT) and Advanced Clean Fleets (ACF) regulations are designed to advance Zero-Emission Vehicle (ZEV) adoption by trucking companies. These rules require that an increasing number of ZEVs are brought to the new truck market and that certain entities operating trucks in California are required to purchase ZEVs for their fleets.

Under ACT, manufacturers of internal combustion engines (ICE) must incrementally increase the ZEV share of their annual sales, starting in 2024 and running through 2036 when 100 percent of Class 4-8 trucks sold must be ZEV.[51]

The ACF focuses on motor carriers, requiring certain trucking companies to increase the percentage of vehicles in their fleet that are ZEV.[52] To enforce this rule in one segment of the industry – drayage – diesel trucks will not be able to enter ports or intermodal terminals once the rule is fully implemented and enforced.

The EU's approach, on the other hand, is more flexible with how member states approach decarbonization. In their statement on provisional new CO_2 standards for heavy-duty vehicles, the Council of the EU stated that "while the strengthened CO_2 reduction targets will accelerate the uptake of zero-emission vehicles, a significant part of the stock of heavy-duty vehicles on the roads will remain internal combustion engine vehicles … the Commission should further develop a coherent framework of incentives for advanced biofuels and biogas and renewable fuels of non-biological origin."[53]

Additionally, the EU took steps in 2023 to "update the goals and rules of the Renewable Energy Directive (RED) to raise the EU's overall renewable energy consumption to 42.5 percent by 2030" across all sectors.[54] The transportation sector has its own goals, with EU member states being able to choose to adhere to either: 1) final energy consumption in the transportation sector being 29 percent renewable by 2030; or 2) a 14.5 percent reduction in transportation GHG compared to 2010.[55] To meet their goals, a combined share of advanced biofuels, biogas, and renewable fuels of non-biological origin (RFNBO) are to be at least 5.5 percent in 2030.[56]

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[51] California Air Resources Board, "Advanced Clean Trucks Fact Sheet: Accelerating Zero-Emission Truck Markets" (August 20, 2021), https://ww2.arb.ca.gov/resources/fact-sheets/advanced-clean-trucks-fact-sheet.
[52] Ibid.
[53] Council of the European Union, *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Regulation (EU) 2019/1242 as regards strengthening the CO_2 emission performance standards for new* heavy-*duty vehicles and integrating reporting obligations, and repealing Regulation (EU) 2018/956* (February 9, 2024), Letter to the Chair of the European Parliament Committee on the Environment, Public Health and Food Safety (ENVI), https://www.consilium.europa.eu/media/70136/hdvs_provisional-agreement.pdf.
[54] Council of the European Union, "Renewable energy: Council adopts new rules" (October 2023), Press Release, https://www.consilium.europa.eu/en/press/press-releases/2023/10/09/renewable-energy-council-adopts-new-rules/.
[55] Council of the European Union, *Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Regulation (EU) 2019/1242 as regards strengthening the CO_2 emission performance standards for new heavy-duty vehicles and integrating reporting obligations, and repealing Regulation (EU) 2018/956* (February 9, 2024), Letter to the Chair of the European Parliament Committee on the Environment, Public Health and Food Safety (ENVI), https://www.consilium.europa.eu/media/70136/hdvs_provisional-agreement.pdf.
[56] Ibid.

ENVIRONMENTAL, OPERATIONAL AND FINANCIAL ANALYSES

In the following section, the research team conducted three analyses that compare the use of heavy-duty tractors propelled by: 1) internal combustion engine using renewable diesel (ICE RD); and 2) BEV to achieve positive environmental, operational and financial results.

Analysis One: Environmental Benefits of RD Usage

According to EPA, the transportation sector is responsible for 28.9 percent of GHG emissions in the U.S., followed by electric utilities (24.8%) and industrial uses (22.7%).[57]

Within the transportation sector, the majority of emissions are from light-duty vehicles (58%), but medium- and heavy-duty vehicles (MHDV) rank second at 23 percent, followed by aircraft (8%), other (6%), ships and boats (3%) and rail (2%).[58]

While GHG emissions – primarily CO_2 – are an unavoidable reality for most economic activity today, all sectors and segments of the economy are looking for ways to reduce their GHG emissions. That includes the trucking industry, which approaches decarbonization through equipment improvements and use of alternative fuels.

For the environmental assessment, the research team analyzed the potential impacts of RD consumption by the trucking sector on CO_2 emissions and air pollution.

Life-Cycle CO_2. Past ATRI research, utilizing the DOE/ANL GREET Model, found that switching from an ICE truck that uses petroleum diesel to a BEV truck would decrease CO_2 emissions by 30 percent.[59] That same research found that using RD in an existing ICE truck could decrease the trucking industry's carbon footprint even more effectively than BEV trucks. The per-truck life-cycle CO_2 reduction using RD compared to petroleum diesel is 67.3 percent (Figure 6).[60]

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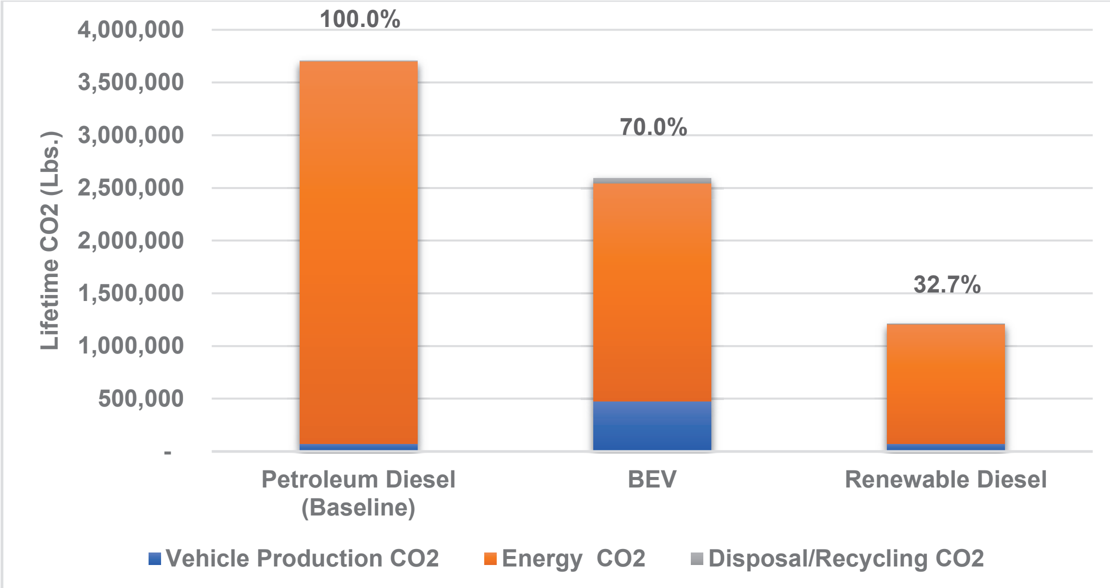
[57] U.S. Environmental Protection Agency, *Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2022* (2024), EPA 430-D-24-001, https://www.epa.gov/system/files/documents/2024-02/us-ghg-inventory-2024-main-text.pdf.

[58] U.S. Environmental Protection Agency, "Fast Facts on Transportation Greenhouse Gas Emissions" (updated on October 31, 2023), https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions.

[59] Jeffrey Short and Danielle Crownover, *Understanding the CO2 Impacts of Zero-Emission Trucks: A Comparative Life-Cycle Analysis of Battery Electric, Hydrogen Fuel Cell and Traditional Diesel Trucks*, American Transportation Research Institute (May 2022), https://truckingresearch.org/2022/05/understanding-the-co2-impacts-of-zero-emission-trucks/.

[60] In the analysis life-cycle CO_2 included emissions during 1) vehicle and battery production including the sourcing of raw materials, 2) energy/fuel production and consumption, and 3) disposal of the vehicle and batteries at end-of-life. It was assumed that the vehicle's useable life was 1,000,000 miles, and specifically for the BEV it was assumed that one replacement of the BEV battery pack would be required at 500,000 miles.

Figure 6: Comparison of Life-Cycle CO2 Emissions for a Class 8 Truck Using Three Fuel Types*



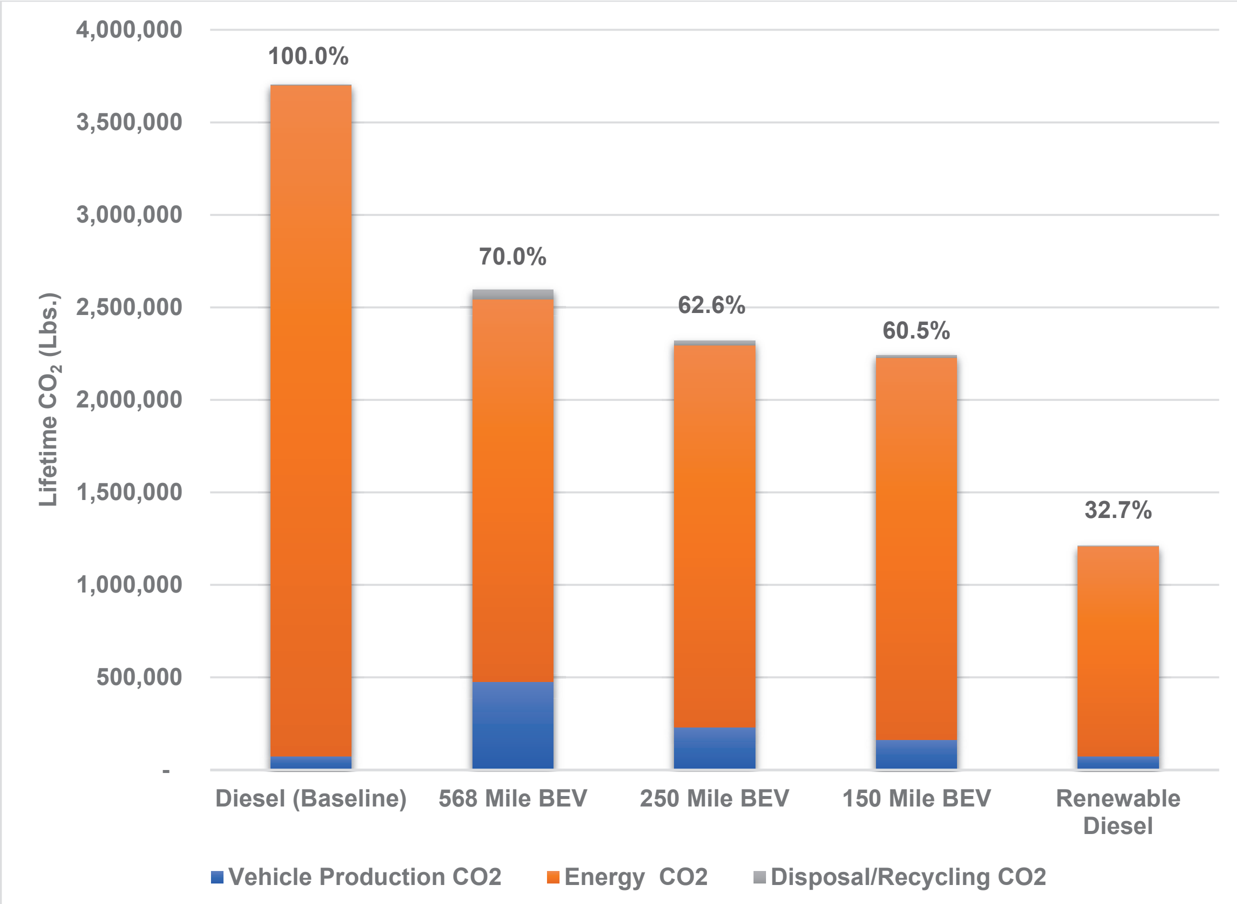
It should be noted that Figures 6 and 7 (below), RD Energy CO_2 encompasses both tailpipe emissions from burning RD and emissions from growing and producing feedstock.

In the aforementioned research, the BEV vehicle production CO_2 is significant. The study team used a Class 8 sleeper cab that could meet the demands of long-haul trucking. As a result, the battery was larger and could drive more miles (568 miles when using 80% of charge) between charges than what is presently available today.[61]

Currently, the Class 8 BEV tractor market is limited to trucks with a smaller battery capacity and driving range. Though these trucks are not comparable to today's long-haul sleep cab tractors, ATRI modeled a day-cab truck with a 150- and 250-mile range (using 80% of a full charge) to offer additional perspective. The results are shown in Figure 7.

[61] In the May 2022 research, the research team looked at a battery that could store 1,622 kWh and had a range of 568 miles when using 80% of its charge.

Figure 7: Comparison of Life-Cycle CO2 Emissions for a Class 8 Trucks with Three BEV Configurations*

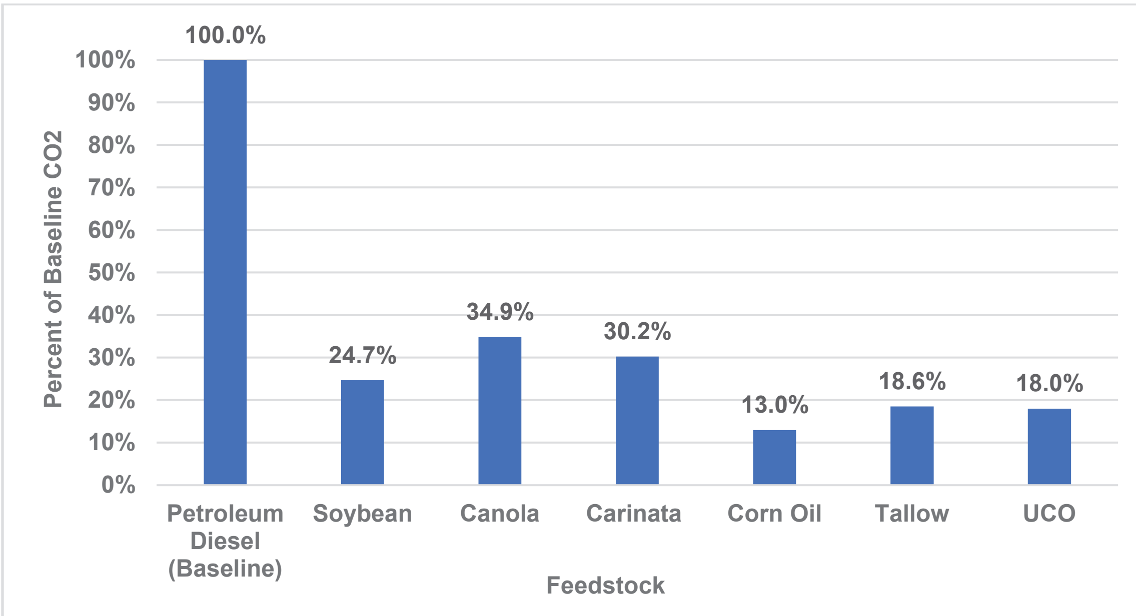


The smaller-range BEV trucks shown in the figure do have up to 13.6 percent lower vehicle CO_2 emissions than the 568-mile BEV that was modeled for the 2022 report. That said, one major caveat is that the smaller-range BEV trucks are modeled with only one battery replacement. It is likely, however, that within a one-million-mile life-cycle many trucks would need more battery replacements than the long-haul truck. This is because more charging cycles will be required, which will degrade the battery faster. Notwithstanding, the shorter-range trucks produce nearly twice the life-cycle CO_2 emissions of a long-haul truck running on RD when incorporating one battery replacement during the life-cycle. Looking specifically at energy use, this comparative analysis shows that the shorter-range BEV energy-cycle emits 82.1 percent more CO_2 than the RD energy-cycle. To match the lower CO_2 emissions of RD, electricity production must decrease CO_2 emissions significantly. It should be noted that these clean energy costs for electric utilities are not captured in the cost-benefit analysis later in this report.

Operational challenges with smaller batteries – which will be covered in the next section – also make it unlikely that vehicles with smaller batteries could operate in the long-haul environment. Thus, in the remainder of this report, data representing the long-haul 568-mile BEV modeled in 2022 will be utilized.

Fuel Production CO_2 Emissions. In 2022, the U.S. DOE/ANL analyzed life-cycle GHG from the production of RD from several different feedstock types, and measured GHG intensity in the form of grams of carbon dioxide equivalent per megajoule, or gCO_2e/Mj.[62] ATRI then analyzed those measurements against a standard petroleum diesel measurement of 95.1 gCO_2e/Mj.[63] The results are shown in Figure 8. While ATRI's 2022 analysis focused on soybean-derived RD, there are feedstock sources associated with lower CO_2 such as corn oil, tallow and UCO. RD derived from corn oil was shown to have the lowest GHG intensity, but all assessed feedstocks were significantly lower than petroleum diesel.

Figure 8: Life-Cycle Carbon Intensity by Feedstock Type: RD Compared to Petroleum Diesel Production*



Potential Headwinds for Industry Efforts to Decrease CO_2. As previously documented, RD use decreases CO_2 emissions significantly when compared to petroleum diesel. Regulations such as California's ACF and ACT – which have acted to mandate BEV trucks – could result in higher overall CO_2 emissions compared to policies and programs that increase the production and use of RD.

Recognizing that BEVs produce far more CO_2 emissions over their life-cycle than do ICE RD trucks, Figure 9 offers a series of scenarios for a fleet of three vehicles.[64]

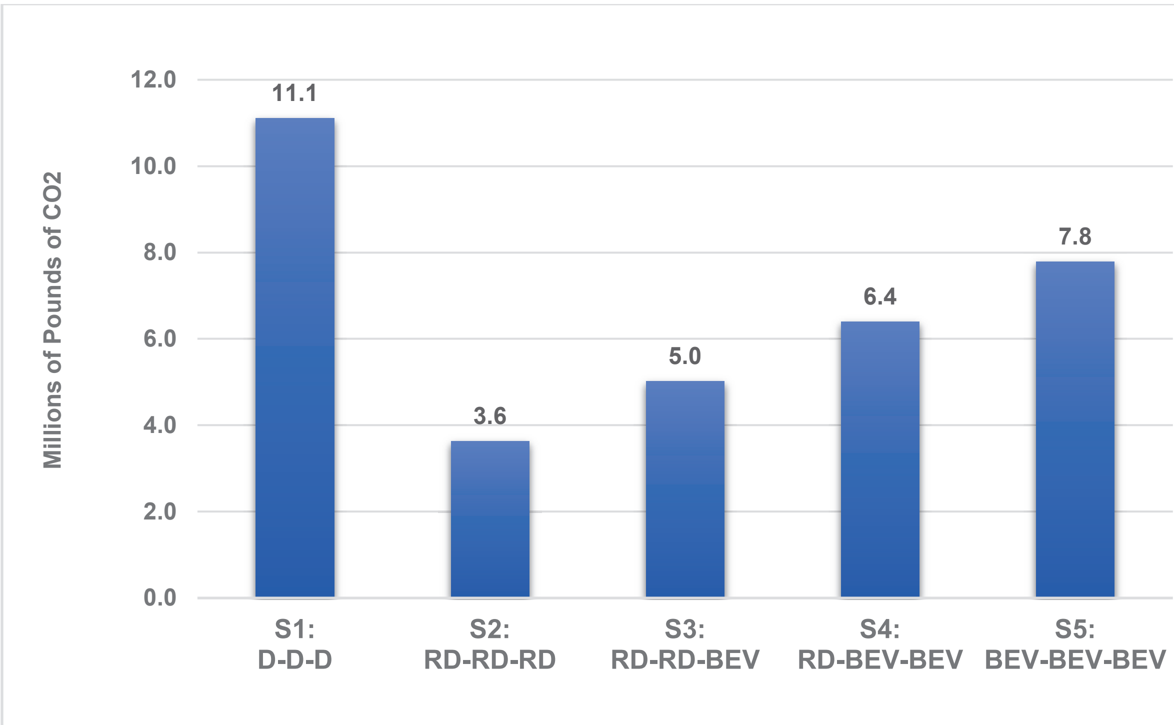
- Scenario 1: In the first scenario (labeled S1) all three trucks in the fleet run strictly on petroleum diesel. The total life-cycle CO_2 emissions are 11.1 million pounds.

[62] Hui Xu et al., "Life Cycle Greenhouse Gas Emissions of Biodiesel and Renewable Diesel Production in the United States," *Environmental Science & Technology* 56, no. 12 (2022), https://pubs.acs.org/doi/10.1021/acs.est.2c00289.
[63] European Environment Agency, "Greenhouse gas emission intensity of fuels and biofuels for road transport in Europe" (October 24, 2023), https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emission-intensity-of?activeAccordion=ecdb3bcf-bbe9-4978-b5cf-0b136399d9f8.
[64] Life-cycle includes production of vehicles and fuels and consumption of fuel. Vehicle useable life is assumed to be 1 million miles.

- Scenario 2: In S2, all three trucks exclusively use renewable diesel, which is available today in some markets. No technical modifications to the trucks are needed, and life-cycle CO_2 emissions decrease to 3.6 million pounds.
- Scenario 3-5: In S3 – S5, the three RD trucks are replaced incrementally with BEV trucks over a period of time. This in-turn increases life-cycle CO_2 emissions incrementally, ultimately reaching 7.8 million pounds of CO_2 for three BEV trucks.

Thus, while a regulation requiring RD trucks (S2) to convert to BEV (S5) may be well intentioned, in reality it more than doubles the CO_2 emissions output of this sample fleet when using RD (S2).

Figure 9: Life-Cycle CO2 Emissions for Fleet Mixes that Utilize Diesel, RD and BEV*



Mandating BEV adoption effectively results in the trucking industry emitting more CO_2 than it otherwise would using ICE RD. Individual trucking companies simply do not have the flexibility to be good stewards of the environment, by emitting less carbon, when mandated to purchase BEVs with higher total carbon footprints under existing policies and regulations.

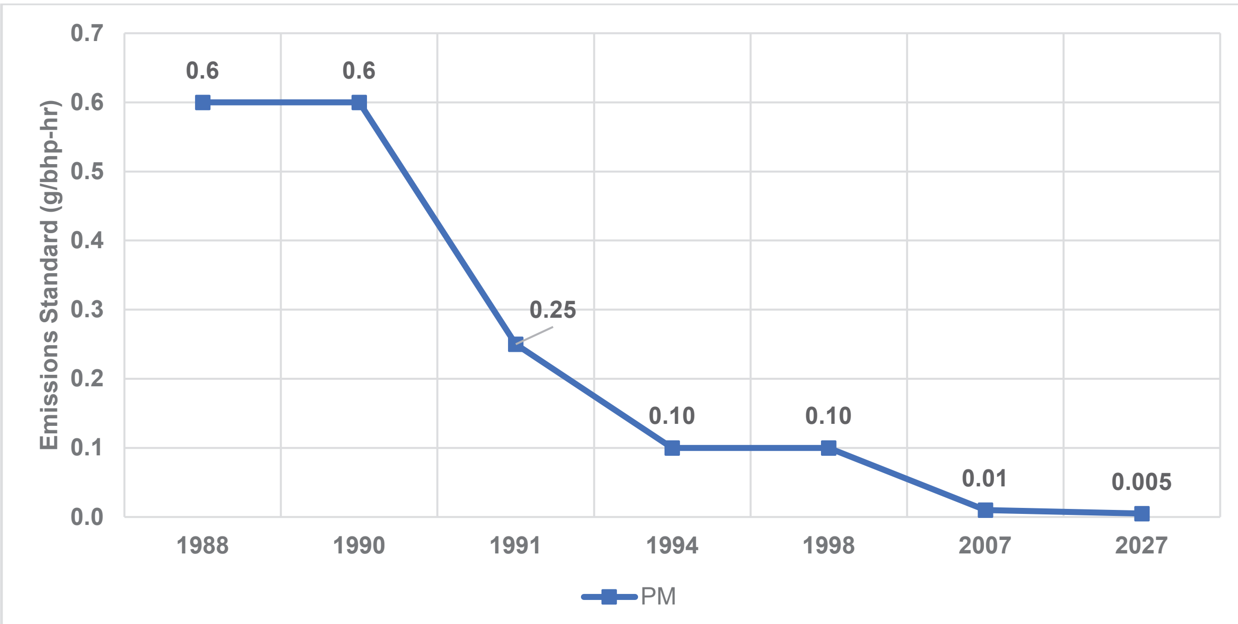
<u>Ambient Air Pollutants.</u> In terms of air pollutants, BEV trucks do not have tailpipe emissions such as particulate matter (PM) or NO_X.[65] Thus, decreasing tailpipe air pollutants is often cited as a rationale for moving from ICE to BEV trucks. While use of RD is still associated with tailpipe PM and NO_x emissions, there are several caveats that must be considered.

[65] This analysis will look specifically at PM 2.5, but it will be referred to throughout simply as PM.

U.S. EPA Engine Emission Standards

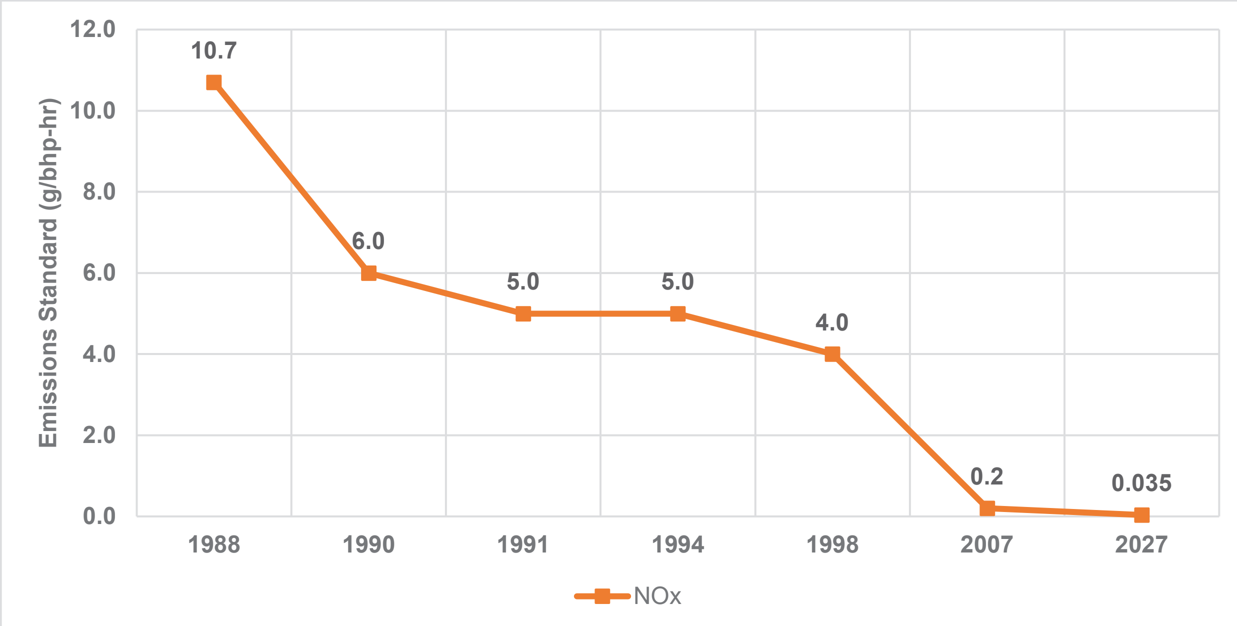
The U.S. EPA engine emission standards for air pollutants on diesel trucks are shown in Figures 10 and 11; both PM and NO_X standards for engines have become significantly more stringent.[66] As an example, reductions associated with EPA's engine emissions standards from 1988 to 2007 decreased PM by 98.33 percent and decreased NO_x by 98.13 percent.

Figure 10: U.S. EPA Heavy-Duty Diesel Engine Standards for PM



[66] DieselNet, "United States: Heavy-Duty Onroad Engines" (accessed March 2024), https://dieselnet.com/standards/us/hd.php.

Figure 11: U.S. EPA Heavy-Duty Diesel Engine Standards for NO_X



Life-Cycle PM and NO_x. While there are no NO_x or PM emissions from a BEV tailpipe, these pollutants are still generated during the truck's life-cycle. Table 4 shows the GREET Model's total grams of air pollutants associated with the production of ICE and BEV trucks (which includes mining and processing of battery materials).[67] A BEV truck's NO_x emissions are nearly 10 times that of an ICE during vehicle production, and PM is more than 7.5 times higher.

Table 4: Total Grams of Air Pollutants Resulting from Production of a Class 8 ICE and BEV Vehicle Production*

	ICE	BEV
NO_x	29,829	296,959
PM	6,455	49,213

During operations, NO_x and PM are not directly released from a BEV. That said, these pollutants are released during *vehicle production* along the supply chain. Therefore, BEV mandates effectively export these pollutants to other countries or locations.

Production of *energy* used in a BEV truck has a similar issue to truck production. When comparing emissions across feedstocks, fuels and vehicle operations for RD and BEV trucks, GREET data indicates that both have NO_x and PM values. For the well-to-tank fuel life-cycle, an RD truck's NO_x values are 1.5 times greater than a BEV truck; but BEV PM values are 1.15 times greater than an RD truck (Table 5).

[67] Argonne National Laboratory, *GREET Model, 2021*, https://greet.es.anl.gov/index.php.

Table 5: Ambient Air Pollution per Mile Driven*

	ICE: Soybean-based RD	Electric Vehicle: U.S. Mix
NO_x g/mile	0.173	0.114
PM g/mile	0.012	0.014

PM from tires may play a role in BEV PM levels. Recent research by Emissions Analytics found that BEV cars must replace their tires more often than regular cars.[68] The result is more frequent tire replacement and ultimately an increase in tire-sourced PM per mile during operation. One study found that BEVs (which are heavier due to their batteries) "emitted roughly one-quarter more particulate matter because of tire wear."[69]

In summary:

- ICE RD life-cycle CO_2 is approximately 50 percent lower than BEV CO_2. RD feedstock choice may decrease this figure further.
- Certain feedstocks have lower CO_2 emissions than others during RD production.
- Government mandates requiring a shift to BEV instead of ICE RD would result in fleets increasing their total CO_2 emissions.
- EPA's engine emissions standards from 1988 and 2007 decreased PM by 98.33 percent and decreased NO_x by 98.13 percent.
- Based on the GREET model, producing a BEV truck (which includes mining and processing of battery materials) results in NO_x emissions that are nearly 10 times that of producing an ICE truck, and PM that is more than 7.5 times higher due to battery production – emissions that are effectively exported to other countries/locations.

Analysis Two: A Comparison of Operational Capabilities of Electric and ICE RD Trucks

The distance a Class 8 truck can travel between charging and the cargo weight a vehicle can carry are key metrics for maintaining operational efficiencies in trucking and supply chains. Two analyses were conducted to determine the operational impacts of operating a BEV truck relative to an ICE RD truck.

Daily Mileage. As stated earlier, current BEV truck technology has a usable trip range of 150 to 250 miles before recharging is needed. This range is dependent on, and limited by, several factors including:

State of Charge. A truck that is charged to 100 percent and uses all available battery power could drive farther than one that operates within the recommended minimum 20 percent state of charge and maximum 80 percent state of charge.[70] This OEM-recommended state of charge range limits the useable electricity from the battery to 60 percent.

[68] Michael Buschbacher and Taylor Myers, "Electric Cars Emit More Particulate Pollution" *The Wall Street Journal* (March 3, 2024), https://www.wsj.com/articles/electric-cars-emit-more-soot-california-ban-gas-powered-vehicles-521b29e3
[69] Ibid.
[70] David Jaskolski, "Considerations for the Adoption of Electric Commercial Trucks," Peach State Truck Centers (August 7, 2023), https://www.peachstatetrucks.com/blog/news/electric-semi-trucks.

Battery Degradation. Like all lithium-ion batteries, a BEV truck battery degrades with age, charging cycles and use. This degradation negatively impacts range. Key factors to battery degradation include number of charges, state of charge practices and environmental factors such as extreme cold or heat.

Mileage limitations are problematic because: 1) BEV charging for Class 8 trucks is not currently available in most of the U.S.; and 2) if charging were available, long recharging in the middle of a workday would negatively impact operational efficiencies.

Alternatively, an ICE truck (with or without RD) is able to achieve a range of 1,000 miles or more before refueling is necessary, which is far greater than the BEV's 150- to 250-mile range. Likewise, the ICE range does not decrease with use, while battery capacity degrades with use.

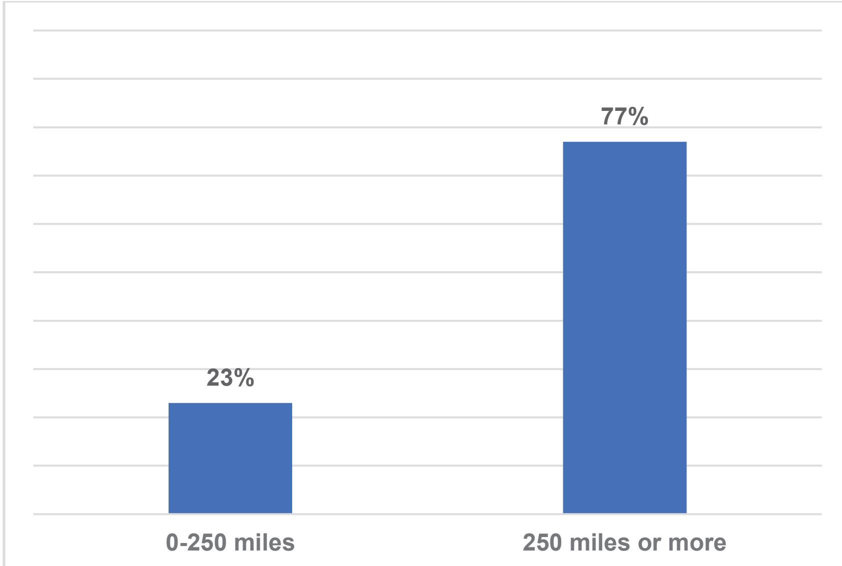
To understand how BEV mileage ranges would impact industry operations compared to ICE RD, ATRI's Operational Costs report was used to estimate the current average daily mileage for Class 8 for-hire trucks.[71] To do this, average daily mileage for the overall trucking industry was estimated by first dividing each motor carrier's average annual miles per truck by the average number of days per year each truck was operated. The resulting daily mileage averages were then weighted by the number of trucks in each fleet and averaged by sector. Finally, averages for the three primary industry sectors – truckload, less-than-truckload, and specialized – were weighted by industry representation based on Bureau of Labor Statistics data.[72] These two weighting steps were taken to accommodate for the convenience sample – small fleet outliers and operational differences – in order approximate the travel patterns of the nationwide Class 8 truck population.

This process found that an estimated 77 percent of Class 8 trucks in the for-hire trucking industry drove more than 250 miles per day in 2022 as shown in Figure 12. This range is beyond the usable trip range of current BEV trucks.

[71] Alex Leslie and Dan Murray, *An Analysis of the Operational Costs of Trucking: 2023 Update*, American Transportation Research Institute (June 2023), https://truckingresearch.org/2023/06/atris-newest-operational-costs-research-details-spikes-in-equipment-wage-and-total-costs-in-trucking/.

[72] U.S. Bureau of Labor Statistics, "Quarterly Census of Employment and Wages, Q3 2022," https://www.bls.gov/cew/. SOC codes used were as follows: 484121 for truckload carriers, 484122 for less-than-truckload carriers, and 484230 for other/specialized carriers.

Figure 12: Percent of Trucks with Daily Truck Travel of 250 Miles or more



Loss of Cargo Capacity. Another unintended consequence associated with a shift to a BEV truck fleet is the likely need for more trucks to move the same freight tonnage. This problem exists because BEV trucks are considerably heavier than their ICE counterparts due to BEV battery weights and existing weight limit caps on the National Highway System.

As background, FHWA limits the maximum gross vehicle weight to 80,000 pounds but allows an extra 2,000 pounds for batteries and auxiliary power units.[73] This means that the weight of a BEV truck, cargo and trailer cannot legally exceed 82,000 pounds without an oversize/overweight permit.

A BEV truck's weight is determined in part by how large the battery is, which directly determines the vehicle's driving range. One Class 8 BEV truck that can be purchased in the marketplace today weighs 4,000 pounds more than its ICE counterpart; this particular BEV truck can travel only 230 miles per charge.[74]

To get a better sense of vehicles that would meet the long-haul sector's requirements, ATRI modeled a BEV Class 8 sleeper cab truck which could operate at trip ranges comparable to ICE trucks (500 miles or more between charges); that BEV truck weighed 13,800 pounds more than its diesel counterpart.[75]

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[73] Federal Highway Administration, "Commercial Vehicle Size and Weight Program," (accessed February 21, 2024), https://ops.fhwa.dot.gov/freight/sw/overview/index.htm.; and Federal Highway Administration, "Fixing America's Surface Transportation Act (FAST Act) Truck Size and Weight Provisions" (February 24, 2016), https://ops.fhwa.dot.gov/freight/pol_plng_finance/policy/fastact/tswprovisions/.

[74] Bianca Giacobone, "Electrifying trucking will mean sacrificing critical weight for heavy batteries, eating into already-slim margins," *Business Insider* (February 2, 2023), https://www.businessinsider.com/electric-trucks-longhaul-batteries-tesla-heavy-cargo-weight-problem-2023-2#.

[75] Jeffrey Short and Danielle Crownover, *Understanding the CO2 Impacts of Zero-Emission Trucks: A Comparative Life-Cycle Analysis of Battery Electric, Hydrogen Fuel Cell and Traditional Diesel Trucks, American Transportation Research Institute* (May 2022), https://truckingresearch.org/2022/05/understanding-the-co2-impacts-of-zero-emission-trucks/.

The added weight, whether it is 4,000 pounds or 13,800 pounds, will impact the amount of revenue weight a BEV truck can haul. The conundrum is that the heavier the truck battery, the longer and farther the truck can drive; but with larger batteries the truck can carry less revenue-generating cargo.

To better understand the number of extra trucks needed to haul the cargo displaced by the added BEV weight, data from ATRI's Operational Costs report was again employed. Based on the carrier-provided data for that report, an estimated 34.3 percent of trucks in the truckload sector have an operating weight in excess of 75,000 lbs. As a result, if 1,000 ICE trucks were replaced with BEV trucks that weigh 7,000 pounds more, as many as 1,343 BEV trucks will be needed to haul the displaced cargo previously moved by 1,000 ICE trucks – generating considerably more truck-related traffic congestion and offsetting the CO_2 emissions reductions that are found in switching to BEV.

In summary:

- Seventy-seven percent of Class 8 trucks in the for-hire trucking sector drove more than 250 miles per day in 2022.
- For every 1,000 ICE trucks replaced by BEV trucks with an additional weight of 7,000 pounds more, as many as 343 additional trucks – and their corresponding additional emissions – will be needed to haul the same amount of freight.

Analysis Three: RD versus BEV Trucks – Financial Comparisons and Considerations

Two key cost centers in trucking operations are vehicle costs and fuel. Consequently, the research team explored the financial implications of a shift to ICE RD as an alternative to BEV.

Vehicle Costs. One major benefit of using RD to decrease CO_2 emissions is that RD is a "drop-in" fuel; hence, existing ICE trucks can run on RD without any modifications or impacts. This is especially important for smaller carriers and owner-operators that depend heavily on sourcing equipment from the used truck market. It should be noted that this research does not consider implications associated with a used BEV truck market (which presently does not exist) primarily because of battery issues – including the degradation of the battery over time.

To better quantify new truck costs, the DOE conducted an analysis of the cost differences between a 2022 BEV and ICE Class 8 long-haul truck.[76] The BEV truck analyzed had an up-front purchase cost of $457,000 while a comparable diesel ICE truck, which can use RD, had a cost of $160,000.[77] This nearly $300,000 price difference is a near-tripling of per-truck costs.

[76] U.S. Department of Energy, *2022 Incremental Purchase Cost Methodology and Results for Clean Vehicles* (December 2022), https://www.energy.gov/sites/default/files/2022-12/2022.12.23%202022%20Incremental%20Purchase%20Cost%20Methodology%20and%20Results%20for%20Clean%20Vehicles.pdf.
[77] Ibid.; the representative model used for the BEV truck had a battery size of 1369 kWh and an assumed range of 500 miles.

There were 245,164 new Class 8 trucks sold in 2022 in the U.S.[78] If 100 percent of those trucks were exclusively ICE, the 2022 new truck fleet would cost the trucking industry $40.66 billion. If the same new truck fleet were 100 percent BEV trucks, the total bill would be $116.15 billion – a cost increase of $75.48 billion for Class 8 trucks alone.

However, the truck purchase cost is only one element of the total cost of ownership (TCO). The International Council on Clean Transportation (ICCT) analyzed and compared the TCO of Class 8 BEV trucks and diesel ICE trucks in 2022 and found that a BEV truck's TCO is 13 percent to 26 percent higher than a diesel truck.[79]

For ICE trucks specifically, there is evidence that maintenance costs for diesel particulate filters and other components are far lower with RD when compared to petroleum diesel.[80]

Fuel Costs. Fuel represented the second largest operational cost center for trucking companies in 2022.[81] The production and distribution of transportation fuels, including petroleum diesel, electricity and RD, are all influenced by markets – thus it is extremely difficult to predict future fuel prices. But it is possible to analyze the factors that go into fuel pricing in order to identify price stability and cost effectiveness.

Diesel Price Factors. For petroleum diesel, the most critical factor is the global price of crude oil. These prices are often impacted by geopolitical events (e.g. sanctions on Russia) or production quotas set by the Organization of Petroleum Exporting Countries (OPEC).[82] While crude oil determines more than 45 percent of the cost of the final diesel product, refining makes up about 25 percent, with distribution, marketing and taxes making up the remaining costs.[83] Diesel price trends over the most recent 10 years are displayed in Figure 13.[84]

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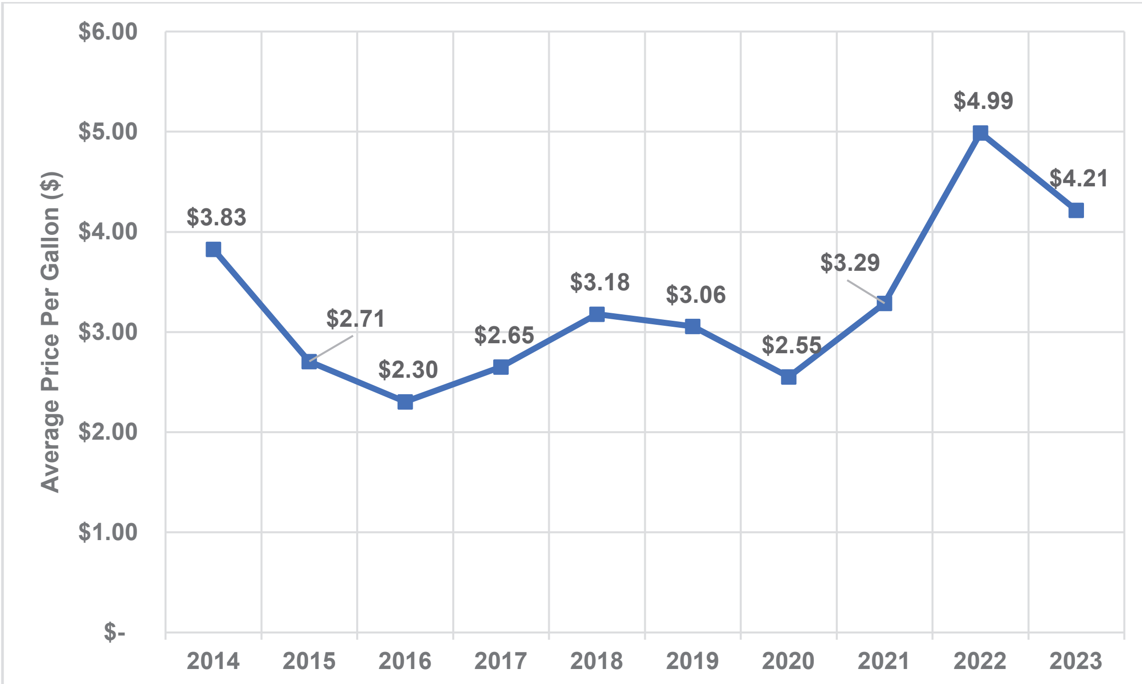
[78] American Trucking Associations, "ATA American Trucking Trends 2023" (July 19, 2023), https://www.trucking.org/news-insights/ata-american-trucking-trends-2023.
[79] Hussein Basma et al., *Total Cost of Ownership of Alternative Powertrain Technologies for Class 8 Long-Haul Trucks in the United States*, The International Council on Clean Transportation (April 2023), White Paper https://theicct.org/wp-content/uploads/2023/04/tco-alt-powertrain-long-haul-trucks-us-apr23.pdf.
[80] Matt Wolfe, "Renewable diesel offers drop-in solution for decarbonization," SAE International (February 7, 2024), https://www.sae.org/news/2024/02/neste-renewable-diesel#. ; and discussions with trucking company owners.
[81] Alex Leslie and Dan Murray, *An Analysis of the Operational Costs of Trucking: 2023 Update, American Transportation Research Institute* (June 2023), https://truckingresearch.org/2023/06/atris-newest-operational-costs-research-details-spikes-in-equipment-wage-and-total-costs-in-trucking/.
[82] U.S. Energy Information Administration, "Oil and petroleum products explained;
Oil prices and outlook" (updated on August 16, 2023), https://www.eia.gov/energyexplained/oil-and-petroleum-products/prices-and-outlook.php.
[83] U.S. Energy Information Administration, "Diesel fuel explained: Diesel prices and outlook" (updated February 16, 2023), https://www.eia.gov/energyexplained/diesel-fuel/prices-and-outlook.php.
[84] U.S. Energy Information Administration, "Petroleum & Other Liquids" (accessed on April 8, 2024), https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMD_EPD2D_PTE_NUS_DPG&f=A.

Figure 13: Diesel Price Trends*



Electricity Price Factors. Most electricity prices in the U.S. are regulated by public utility commissions (PUC), which approve the rates that utilities can charge and investments that utilities make. With more than 3,000 utilities in the country, rules and allowable investments can vary significantly across the country.

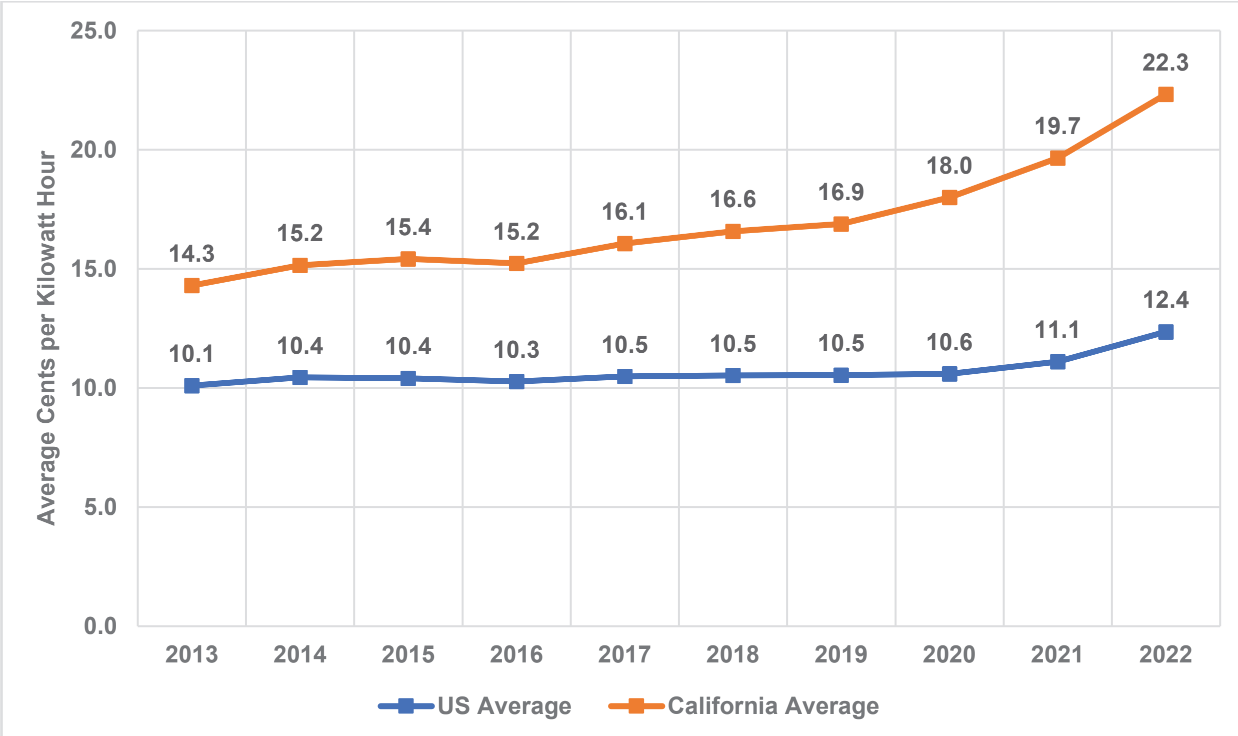
There are many factors that go into the cost of providing electricity. The fuel used for electricity, power plant operations and financing, as well as transmission and distribution lines, are all costs that factor into the price of electricity.[85]

Electricity prices have been increasing in the U.S. due to energy, maintenance and infrastructure costs as well as increased demand. Data show that electricity in urban areas is often even more expensive; in large U.S. cities, the price of electricity has increased 29.1 percent from January 2020 to January 2024.[86] Ostensibly, during this same time period, a BEV would experience this same cost increase for vehicle charging.

Average U.S. and California price trends over the most recent 10 years are displayed in Figure 14.[87]

[85] U.S Energy Information Administration, "Electricity explained: Factors affecting electricity prices" (updated June 29, 2023), https://www.eia.gov/energyexplained/electricity/prices-and-factors-affecting-prices.php.
[86] Federal Reserve Economic Data, "Average Price: Electricity per Kilowatt-Hour in U.S. City Average" (accessed March 19th, 2024), Federal Reserve Bank of St. Louis, https://fred.stlouisfed.org/series/APU000072610.
[87] U.S. Energy Information Administration, "US Electricity Profile 2022" (November 2, 2023), https://www.eia.gov/electricity/state/.

Figure 14: Annual Average Price (per kWh) of Electricity



Overall, the average price of electricity varies more than diesel depending on location.[88]

- In the continental U.S. average prices for electricity in a state could be more than 80 percent above the average or 33.3 percent lower than the average (ranging from 22.33 cents per kWh to 8.24 cents per kWh).
- For diesel fuel on the other hand, per-gallon average prices range from 27.2 percent higher or 7 percent lower than average (ranging from $5.35/gallon to $3.91/gallon).[89]

Unlike diesel prices, electricity prices may vary considerably by time-of-day and day-of-week, adding further uncertainty to costs for trucking. For trucking, these prices may also have additional demand charges to cover the cost of extending electricity infrastructure.

The price of electricity will continue to be driven by the need to expand and update infrastructure. Currently, growing demand from data centers and industrial customers is having a significant impact on costs and straining the electricity infrastructure.[90]

[88] These figures are averages across 2022.
[89] Ibid.; U.S. Energy Information Administration, "Gasoline explained: Regional gasoline price differences" (updated on February 22, 2023), https://www.eia.gov/energyexplained/gasoline/regional-price-differences.php#:~:text=Gasoline%20prices%20vary%20over%20time,retail%20competition%20and%20operating%20costs.; and U.S Energy Information Administration, "U.S. No 2 Diesel Retail Prices" (accessed March 2024), https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMD_EPD2D_PTE_NUS_DPG&f=A. ;and U.S Energy Information Administration, "U.S. No 2 Diesel Retail Prices" (accessed March 2024), https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=EMD_EPD2D_PTE_NUS_DPG&f=A.
[90] Evan Halper, “Amid explosive demand, America is running out of power,” *The Washington Post* (March 7, 2024), https://www.washingtonpost.com/business/2024/03/07/ai-data-centers-power/.

Adding medium- and heavy-duty (MHDV) BEV truck charging to the electric grid will increase this demand. It is estimated that the new infrastructure required to supply electricity to support a BEV truck fleet would cost nearly $1 trillion.[91] More than $620 billion of this would be for local and on-highway charging infrastructure and another $370 billion would be for utility upgrades. These costs do not include costs such as ongoing charger maintenance.

While the majority of this charging infrastructure cost will be borne by trucking fleets and charging providers, utility infrastructure costs may be passed through to ratepayers in the form of higher electricity costs.

RD Prices. While RD is still an emerging fuel type, it is clear that feedstock prices will be key to determining RD prices.

For first generation feedstocks, this means prices for agricultural products such as soybeans will help set RD price. This report will not cover the full complexity of agricultural economics, but there are many factors that determine the price of agricultural commodities. These of course include supply and demand, both domestic and global.

There are also federal programs that provide price supports to farmers (which could lead to overproduction).[92] With such price supports, the impact of additional demand for RD on price is unclear. In theory the additional demand on agriculture commodities provided by RD could help maintain or increase prices.

Finally, subsidies presently play a role in the retail price of RD. As shown earlier, in California RD has a price similar to petroleum diesel, but that RD price is subsidized by the LCFS carbon credit program. Federal tax credits also play a role. It is clear that in the short-term these programs are essential to fostering this new fuel type. As corroborated in this report, subsidies to help RD meet diesel price parity are likely far more cost-effective than shifting to BEV.

Additionally, it should be noted that U.S. production of commodities like soybeans has become more efficient. As shown in Figure 15, yields per acre have increased more than 38 percent in the past 25 years.[93]

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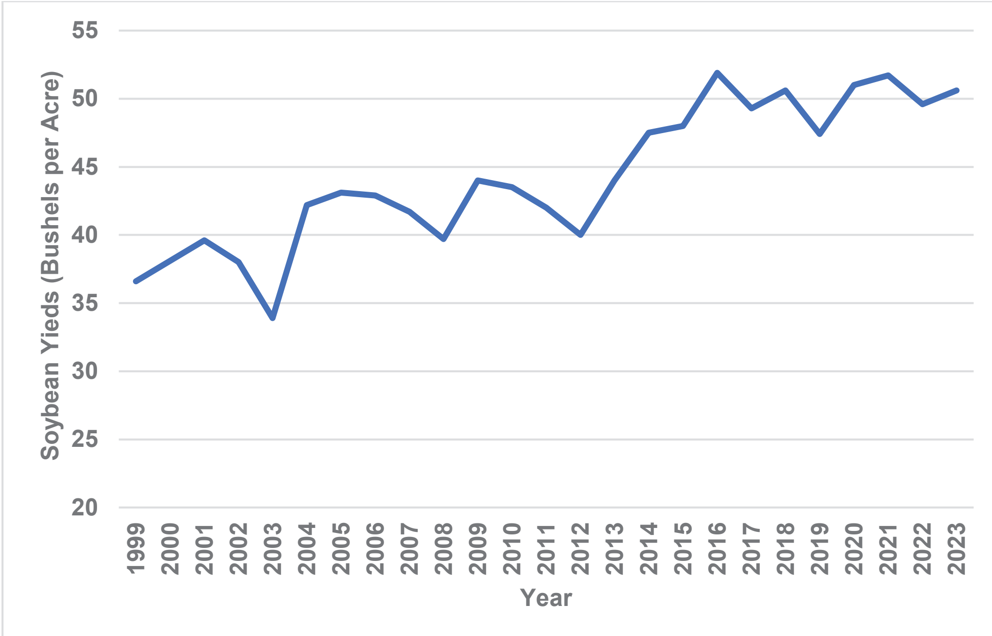
[91] Roland Berger, ***Forecasting a Realistic Electricity Infrastructure Buildout for Medium- & Heavy-Duty Battery Electric Vehicles: Executive Summary*** (March 18, 2024), commissioned by The Clean Freight Coalition, https://roar-assets-auto.rbl.ms/documents/60460/2024_03_18_CFC_Final_Results_ExecSummary_VFinal.pdf.

[92] Chris Edwards, "Cutting Federal Farm Subsidies," CATO Institute (August 31, 2023), https://www.cato.org/briefing-paper/cutting-federal-farm-subsidies#.

[93] National Agricultural Statistics Service, "Quick Stats" (accessed on April 15, 2024), U.S. Department of Agriculture, https://quickstats.nass.usda.gov/results/ED97945D-94E5-3F9B-A545-1428DA0FB57D?pivot=short_desc.

Figure 15: U.S. Soybean Yields per Acre



For second generation feedstocks, supply of one particular product or waste stream (e.g. UCO) is not likely to change each season. That said, ultimately the diversity and availability of feedstocks bodes well for RD pricing and price stability. As more feedstock types are introduced through new processes, and as waste stream collection systems are developed, more options will be available to produce RD.

In summary:

- The trucking industry spends more than $40 billion annually on new Class 8 ICE trucks; that same fleet cost would be more than $116 billion annually for BEV trucks.
- Electricity prices vary greatly across the U.S. compared to diesel prices; the cost of infrastructure to deliver electricity to the MHDV fleet has been estimated to be $1 trillion.[94]
- Feedstock diversity and development of feedstocks will determine price stability of RD.

[94] Roland Berger, *Forecasting a Realistic Electricity Infrastructure Buildout for Medium- & Heavy-Duty Battery Electric Vehicles: Executive Summary* (March 18, 2024), commissioned by The Clean Freight Coalition, https://roar-assets-auto.rbl.ms/documents/60460/2024_03_18_CFC_Final_Results_ExecSummary_VFinal.pdf.

CHOICES FOR DECARBONIZING LONG-HAUL TRUCKING

The next research task in this report is a review of two scenarios for truck-related decarbonization deployed across a 15-year timeline. The first scenario focuses on BEV expansion as a means to lower CO_2 emissions and considers both costs and environmental benefits. The second scenario explores what is needed to meet and exceed the net-benefits of the BEV expansion scenario using RD expansion.

BEV Expansion: Energy and Vehicle Costs and Environmental Benefits

Two major cost centers for achieving measurable decreases in CO_2 emissions are BEV infrastructure and vehicles.

BEV Infrastructure. As has been discussed earlier and outlined in previous ATRI research, producing and delivering enough energy to the trucking industry is a significant task.[95] ATRI's past research on the subject found that vehicle electrification in the U.S. will require a 40.3 percent increase in electricity generation. Additionally, thousands of truck parking spaces will need access to large quantities of electricity – and new transmission and distribution lines (along with substations) will be needed to carry that electricity to truck charging stations. Research in 2024 estimated that the infrastructure needed to deliver enough electricity to the MHDV fleet will cost as much as $1 trillion.[96]

ATRI estimates that the new electric infrastructure investments needed by heavy-duty vehicles would account for $596 billion of the $1 trillion.[97] These estimates were derived from the study's local on-site charging, local on-route changing, and highway charging allocations for heavy-duty trucks which accounted for 58 percent of the total cost. That percentage was then applied to distribution, generation and transmission needs. These costs are documented in Table 6.

Table 6: Electricity Infrastructure Costs Related to Heavy-Duty BEV Deployment

	Total MHDV Cost (billion)	Costs Specific to Heavy-Duty
Charging	$622.0	$361.0
Distribution	$370.0	$215.0
Generation	$22.0	$13.0
Transmission	$12.0	$7.0
Total	$1,026.0	$596.0

BEV Vehicle Costs. There are substantial costs associated with replacing existing ICE trucks with BEV trucks. As noted earlier, BEV Class 8 long-haul trucks are estimated to cost $457,000

[95] Jeffery Short, Alexandra Shirk, and Alexa Pupillo, Charging Infrastructure Challenges for the U.S. Electric Vehicle Fleet, American Transportation Research Institute (December 2022), https://truckingresearch.org/2022/12/new-atri-research-evaluates-charging-infrastructure-challenges-for-the-u-s-electric-vehicle-fleet/.
[96] Roland Berger, *Forecasting a Realistic Electricity Infrastructure Buildout for Medium- & Heavy-Duty Battery Electric Vehicles: Executive Summary* (March 18, 2024), commissioned by The Clean Freight Coalition, https://roar-assets-auto.rbl.ms/documents/60460/2024_03_18_CFC_Final_Results_ExecSummary_VFinal.pdf.
[97] Ibid.

each, with comparable ICE vehicles costing $160,000. The difference is $297,000 per truck. Roughly 3.25 million Class 8 trucks will need to be replaced.

In the past decade, new Class 8 truck sales have reached as high as 276,000 and as low as 184,800, with slightly more than 250,000 being sold in 2022.[98] For this scenario the 250,000 figure will represent the annual sales figure, and it will also be assumed that starting in 2024, 6.67 percent of Class 8 truck sales will be converted over to BEV annually (with sales of 16,667 in the first year). At the 6.67 percent rate, new sales will be shifted across 15 years to 100 percent BEV. Table 7 shows the additional cost across 15 years for the conversion to BEV.

Table 7: Additional Retail New Vehicle Costs – ICE to BEV Class 8

Year		ICE Class 8 Sales	BEV Class 8 Sales	Additional BEV Costs (Billions)
	2023	250,000	-	
Year 1	2024	233,333	16,667	$4.95
Year 2	2025	216,667	33,333	$9.90
Year 3	2026	200,000	50,000	$14.85
Year 4	2027	183,333	66,667	$19.80
Year 5	2028	166,667	83,333	$24.75
Year 6	2029	150,000	100,000	$29.70
Year 7	2030	133,333	116,667	$34.65
Year 8	2031	116,667	133,333	$39.60
Year 9	2032	100,000	150,000	$44.55
Year 10	2033	83,333	166,667	$49.50
Year 11	2034	66,667	183,333	$54.45
Year 12	2035	50,000	200,000	$59.40
Year 13	2036	33,333	216,667	$64.35
Year 14	2037	16,667	233,333	$69.30
Year 15	2038	-	250,000	$74.25
Total				$594.30

The total number of BEV trucks that enter the fleet across the 15-year timespan is 2 million out of the 3.25 million registered vehicles, or 61.5 percent of the combination truck fleet.

To replace all 3.25 million registered vehicles with BEV Class 8 tractors nearly all vehicle sales would have to be BEV. For instance, if BEV trucks were 50 percent of sales for 2024-2027 and 100 percent of sales for 2028-2038, the entire current fleet could be replaced at a price tag of $965.25 billion. Considering that only 441 Class 8 BEV trucks were sold in 2023, and that a

[98] American Trucking Associations, "ATA American Trucking Trends 2023" (July 19, 2023), https://www.trucking.org/news-insights/ata-american-trucking-trends-2023.

long-haul option does not presently exist in the market, sales at that level and on that timeline are not realistic.[99]

BEV CO_2 Impacts. CO_2 emissions are calculated for both heavy-duty truck populations at year 15 using GREET Model life-cycle data for diesel and BEV trucks. In this calculation it is assumed that all electric trucks sold will remain in the fleet population – though it is certain that vehicles sold earlier would reach the end of their useable life well before 2038.

In 2038 the fleet would reach 61.5 percent BEV and 38.5 percent petroleum diesel. For those 3.25 million vehicles registered in 2038, lifetime CO_2 emissions would be 9.82 trillion pounds as shown in Table 8. This represents a decrease of 22.6 percent from the baseline vehicle population of 100 percent petroleum diesel trucks.

Table 8: BEV Scenario Life-Cycle CO2 Emissions for 2038 Vehicle Population

	BEV	ICE Diesel	Total
Truck Population	2,000,000	1,250,000	3,250,000
Per Vehicle Life-Cycle CO_2 (Pounds)	2,593,919	3,703,895	-
Total CO_2 (Trillions of Pounds)	5.19	4.63	9.82

RD Deployment Costs and Benefits

The research team next looked at how trucking could match the total 9.82 trillion-pound CO_2 emission figure of the mixed national BEV/Diesel fleet in Table 8 using a national mixed RD/Diesel fleet. Through a comparative analysis based on the life-cycle emissions differential in Figure 6, ATRI determined that an equivalent BEV truck's CO_2 outcome could be reached if only 28.35 percent of trucks (921,398) ran exclusively on RD. This would require consumption of 8 billion gallons of RD annually. These numbers are displayed in Table 9.

Table 9: RD Scenario Life-Cycle CO2 Emissions for 2038 Vehicle Population

	ICE RD	ICE Diesel	Total
Truck Population	921,398	2,328,602	3,250,000
Per Vehicle Life-Cycle CO_2 (Pounds)	1,211,287	3,703,895	-
Annual Gallons (Billions)	8.00	20.22	28.22
Total CO_2 (Trillions of Pounds)	1.12	8.62	9.74

[99] Jacob Richard, Jessie Lund, and Baha Al-Alawi, *Zeroing in on Zero-Emission Trucks: The State of the U.S. Market*, CALSTART (January 2024), https://calstart.org/wp-content/uploads/2024/01/ZIO-ZET-2024_010924_Final.pdf.

This level of RD consumption could be reached by 2030 at a 15.79 percent annual growth rate in consumption, which is documented in Table 10. This assumes no annual RD consumption growth beyond 2030.

Table 10: Scenario RD Consumption Increase

Year		Annual RD Consumption (Billions of Gallons)	Growth from Previous Year (Billions of Gallons)
	2023	2.87	-
Year 1	2024	3.32	0.45
Year 2	2025	3.85	0.52
Year 3	2026	4.45	0.61
Year 4	2027	5.16	0.70
Year 5	2028	5.97	0.81
Year 6	2029	6.91	0.94
Year 7	2030	8.00	1.09
Year 8	2031	8.00	-
Year 9	2032	8.00	-
Year 10	2033	8.00	-
Year 11	2034	8.00	-
Year 12	2035	8.00	-
Year 13	2036	8.00	-
Year 14	2037	8.00	-
Year 15	2038	8.00	-

If growth in RD consumption continued beyond the 8-billion-gallon mark, however, the CO_2 levels could fall well below the BEV scenario.

Cost Comparison

Next, costs were calculated for meeting the 22.6 percent decrease in life-cycle CO_2 emissions for the 2038 Class 8 tractor population if BEV sales grew at the assumed annual rate of 6.67 (Table 7). As stated earlier, additional vehicle costs and infrastructure costs for Class 8 BEVs were nearly $600 billion each, totaling $1,190 billion as shown in Table 11. Transitioning to ICE RD did not have these same costs, since RD is a drop-in fuel identical to diesel, and today's trucks and fuel distribution systems would remain the same.

Table 11: Cost Comparison

	Costs in Billions of Dollars			
	Vehicle Change	Infrastructure Change	RD Subsidy/Facility (at $2 /gallon)	Total
BEV Costs	$594.30	$596.00	-	$1,190.30
ICE RD Costs	-	-	$203.72	$203.72

RD subsidies and production facility costs would exist, though it is unclear if those would remain a necessity through 2038. There is currently a $1 per gallon federal subsidy for producers, and the California LCFS costs may be as high as an additional $0.50 per gallon.[100] Likewise, new or converted refineries have a cost. ATRI conducted a scan of the costs and production capacity of new or planned RD production facilities. It was found that these costs averaged $3.70 per gallon of new capacity. Annualized over 15 years, this is roughly $0.25 per gallon per year.

Using these examples, it can be assumed that RD market development program costs (including subsidies) and production capacity costs would not be greater than $2.00 per gallon per year. These costs are reflected in Table 11, which consists of a $2 per gallon subsidy and facility cost per gallon across a 15-year time period. This cost would be $203.72 billion for the 15 years of production which totals 101.686 billion gallons of RD.

The BEV cost would therefore be 5.8 times higher than the RD cost to achieve the same goal.

[100] California Air Resources Board, "Low Carbon Fuel Standard Reporting Tool Quarterly Summaries: Quarterly Data Summary and Spreadsheet" (accessed on March 15, 2024), https://ww2.arb.ca.gov/resources/documents/low-carbon-fuel-standard-reporting-tool-quarterly-summaries.
California Air Resources Board, "Monthly LCFS Credit Transfer Activity Reports: Monthly Credit Prices" (accessed on March 15, 2024), https://ww2.arb.ca.gov/resources/documents/monthly-lcfs-credit-transfer-activity-reports.

CONCLUSIONS

This report demonstrates that ICE RD is a far more effective tool to decarbonize long-haul trucking than BEV.

- Environmentally: There is simply more CO_2 produced by a BEV than an ICE RD truck across the life-cycle.
- Operationally: BEV trucks cannot do the same job as an ICE RD – in terms of uninterrupted mileage, revenue weight and even the ability to refuel when needed. All of these factors limit the potential emission reductions of BEV trucks.
- Financially: BEV vehicle and infrastructure costs are far more expensive than ICE RD costs.

Potential Headwinds

There are potential headwinds to adoption of RD by the trucking industry.

1) Feedstocks. Though feedstock have kept up with growing demand, it is thought that a point will be reached where first-generation feedstocks can no longer meet the demand from RD producers.
2) Subsidies. While the full impact of subsidies on the RD market is not known, they are clearly encouraging production. Should subsidies be removed from the market too early, supply may decrease.
3) Sustainable Aviation Fuel (SAF). Interest is growing in SAF, which uses similar feedstocks and processes for production. It is possible that public policy could shape the SAF market, and divert RD from the trucking industry, thus working against industry efforts to decarbonize.

These issues can be overcome through reasonable next steps.

Recommendations to Increase RD Production

Feedstock Development. RD is not limited to one feedstock. First- and second-generation feedstocks are fully capable of supplying RD production capacity. Research has been underway for third-generation feedstocks (made from algae) as well. Research and development are key to enhancing the effectiveness of existing feedstocks and developing new feedstocks.

Continue to Support the Market. RD has the ability to achieve public policy goals related to CO_2 emissions at a discounted price and with greater certainty than BEV. Existing programs, such as the federal producers tax credit, must continue for the foreseeable future to encourage new entrants (both in terms of companies and facilities) into the RD production environment.

Avoid Biofuel Production Policy that Favors Certain Industries. Much like the long-haul trucking industry, aviation is difficult to decarbonize through electrification. SAF has been seen as one solution to help aviation meet CO_2 emissions goals. Though today's jets are not equipped to consume 100 percent SAF and the product is more difficult to produce than RD, special subsidies were created for SAF that could work to undermine RD production.

The trucking industry – like aviation – needs an achievable path towards decarbonization. There is no doubt that biofuels such as RD and SAF will be important factors in decarbonizing transportation. That said, encouraging SAF production over RD – through enhanced subsidies for aviation fuel – simply works to undermine the trucking industry's efforts to decarbonize.

Final Summary

While 8 billion gallons of annual RD consumption by the end of the decade may seem large, it is entirely possible considering the projections and new refining capacity described in this report. The net benefits of RD – as shown in Table 12 – far exceed those of BEV.

Table 12: Summary of Costs and Benefits of ICE RD and BEV

	ICE RD	BEV
Environmental Benefits	67.3 percent decrease in per truck life-cycle CO_2 from ICE diesel	30.0 to 39.5 percent decrease in per truck life-cycle CO_2 from ICE diesel
Operational Changes	No operational changes from ICE diesel	Limited range and cargo capacity; substantial operational challenges using today's BEV equipment
Costs to Reach 22.6% CO_2 Decrease	$203 billion across 15 years	$1,190 billion across 15 years
Cost per Percentage Point Decrease in CO_2	$8.982 billion	$52.654 billion

Additionally, there are no significant structural impediments to consuming RD: the trucks and the delivery system already exist. Plus, any consumption beyond the 8-billion-gallon level would have an even greater CO_2 emissions reduction impact than even the most promising BEV scenarios.

Finally, it goes without saying that RD production may have significant benefits in rural America and diminish the industry's exposure to fluctuating global oil markets.

The BEV scenario described in this report is a "best-case," considering: 1) there are no long-haul BEV trucks on the market today; and 2) the infrastructure to support BEV is costly with no clear path to cover those costs. Additionally, it will take a tremendous amount of time to plan, permit and build that infrastructure. In the BEV scenario – while electric utilities and others struggle to meet infrastructure needs – the opportunity to meaningfully decrease CO_2 emission in the industry through RD could be missed.

APPENDIX A: RD INCENTIVE PROGRAMS

The following is a compilation of data and background information sourced directly from the Department of Energy's Alternative Fuels Data Center.[101]

Table A1: RD Incentive Programs

Title	Jurisdiction	Agency	Incentive Type	Description
Biofuel Feedstock Research and Development Grants	Federal	DOE	Grant	The U.S. Department of Energy's (DOE) Industrial Efficiency and Decarbonization Office (IEDO) provides funding for the research, development, and demonstration of technologies that decrease greenhouse gas emissions in emissions intensive industries, including projects that pursue advance process technologies for converting feedstocks to biofuels. Eligible applicants include universities, businesses, and nonprofit organizations.
Advanced Biofuel Technology Development Grants	Federal	DOE	Grant	The U.S. Department of Energy and the U.S. Environmental Protection Agency offer grants of up to $9.4 million for the development of advanced biofuel technologies. Eligible transportation fuels include biofuels and sustainable aviation fuel. Eligible applicants include universities, businesses, and nonprofit organizations. A cost share of at least 20% is required.
Biodiesel Income Tax Credit	Federal	IRS	Tax	A taxpayer that delivers pure, unblended biodiesel (B100) into the tank of a vehicle or uses B100 as an on-road fuel in their trade or business may be eligible for an incentive in the amount of $1.00 per gallon of biodiesel, agri-biodiesel, or renewable diesel. If the biodiesel was sold at retail, only the person that sold the fuel and placed it into the tank of the vehicle is eligible for the tax credit. The incentive is allowed as a credit against the taxpayer's income tax liability. Claims must include a copy of the certificate from the registered biodiesel producer or importer that: identifies the product; specifies the product's biodiesel, agri-biodiesel, and/or renewable diesel content; confirms that the product is properly registered as a fuel with the U.S. Environmental Protection Agency (EPA); and confirms that the product meets the requirements of ASTM Standard D6751. Renewable diesel is defined as liquid fuel derived from biomass that meets EPA's fuel registration requirements and ASTM Standards D975 or D396; the definition of renewable diesel does not include any fuel derived from co-processing biomass with a feedstock that is not biomass.

[101] Alternative Fuels Data Center, "Biodiesel Laws and Incentives" (accessed February 2024), U.S. Department of Energy, https://afdc.energy.gov/fuels/laws/BIOD.

Title	Jurisdiction	Agency	Incentive Type	Description
Biodiesel Mixture Excise Tax Credit	Federal	IRS	Tax	A biodiesel blender that is registered with the Internal Revenue Service (IRS) may be eligible for a tax incentive in the amount of $1.00 per gallon of pure biodiesel, agri-biodiesel, or renewable diesel blended with petroleum diesel to produce a mixture containing at least 0.1% diesel fuel. Only blenders that have produced and sold or used the qualified biodiesel mixture as a fuel in their trade or business are eligible for the tax credit. The incentive must first be taken as a credit against the blender's fuel tax liability; any excess over this tax liability may be claimed as a direct payment from the IRS. Claims must include a copy of the certificate from the registered biodiesel producer or importer that: identifies the product; specifies the product's biodiesel, agri-biodiesel, and/or renewable diesel content; confirms that the product is properly registered as a fuel with the U.S. Environmental Protection Agency; and confirms that the product meets the requirements of ASTM Standard D6751. Renewable diesel is defined as liquid fuel derived from biomass that meets EPA's fuel registration requirements and ASTM Standards D975 or D396; the definition of renewable diesel does not include any fuel derived from co-processing biomass with a feedstock that is not biomass.
Clean Fuel Production Credit	Federal	IRS	Tax	Beginning January 1, 2025, the Treasury Department will offer tax credits for the production and sale of low-emission transportation fuels, including sustainable aviation fuel (SAF). The tax credit amount is $0.20 per gallon for non-aviation fuel and $0.35 per gallon for SAF. For facilities that satisfy the prevailing wage and apprenticeship requirements, the credit amount is $1.00 per gallon for non-aviation fuel and $1.75 per gallon for SAF. For any taxable year, the Clean Fuel Production Credit is equal to the applicable credit amount per gallon multiplied by the fuel's carbon dioxide emissions factor. Emissions factors will be published annually by the Secretary of the Treasury. Beginning January 1, 2025, tax credits will be adjusted for inflation. Further guidance is forthcoming. For more information, including guidance updates, see the Internal Revenue Service Credits and Deductions under the Inflation Reduction Act website.

Title	Jurisdiction	Agency	Incentive Type	Description
Clean Fuels and Products Demonstration Projects	Federal	DOE	Grant	The U.S. Department of Energy's Energy Earthshots Initiative Clean Fuels & Products Shot aims to decarbonize the fuel and chemical industry through alternative sources of carbon to advance cost-effective technologies with the goal of reducing industry greenhouse gas emissions 85% by 2035. Clean Fuels & Products Shot focuses on various projects to mobilize biomass and waste feedstock, efficiently capture and convert carbon dioxide, develop carbon-efficient conversion processes, demonstrate integrated processes, and understand sustainability implications.
Regional Biofuel Research and Development Grants	Federal	DOE	Grant	The U.S. Department of Energy (DOE) has grants of up to $10 million for research and development of low carbon intensity feedstock crops for transportation fuels – this includes biofuels. Those eligible to apply include institutes of higher education, for-profit entities, nonprofit organizations, state and local governments, and tribal governments.
Resilient Surface Transportation Grants	Federal	FHWA	Grant	The U.S. Department of Transportation Federal Highway Administration (FHWA) established the Promoting Resilient Operations for Transformative, Efficient, and Cost-Saving Transportation (PROTECT) Discretionary Grant Program to provide funding for projects that improve the resilience of the surface transportation system through support of planning activities, resilience improvements, community resilience and evacuation routes, and at-risk costal infrastructure. Eligible projects include those that demonstrate greenhouse gas reductions in the transportation sector through the transition to clean vehicles and fuels, including electrification.
Biodiesel Production Tax Credit	Virgina	Dept. of Taxation	Tax	Qualified biodiesel and green diesel producers are eligible for a tax credit of $0.01 per gallon of biodiesel or renewable diesel fuels produced. This credit is available for producers who generate up to two million gallons of biodiesel or renewable diesel fuel per year. The annual credit may not exceed $5,000, and producers are only eligible for the credit for the first three years of production. The Virginia Department of Mines, Minerals and Energy must certify qualified producers.

Title	Jurisdiction	Agency	Incentive Type	Description
Biofuel Loan Program	North Dakota	Bank of ND	Loan	The Biofuels Partnership in Assisting Community Expansion (PACE) Loan Program provides an interest buy down of up to 5% below the note rate to biodiesel, ethanol, or renewable diesel production facilities; livestock operations feeding by-products produced at a biodiesel, ethanol, or renewable diesel facility; and grain handling facilities which provide storage of grain used in biofuels production. Qualified biodiesel, ethanol, and renewable diesel production facilities located in North Dakota may receive up to $500,000 of interest buy down for the purchase, construction, or expansion of a production facility, or the purchase or installation of equipment at the facility.
Biodiesel and Renewable Diesel Sales Equipment Tax Credit	North Dakota	Office of State Tax Commissioner	Tax	"Qualified retailers may be eligible for a corporate income tax credit of 10% of the direct costs incurred to adapt or add equipment to a facility so that it may sell diesel fuel containing at least 2% biodiesel or renewable diesel. A retailer may only claim the credit for up to five years and is limited to $50,000 in cumulative credits for all taxable years. The biodiesel or renewable diesel must meet applicable ASTM standards.
Biodiesel and Renewable Diesel Blender Tax Credit	North Dakota	Office of State Tax Commissioner	Tax	A licensed fuel supplier who blends biodiesel or renewable diesel with diesel fuel may claim an income tax credit of $0.05 per gallon for fuel containing at least 5% biodiesel or renewable diesel. The tax credit may not exceed the taxpayer's liability for the taxable year and each year's unused credit amount may be carried forward for up to five taxable years. The biodiesel or renewable diesel must meet applicable ASTM standards.
Biodiesel and Renewable Production and Blending Equipment Tax Credit	North Dakota	Office of State Tax Commissioner	Tax	Qualified producers or blenders may be eligible for a corporate income tax credit of 10% of the direct costs incurred to add equipment to retrofit an existing facility or construct a new facility in the state for the purpose of producing or blending diesel fuel containing at least 2% biodiesel or renewable diesel. A taxpayer may only claim the credit for up to five years and is limited to $250,000 in cumulative credits for all taxable years. The biodiesel or renewable diesel must meet applicable ASTM standards.

Title	Jurisdiction	Agency	Incentive Type	Description
Biodiesel Production and Blending Tax Credit	Kentucky	Department of Revenue	Tax	Qualified biodiesel producers or blenders are eligible for an income tax credit of $1.00 per gallon of pure biodiesel (B100) or renewable diesel produced or used in the blending process. Re-blending of blended biodiesel does not qualify for the tax credit. The total amount of credits claimed by all biodiesel producers may not exceed the annual biodiesel tax credit cap of $10 million. Unused credits may not be carried forward. For the purpose of this credit, biodiesel must meet ASTM Standard D6751, and renewable diesel is defined as a renewable, biodegradable, non-ester combustible liquid derived from biomass resources that meets ASTM Standard D975.
Biofuel Blend Tax Exemption	Texas	Texas Comptroller of Public Accounts	Exemption, Tax	The biodiesel, renewable diesel, or ethanol portion of blended fuel containing taxable diesel is exempt from the diesel fuel tax. The biodiesel, renewable diesel, or ethanol fuel blend must be clearly identified on the retail pump, storage tank, and sales invoice in order to be eligible for the exemption.
Heavy-Duty Emission Reduction Grants	Pennsylvania	DEP	Grant	The Pennsylvania Department of Environmental Protection (DEP) offers grants for the repower or replacement of ferries, tugboats, and freight switcher locomotives with any new U.S. Environmental Protection Agency or California Air and Resource Board-certified diesel, alternative fuel, or all-electric equivalent.

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Exhibit 21

March 19, 2024

Forecasting a Realistic Electricity Infrastructure Buildout for Medium- & Heavy-Duty Battery Electric Vehicles

Clean Freight Coalition

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Members of the Clean Freight Coalition

- American Bus Association
- American Truck Dealers
- American Trucking Associations
- National Association of Truck Stop Operators
- National Motor Freight Traffic Association
- National Tank Truck Carriers
- Truckload Carriers Association

Report prepared by Roland Berger 2024

List of Acronyms

MDHD	Medium-Duty Heavy-Duty
MD	Medium-Duty
HD	Heavy-Duty
BEV	Battery Electric Vehicle
ZEV	Zero Emission Vehicle
NREL	National Renewable Energy Laboratory
TCO	Total Cost of Ownership
L2	Level 2 Charger
L3	Level 3 Charger
DC	Direct Current
DCFC	Direct Current Fast Charger

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EXECUTIVE SUMMARY

Numerous new pressures are being placed on the trucking industry. States and the federal government are examining regulations to quickly transition the industry by 2040 to full electrification with the goal to reduce commercial vehicle carbon emissions. The Clean Freight Coalition contracted a study with Roland Berger to determine the added costs to the freight industry and utilities if commercial vehicles reach 100% electrification. This study examined two scenarios- one with current vehicle and charging technology offerings, and the other with modest improvement in both vehicles and chargers- to determine the realistic electricity infrastructure buildout scenario for medium- and heavy-duty battery electric vehicles.

Key Findings:

- Preparing today's commercial vehicle fleet for electrification would require the industry to invest upwards of $620 billion in charging infrastructure alone, including chargers, site infrastructure, and electric service upgrades.
- Utilities will need to invest $370 billion to upgrade their grid networks to meet the demands of commercial vehicles exclusively.
- This nearly $1 trillion expenditure does not account for the cost of purchasing new battery-electric trucks, which, according to market research, can be 2 to 3 times as expensive as their diesel-powered equivalents.
- Given current economic and operational constraints, longhaul, over-the-road trucking is ill-suited for electrification today. However, if significant upfront infrastructure investments are made, opportunities for medium-duty (MD) vehicles and last-mile logistics exist. In addition to infrastructure investments, the feasibility of longhaul battery electric vehicles (BEV) will depend on further vehicle and charger technology advances.
- Policymakers will need to address these cost concerns and technological hurdles to ensure an electrified supply chain functions smoothly for the American economy.

Our findings highlight the significant electric infrastructure costs involved in transitioning to BEVs and emphasize its impact across sectors, notably the trucking industry, the supply chain, and the broader economy. Over the next two decades, a full transition to BEVs would require a substantial and direct expenditure shared by both fleets and utilities, with unknown consequences for the American consumer and ratepayer. Rather than mandating BEVs, policymakers should examine ways to incentivize these vehicles over realistic and reasonable timelines. At the same time, governments should encourage and incentivize the adoption of more efficient clean diesel and alternative-fueled vehicles on the road by eliminating the federal excise tax on trucks.

METHODOLOGY

We employed a scenario analysis based on a charging network simulation and utility infrastructure needs assessment to forecast the realistic electricity infrastructure buildout required for medium-duty and heavy-duty (MDHD) BEVs.

Charging Network Analysis

Our study began with a charging network analysis to understand the different operating dynamics of local, regional, and highway operations within the trucking industry, and the required charging networks for each. We conducted a comprehensive geographic analysis for local charging to delineate regional truck distributions across metro, suburban, and rural areas. This granular analysis enabled us to identify areas of high truck concentration that may necessitate grid upgrades. A charging strategy analysis was then employed to allocate truck populations to on-site or on-route charging stations based on factors such as battery capacity and route distances. In parallel, we devised a charging location network for the highway segment to map traffic flows and simulate a highway traffic network. This effort involved estimating the appropriate configuration of chargers, including their number and power capacity. Through these simulations, we derived a regional distribution of peak load profiles and identified an estimated number of depot or charging stations to support MDHD BEVs.

Utility Infrastructure Needs Assessment

Following the charging network simulation, we assessed the utility upgrades required in the existing infrastructure to accommodate MDHD BEVs. This assessment was comprised of several components:

1. **Electric load impact analysis:** We aggregated load profiles and overlaid geographical data to assess available capacity against projected demand.
2. **Site infrastructure analysis:** We estimated on-site infrastructure costs based on charger quantity and size.
3. **Distribution infrastructure analysis:** This involved evaluating local grid capacity upgrade needs and associated utility investment requirements.
4. **Power system infrastructure analysis:** We estimated investments in power system assets necessitated by increased capacity demand.
5. The results of the infrastructure needs assessment were synthesized to provide insights into the investment needs and challenges across both charging infrastructure and energy infrastructure.

Scenario Analysis

Our study uses two scenarios to explore pathways for electrifying the U.S. MDHD vehicle fleet based on the pace of technological improvement.

1. **Current technology scenario:** This scenario assumes the continuation of existing technology and performance characteristics. We assume a maximum Class 8 usable vehicle range of 180 miles and a maximum fast-charging capacity of 350 kW supported by real world fleet mileage.
2. **Improved technology scenario:** This scenario assumes advancements in battery density and charging speeds over the medium term. Due to an improved battery density of 40%, we assume an increased range for Class 6-8 vehicles. The maximum Class 8 usable vehicle range increases to 250 miles. Maximum fast-charging capacity increases to 500 kW for locally operated vehicles and up to 1MW for highway vehicles.

Table 1 summarizes the types of charging that would be used for different types of fleets operating electric commercial vehicles. For the local charging network, we analyzed where, when, and how vehicles will charge to determine the best network configuration and its load profile. On-site charging refers to private “behind the fence” chargers at a fleet's depot or terminal. These chargers are typically Level 2 (L2), slower than DC fast chargers (DCFC) but can charge a truck overnight. Depot charging is suitable for Class 3-6 trucks with operational profiles for urban package and delivery, point-to-point operations under 180 miles, and dedicated routes, like school buses.

On-route charging refers to chargers located along highways or other major roads, typically DCFC that provide a significant charge in a relatively short time. For this study, on-route charging is public but designed specifically for commercial vehicles. Chargers are designed for truck operations with pull through connections and in areas where trucks congregate. On-route charging is suitable for on-highway tractors, regional haul and MD trucks that require extended battery range. These truck fleets would use DCFC at least once daily.

Table 1. Summary of local and highway charging strategies

Location	Local charging			Highway charging
Strategy	On-site charging		On-route charging	
Description	**Private chargers** installed at fleet's owned depot location	**Shared charging hubs** with dedicated availability for fleet customers	**Fully public-access** chargers for on-route or destination use	**Fully public-access** chargers along the highway network
Typical fleet characteristics	Large national fleets with **sufficient depot infrastructure**	Small to medium sized fleets with **insufficient depot characteristics**	Used by **various** fleet types (esp. for high-mileage use cases)	Used by **long-haul** vehicles (trucks and OTRBs)
Charger configurations[1)]	**Level 2** **Level 3** **DCFC** (limited cases)	**Level 2** **Level 3** **DCFC** (limited cases)	**DCFC**	**DCFC**

1) Level 2 charging refers to AC chargers less than 20 kW. Level 3 refers to DC chargers 50-150 kW. DCFC refers to DC fast chargers 350 kW and above.

Within the MDHD population, we mapped four broader use case segments to different charging location types (Figure 1).

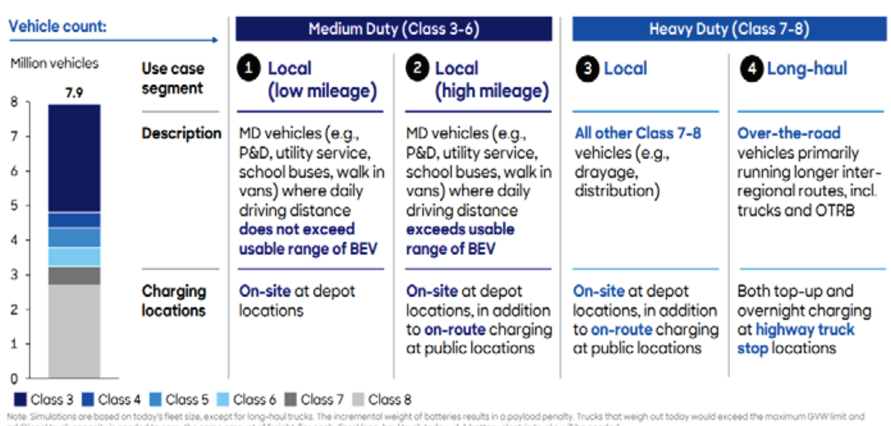

Figure 1. Four use case segments for MDHD vehicle population

We then analyzed when, where, and how often heavy-duty (HD) BEVs will charge for local vehicles to determine duty cycle and electric load profiles. These data points were based on National Renewable Energy Laboratory's (NREL) Fleet DNA telematics data project, which derived the daily driving mileage distribution to identify how much demand can be served by overnight and on-route charging.[1] Aggregated profiles for overnight and on-route charging demand identified how much charging occurs at base versus on-route, respectively, and the extent to which private or public stations need to be installed. The aggregation of these profiles revealed the overall load curve per vehicle class at the county level.

These analyses also used NREL's fleet data to create load profiles for the local charging network supporting Class 3-8 vehicles. We generated a mileage distribution and duty cycle curve to identify the proportions of charging demand best served by overnight versus on-route charging. This determined the respective amounts of charging occurring at base versus on-route locations. Combining these profiles yields electricity load curves for each region and vehicle class, which we then used to simulate county-level electricity demand. For longhaul trucks, we identified truck stop locations throughout the United States and simulated longhaul truck traffic. We analyzed longhaul duty cycles to determine top-up and overnight charging demand, revealing the infrastructure needed at each station type. The aggregated average load curve shows the expected charger needs and county-level electricity load curve.

CURRENT VEHICLE AND CHARGER TECHNOLOGY

Vehicles

Our study examined current BEV commercial vehicles available for purchase and the real-world range for each available truck. The average usable range was computed with a charge range of 20 to 80% per the recommendations from battery manufacturers. Table 2 below includes the vehicle classifications and available BEV trucks studied to determine the operational ranges and charging profiles required.

Table 2. Typical operational ranges of different classes of current technology BEV

			Current technology		
	Example vehicles	Mileage efficiency [kWh/mi]	Battery capacity [kWh]	OEM spec range [mi]	Usable range [mi][1)]
Class 3	Rivian, Ford eTransit, MB eSprinter	0.7	100	150	**90**
Class 4	Workhorse W4CC	0.7	100	150	**90**
Class 5	Freightliner Mt50e, Workhorse W56	1.5	100	150	**90**
Class 6	Kenworth, Navistar eMV, Freightliner eM2	1.3	218	163	**98**
Class 7	Kenworth, Navistar eMV, Freightliner eM2	1.3	218	163	**98**
Class 8	Freightliner eCascadia, Volvo VNR	2.0	440	220	**132**
Long-haul	No electric long-haul truck in series production today. Range estimate is based on the Daimler eActros 600[3)]	2.0	600	300	**180**

1) "Usable range" assumes the battery never falls below 20% SOC, and is never charged above 80% SOC
2) Assumed improvement in gravimetric density: 40%; OEMs use improvement to increase range while keeping battery weight constant
3) European model, also expected to become available in the US; specs for currently available OTRBs comparable to RB assumptions

Source: OEM websites, Roland Berger analysis

[1] "Fleet DNA Product Data." 2024. National Renewable Energy Laboratory.

Class 3-5 fleets with local usable ranges below 90 miles can utilize overnight charging for efficient operations. For MD vehicles that typically return to base within 12 hours, slower Level 2 (L2) or Level 3 (L3) overnight charging suffices. However, Figure 2 illustrates how the NREL vehicle profiles showed that approximately 7% of Class 3-6 vehicles exceed today's operational mileage, necessitating supplementary on-route charging. The picture becomes more pronounced among local fleets running heavier classed vehicles and operating with higher daily mileage requirements.

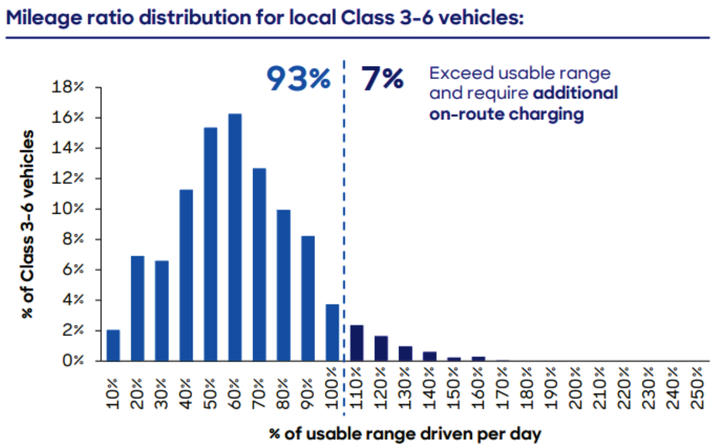

Figure 2. Local Class 3-6 routes as a percentage of usable range with current technology

Under current vehicle technology, local class 7 or 8 tractors returning to base may have as few as 2 to 6 hours available for charging, necessitating costlier L3 or DCFC on-site chargers. Given current vehicle ranges, roughly half of the HD local fleets could exceed the usable range of BEV trucks, requiring access to on-route fast charging to meet their operational needs (Figure 3). Before these high mileage vehicles can electrify, fleets require a sufficiently dense, geographically dispersed, and reliable local on-route charging network to avoid long wait times during peak charging hours.

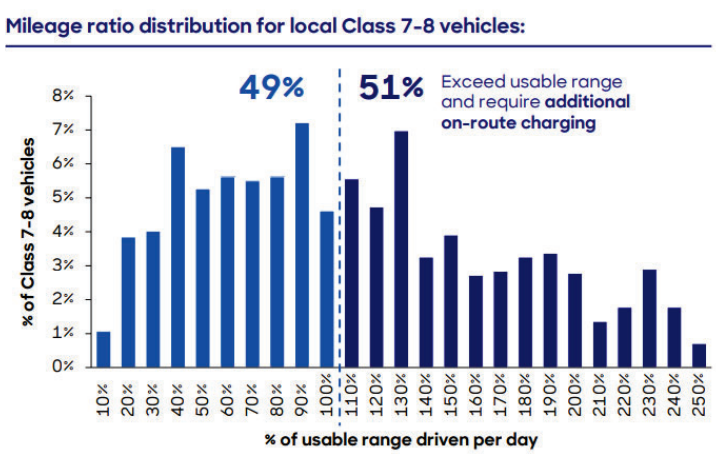

Figure 3. Local Class 7-8 routes as a percentage of usable range with current technology

Longhaul trucks face a significant challenge due to their limited range and the time required for charging. This results in a charging penalty of one to two hours per day for top-up charging, directly impacting fleets' total cost of ownership (TCO). Because most longhaul trucks cover daily mileages exceeding 200 miles, drivers must make at least one, and frequently two or more, stops for charging due to the current usable range being limited to 180 miles. Even with 350 kW chargers, nearly 80% of Class 8 longhaul trucks and truck drivers would need at least an hour of off-duty time during on-route charging, incurring a time penalty compared to traditional internal combustion engines vehicles.

Chargers

MDHD fleets will invest in on-site charging to support BEV deployments. Controlling charging times and costs will provide flexibility during the day charge time, cost containment for electricity costs, and management of departure and arrivals for trucks.

Local mileage operations for MD vehicles can rely on L2 chargers to minimize charger and utility investments. These low-mileage vehicles will have a larger opportunity window to charge at off-peak hours, reducing a fleet's electricity costs. A L2 charger can assist in minimizing on-site investment with longer charge times, though fleets might choose to invest in future on-site high capacity charging to support diverse vehicle operations, thus allowing for different charging profiles.

On-site costs per vehicle can vary depending on BEV fleet size, available power capacity at existing sites, and the local utilities' make-ready programs. While L2 chargers can minimize electric vehicle equipment investment at low vehicle adoption rates, scaling to higher BEV vehicles on-site can dictate significant power, which could require the utility to upgrade upstream infrastructure, such as new substations. New investment from a utility to on-site charging can quickly increase costs on a per vehicle basis.

Regardless of charger capacity on-site, several unknown costs and time constraints can impact a fleet's upfront costs to support electrification. Site improvements, utility investments to support energization of chargers, lead times for utility improvements, and any redundant power solutions can ultimately impact deployment, investment plans and operational costs.

HD local use cases will leverage on-site charging but will require higher energy on premises to support a higher battery range with reduced downtime due to charging. To support a fleet's duty operations, L3 or DCFC will be required on-site. Potential paths towards electrification for all these fleets involve significant costs and risks. Fleet investment can range from $150,000 to $600,000 per vehicle depending on on-site utility service upgrades. These upgrades would be outside of vehicle acquisition costs. If fleets cannot install the requisite power on-site for their operation, they will need to charge at lower rates with more BEV trucks—resulting in higher vehicle purchase and operational costs.

To electrify higher mileage MD or longhaul HD trucks, a reliable and robust on-route charging network needs to exist before these trucks can operate. At unknown utilization today and the need to overbuild on-site to reduce queuing times at chargers, investment for an on-route network is costly and comes with a first-mover disadvantage. Today's range for longhaul BEV trucks is insufficient to cover daily operations and would require multiple on-route charging stops (Figure 4). Even with today's 350 kW chargers, drivers would need to spend long periods of time charging on-route, impacting their hours-of-service requirements, downtime, and delays.

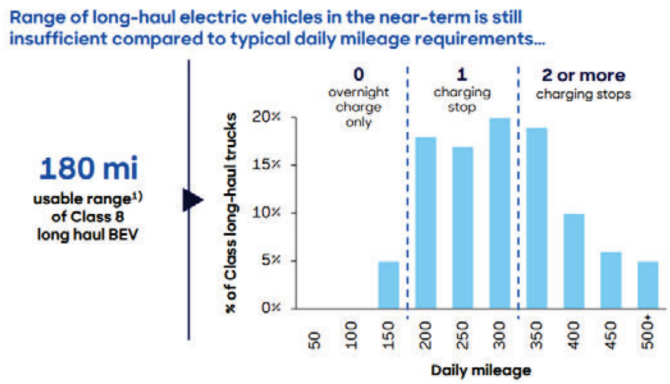

Figure 4. Expected charging stops required for longhaul Class 8 BEV using current technology

IMPROVED VEHICLE AND CHARGER TECHNOLOGY

Vehicles

Using the improved technology scenario, which assumes battery improvements that allow for a usable range of 250 miles (Table 3) and on-route charging improvements that allow for 500 kW or 1MW of power, a significant on-route charging network would still be essential for high-mileage vehicles for MDHD.

Table 3. Typical operational ranges of different classes of improved technology BEV

	Example vehicles	Mileage efficiency [kWh/mi]	Improved technology: Battery capacity [kWh]	OEM spec range [mi]	Usable range [mi][1]
Class 3	Rivian, Ford eTransit, MB eSprinter	0.7	100	150	**90**
Class 4	Workhorse W4CC	0.7	100	150	**90**
Class 5	Freightliner Mt50e, Workhorse W56	1.5	100	150	**90**
Class 6	Kenworth, Navistar eMV, Freightliner eM2	1.3	305[2]	228	**137**
Class 7	Kenworth, Navistar eMV, Freightliner eM2	1.3	305[2]	228	**137**
Class 8	Freightliner eCascadia, Volvo VNR	2.0	616[2]	308	**185**
Long-haul	No electric long-haul truck in series production today. Range estimate is based on the Daimler eActros 600[3]	2.0	850[2]	420	**250**

1) "Usable range" assumes the battery never falls below 20% SOC, and is never charged above 80% SOC
2) Assumed improvement in gravimetric density: 40%; OEMs use improvement to increase range while keeping battery weight constant
3) European model, also expected to become available in the US; specs for currently available OTRBs comparable to RB assumptions

Source: OEM websites, Roland Berger analysis

Class 3-5 fleets remain steady within their usable range as their duty cycles allow them a longer window of opportunity to charge on-site. Lower L2 chargers continue to suffice for charging management investment and planning for daily vehicle operations. Improved battery range begins to capture a larger percentage of the daily range for MD vehicles, though 3% of duty cycles still exceed the useable battery 250-mile range (Figure 5). A smaller portion of MD vehicles would still require an on-route charging network to complete their daily operations.

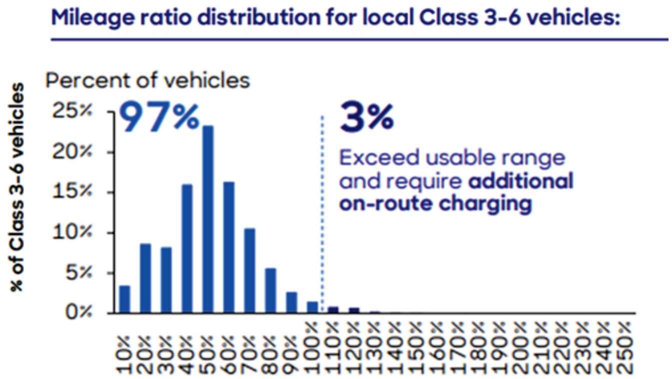

Figure 5. Local Class 3-6 routes as a percentage of usable range with improved technology

Even with improved technology, many Class 7-8 HD will still exceed their usable range to satisfy daily range requirements (Figure 6). To ensure uninterrupted operations, fleets will be required to invest in higher capacity L3 charging on-site and rely on on-route charging at higher outputs to manage charging times with drivers' hours of service requirements.

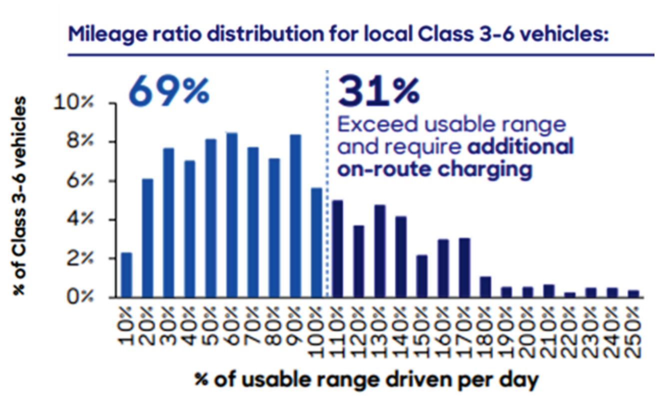

Figure 6. Local Class 7-8 routes as a percentage of usable range with improved technology

Fleets continue to face similar economic challenges for on-site infrastructure investment and costs of a robust on-route charging network. To support adoption and meet TCO requirements, on-route charging will need higher outputs to cover a truck's duty range. While these increased charging levels may reduce time penalties for on-route charging, they may also substantially increase distribution requirements, grid impacts, and, ultimately, cost.

Chargers

Using NREL data, assuming the technology improvements above, and assuming that as much on-site charging would be used as possible to meet electrification needs, we estimate significant on-site (Table 4) and on-route (Table 5) quantities of chargers would be necessary.

Table 4. On-site charger requirements to meet improved technology scenario

Required On-Site Technology and Costs	Number Required	Max Power	Costs
L2 (up to 20kW)	4,840,000	96,800,000	141 B
L3 (350 kW)	1,530,000	535,500,000	113 B

Table 5. On-route charger requirements to meet improved technology scenario

Required On Route Technology and Costs	Number Required	Max Power	Costs
L3 (up to 350kW)	120,000	42,000,000	30 B
500 kW	46,000	23,000,000	69 B
1 MW	12,000	12,000,000	27 B

Two important observations about these estimates stand out. First, achieving 100% electrification would demand a substantial quantity of on-site charging infrastructure. Installing over 6 million individual L2 and L3 charging units would necessitate tens or hundreds of thousands of separate projects involving various fleets. According to the U.S. Department of Energy's Alternative Fuels Data Center, 178,517 new L2 and L3 chargers were installed across the entire U.S. in 2023 for both public and private use. The build-out of on-site charging just for commercial vehicle electrification would take over 35 years to construct at the current pace.[2]

Second, although on-route charging requires fewer units, individual sites will still require significant power even with a small number of units. On-route charging requires the concentration of grid infrastructure at a limited number of locations, which are often situated away from existing infrastructure. Investments in equipment and distribution may need to be substantially higher to accommodate these elevated power requirements. It is also worth reiterating that on-route infrastructure is largely outside fleet control and therefore must be substantially completed along a given route before a fleet can acquire and plan to operate BEV on those routes. 500 kW and 1 MW chargers are not widely deployed, and there is significant uncertainty if these chargers will be available ahead of mandated adoption of BEVs. All stakeholders will

[2] https://afdc.energy.gov/stations/#/find/nearest?country=US

need to consider how the design and construction of high-power chargers will differ from L2/L3 chargers, particularly how to plan the on-route charging network to ensure usable routes created along major freight corridors.

A final point of emphasis is that all this infrastructure will require new construction, specifically designed for commercial vehicles, and generally not compatible with other road users. Commercial vehicle operations are time-sensitive and cannot rely on public charging solutions for which reliability and queue times are not controlled. In the case of on-site charging, fleets will need to acquire the land, plan the designs, and coordinate construction projects with each utility with which they need to build charging capacity. For on-route charging, that means pull-through designs specifically made for efficient commercial vehicle charging will need to be used, and 3- to –8-year lead times will need to be planned if new substation-level infrastructure is part of the construction.

UTILITY IMPACTS AND INVESTMENTS

Given the estimates of charging requirements for 100% electrification, we evaluated the impacts that charging build out would have on upstream utilities. Using the route data from the charging estimate and county-level utility data, we estimated some of the local-level impacts of commercial vehicle electrification.

Capacity

In many counties, the addition of on-site charging would significantly change daily electricity load profiles. On-site charging would predominantly be used during overnight dwell times, creating a new peak during overnight hours rather than mid-day. It would also push these new peaks well beyond current ones, eliminating existing headroom or overloading existing capacity. This new demand creates major risks for fleets as they try to identify which operations are the best candidates for electrification and how to plan those operations. If overhead is eliminated, there will be significant costs for charging during peak times, and if peak times shift, TCO will also dramatically shift. The most significant impacts would be felt the further away a site is from existing urban infrastructure. This is because the overloads are a greater percentage of existing capacity when starting from a lower baseline, and because of the increased cost to build that capacity in geographically distant locations.

Distribution & Transmission

Utilities have a limited toolbox for dealing with capacity upgrades to accommodate higher electricity demand from commercial vehicle electrification. They can add or replace lines at the feeder level to deliver the necessary power if existing infrastructure supports it. However, if these new loads are introduced in locations that still need significant infrastructure, then additional upgrades will be needed. This would entail adding or replacing transformers, or if capacity exceeds what is available with the current substation, replacing or adding substations themselves. This problem is particularly relevant to on-route charging, which may be located far away from existing urban infrastructure and would be focused on high-power charging solutions. In cases where entirely new transmission and substation infrastructure may be necessary, typical lead times are 3 to 8 years. At a higher level, we found that the overall cost of utility infrastructure per commercial vehicle electrified will increase exponentially with distance from urban centers. Policymakers should carefully consider this correlation when charting a path to electrification.

Aggregate Planning

Utilities will need to understand the individual charging needs of each fleet operation to build the infrastructure effectively, predict how demand will impact overall capacity, and ultimately provide fleets with accurate, predictable costs, and timelines. Although we furnished county-level estimates for commercial vehicle electrification needs in this report, utilities typically require fleet customers to provide concrete plans to commence infrastructure development. Currently, utilities face the hurdle of liaising with numerous individual fleets to address specific on-site charging requisites. This makes it difficult for utilities to aggregate demands or plan for industry-level technology shifts.

Individual fleets, particularly smaller fleets, may not be equipped to provide concrete long-term electrification plans to their utilities. Most early adopters of BEV technology in commercial vehicles are at the early stages of their first deployments of the vehicles. They are in the nascent stages of collecting operational data essential for providing utilities with long-term plans regarding the timing, location, and extent of infrastructure required. The net effect is that utilities face challenges building the cases for infrastructure investment to their stakeholders, they lack data to effectively plan how to handle aggregate needs across disparate fleets, and then cannot provide fleets with reliable estimates of what infrastructure and energy costs might be in order to justify BEV adoption.

Distribution Grid Investment

Chargers are not the only infrastructure that must be installed to enable commercial BEV adoption. In many cases components of the distribution grid (Figure 7) must be upgraded to handle the power being added at the site, local, and even regional level. Our study conducted a detailed analysis of distribution grid impacts and investment needs for select geographies across California, Texas, and North Carolina – covering rural and urban areas. Grid infrastructure models were available for selected geographies from NREL Smart DS.[3]   The impact of MDHD electrification on every feeder and substation within each geography was analyzed.

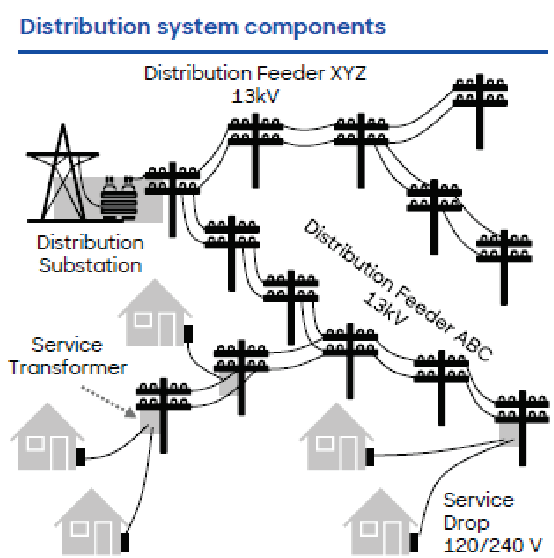

Figure 7. Diagram of the components in a distribution system

[3] Analysis was run on simulated NREL Smart DS simulated distribution grid architecture and customer load datasets for Austin, Greensboro and Northern California regions. The Smart DS dataset includes customer counts, load profiles, and detailed infrastructure data.

The analysis simulated the impact of MDHD charging on existing grid infrastructure and estimated the "overnight cost" of increasing the capacity of impacted grid assets. MDHD charging was layered onto existing loads for each feeder to determine impacted assets.[4] Based on each feeder's architecture, each upgrade cost was determined.

The grid impacts and investment needs for each county within the grid dataset were analyzed to determine the investment required on a per vehicle basis. For each region, the impact of MDHD charging on all grid assets in each county was analyzed to determine county-level distribution investment.

Investment needs per vehicle vary significantly across geographies. In more rural and industrial areas, utilities will need to spend more per vehicle primarily due to greater distances between customer locations (requiring more miles of conductor). Per vehicle distribution grid investment needs to increase farther away from denser urban areas. This correlation was applied to determine the "per vehicle" investment needs for all other U.S. counties.[5]

Based on this methodology, utilities will need to invest around $370 billion nationally on distribution grid upgrades and new construction to meet local charging demand from Class 3-8 trucks (Figure 8).[6,7] In comparison, utilities cumulatively invested roughly $450 billion across the U.S. for all distribution investment over the last 15 years. The utility costs for MDHD charging represent 82% of what was spent on all distribution grid investments over the past 15 years.

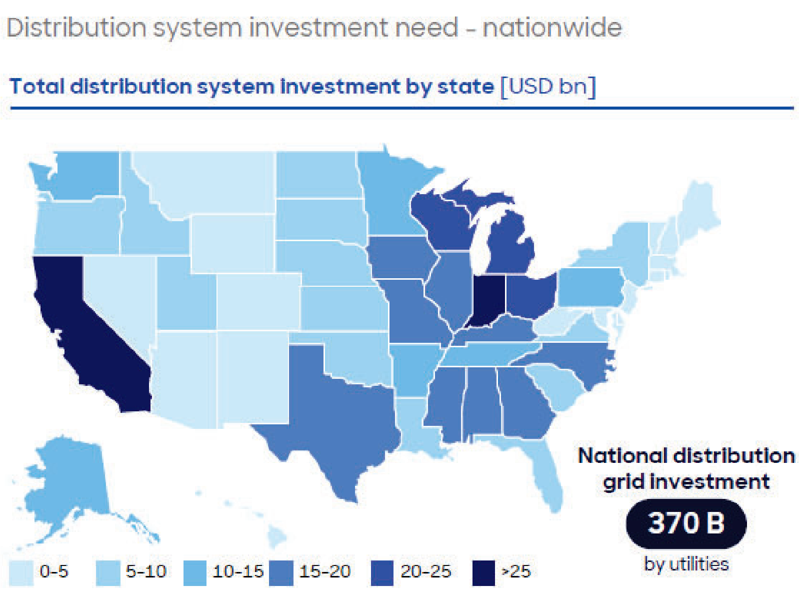

Figure 8. Investments required in distribution systems by U.S. state

[4] There is a limited solution set for utilities to expand the capacity of impacted grid assets.
[5] Predictor variable used for correlation is the percentage share of total county-level employment in agriculture, construction, and manufacturing sectors.
[6] Based on "overnight" capital cost of grid infrastructure at current price levels – actual utility investment will be higher due to 1) price inflation of labor and equipment, and 2) utility guaranteed rate of return.
[7] Distribution grids will serve on-site and on-route charging demand from local fleets. Longhaul trucks and highway charging stations will be served by the transmission grid and bulk power system.

Moreover, distribution spending is expected to continue increasing across multiple priorities (e.g., integration of distributed energy resources, resiliency) of which MDHD electrification is just one priority. Proactive investments will likely be constrained by limits on rate increases, potentially delaying charging infrastructure buildout.

Challenges:

- Utilities will need to build infrastructure ahead of MDHD deployment to avoid bottlenecks and delays.
- These types of investments require more sophisticated grid planning, and regulatory support, which have been limited to date.
- The overall pace of investment will still be constrained by the need to control rate increases and maintain affordability.

Potential Mitigating Factors:

- If fleets can successfully shift or manage peak charging load (e.g., battery-integrated chargers), utility investment could be significantly reduced.
- Appropriate incentives and/or price signals need to exist to support fleet economics.

Power System Investment

MDHD charging will require a meaningful increase in energy generation. However, MDHD charging will have a less significant impact on system capacity requirements, primarily a function of peak energy demand across a region (Figure 9). The impact of MDHD charging on peak energy demand is diminished, as most charging occurs overnight – avoiding system peaks. Thus, increased energy generation needs typically translate to increased utilization of existing assets.

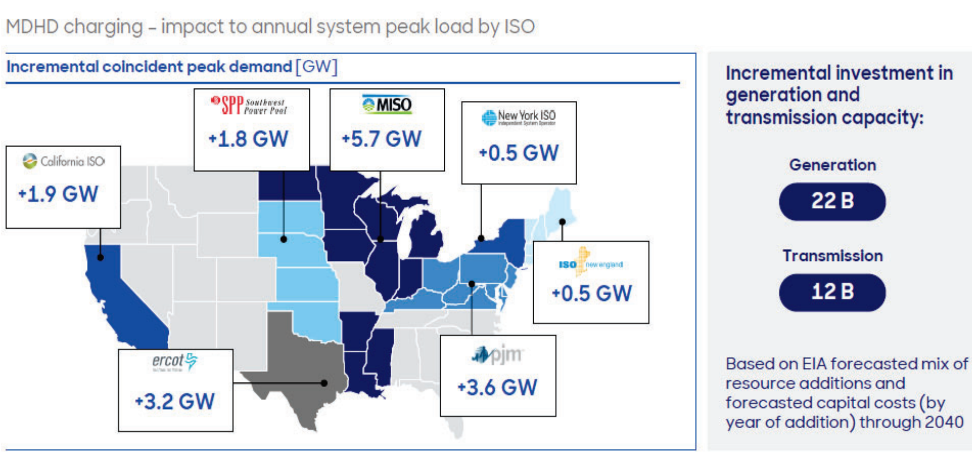

Figure 9. Incremental increases in peak demand for regional utilities due to MDHD charging

MDHD charging will create some incremental capacity and investment needs; however, power system operators are already planning for significant generation and capacity growth from transportation electrification, as well as other trends.

CONCLUSION

This study brings to light that fleets will bear a significant financial burden on the heavy-duty vehicle sector's transition to electrification. In addition to hurdles on the build and investment costs associated with infrastructure support for MDHD vehicles as mentioned in this report, fleets will continue to face operational constraints as they are required to electrify.

- Fleets expect that the price of BEV trucks will continue to be higher than their diesel equivalent for the foreseeable future due to increased battery capacity for range improvements.
- BEVs experience a weight penalty compared to their equivalent diesel trucks. Unless the BEV reduces weight to match the diesel equivalent truck, fleets will have a payload disadvantage. Fleets would be required to reconfigure business operations with higher freight rates to cover higher vehicle and operational costs. In addition, certain segments of the trucking industry that "weigh out" before they "cube out" would be penalized more than others, for example, tank trucks.
- Vehicle offerings must expand considerably because manufacturers' proposed product plans are currently limited. The dearth of scalable and commercially viable alternatives cannot cover the diverse vehicle needs of the industry. Many fleets are unable to purchase longhaul BEVs due to none being in production.
- Drivers will need to be compensated if they must wait for trucks to be charged during their federal hours-of-service window. Fleets will have to align drivers' utilization rates with the vehicles' charging windows, and if misaligned, will negatively impact a fleet's profitability and drive-up freight rates.
- Fleets are disproportionately penalized for purchasing the latest, cleanest technology on the market today. Eliminating the 12% federal excise tax on the purchase of a new vehicle will reduce emissions while the BEV technology and corresponding charging infrastructure improve to meet industry's needs.

BEFORE THE ILLINOIS POLLUTION CONTROL BOARD

	)	
	)	
IN THE MATTER OF:	)	
	)	R2024-017
PROPOSED CLEAN CAR AND	)	
TRUCK STANDARDS	)	(Rulemaking – Air)

CERTIFICATE OF SERVICE

I, the undersigned, on affirmation state the following:

That I have served the attached Notice of Filing; Rule Proponents' Second Hearing Exhibits; and Certificate of Service, by e-mail upon the following individuals listed at the e-mail addresses indicated:

TO:

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That my e-mail address is robert.weinstock@law.northwestern.edu.
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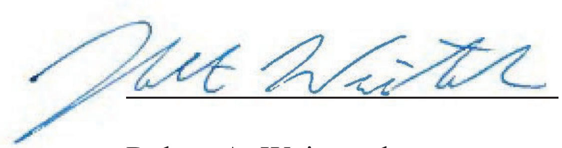
Date: March 10, 2025

Respectfully submitted,



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