Renewable Diesel – A Catalyst for Decarbonization

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Prepared by the American Transportation Research Institute

ATRI American Transportation Research Institute

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Jeffrey Short
Vice President
American Transportation Research Institute
Atlanta, GA

American Transportation Research Institute

Atlanta, GA • Minneapolis, MN • Washington, DC • Sacramento, CA

TruckingResearch.org

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Owner-Operator Independent Drivers Association Foundation

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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

[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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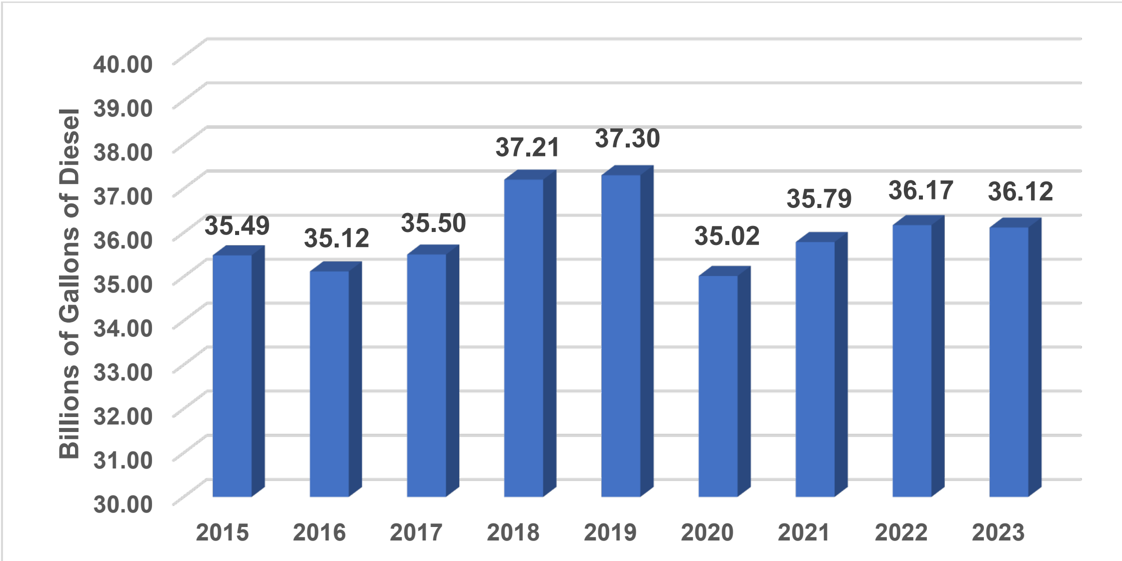
[14] Venkatesh Mandari and Santhosh Kumar Devarai, "Biodiesel Production Using Homogeneous, Heterogeneous, and Enzyme Catalysts via Transesterification and Esterification Reactions: a Critical Review," *BioEnergy Research* 15, no. 2 (September 2021), https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8476987/.
[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*

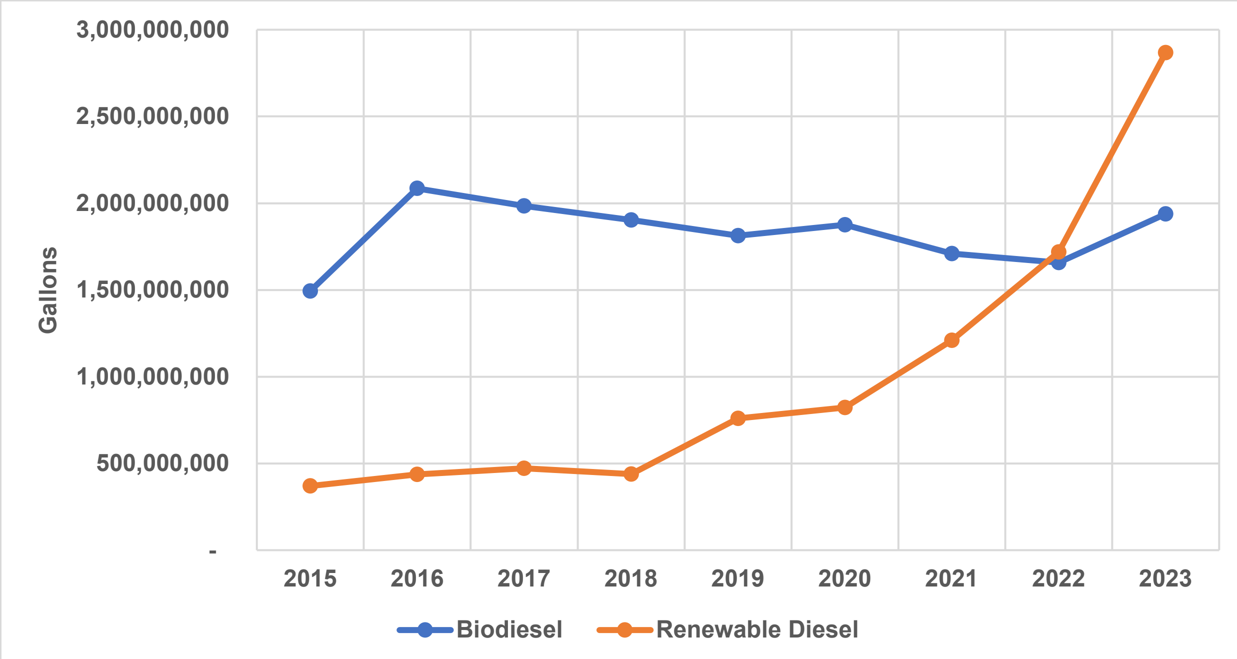


This report, however, focuses on petroleum diesel and RD use specifically by heavy-duty tractors. ATRI utilized the Federal Highway Administration (FHWA) Highway Statistics series to identify diesel consumption by this group. The statistics show that the nation's 3.25 million registered combination trucks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

<u>In summary:</u>

- 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]

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[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]

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

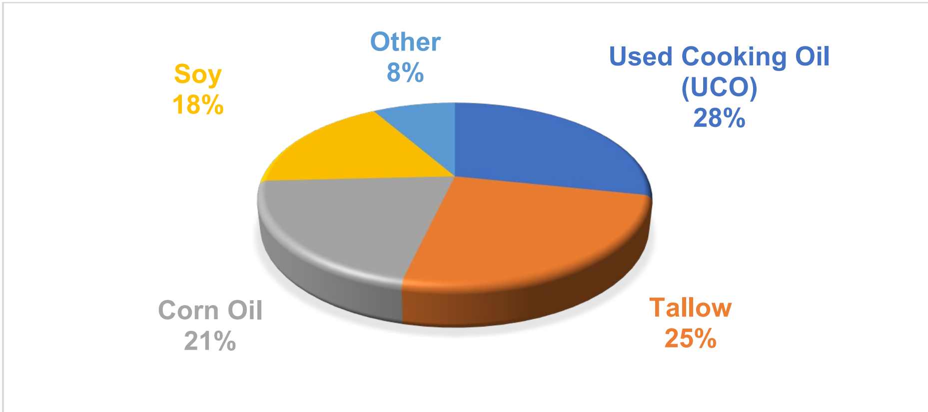
Type	Oil/Fat Group
Canola Oil	Vegetable Oil
Distillers Corn Oil	Vegetable Oil
Cottonseed Oil	Vegetable Oil
Palm Oil	Vegetable Oil
Soybean Oil	Vegetable Oil
Poultry Fat	Animal Fat
Tallow (Beef)	Animal Fat
White Grease (Pork)	Animal Fat
Yellow Grease	Waste Fats & Oils
Used Cooking Oil (UCO)	Waste Fats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

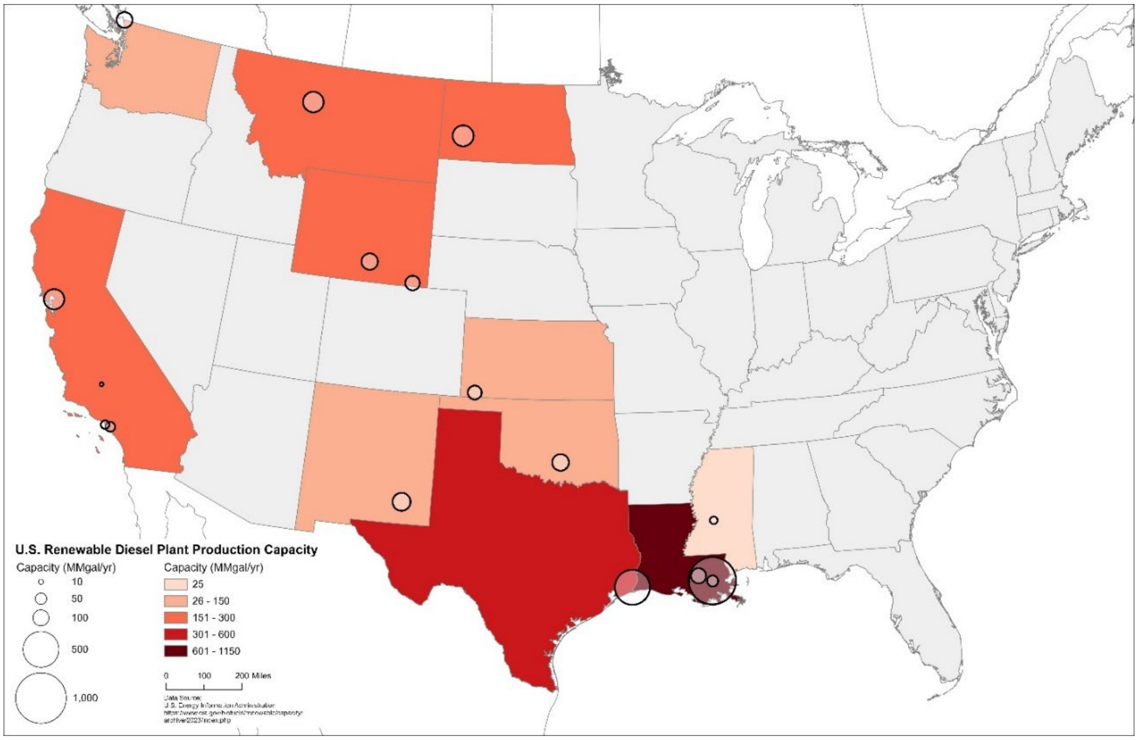
Additionally, the study indicates that all major cities in the United States are key sources of UCO.

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.

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[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.

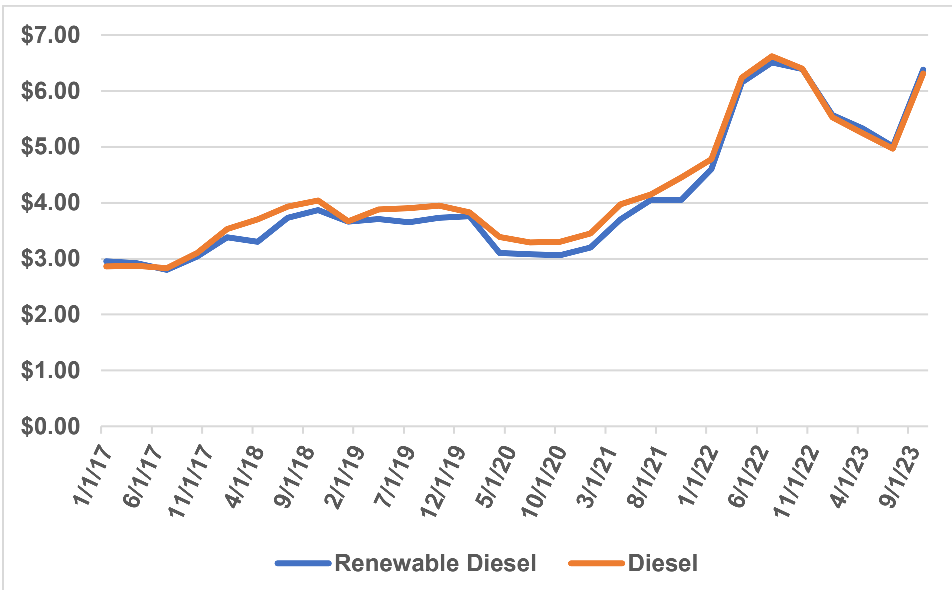
The *Biodiesel Income Tax Credit* allows fuel producers to receive a tax credit of $1 per gallon of biofuel (including renewable diesel) that is delivered to on-road vehicles. This tax credit, which was enacted in 2004, was recently extended by the Inflation Reduction Act (IRA) to run through the end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

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]

<u>In summary:</u>

- 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]

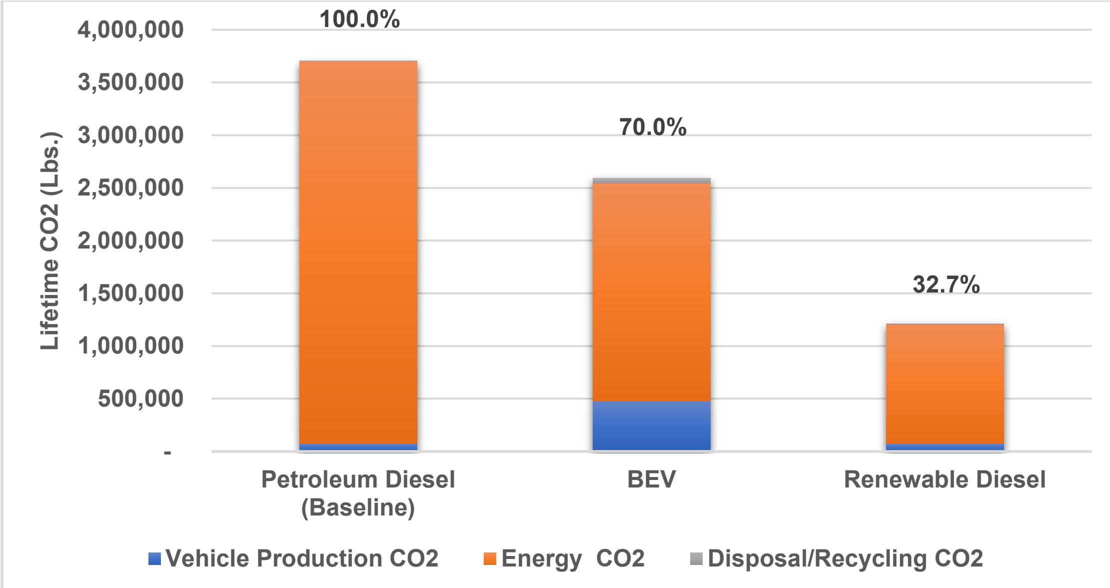
While GHG emissions – primarily CO_2 – are an unavoidable reality for most economic activity today, all sectors and segments of the economy are looking for ways to reduce their GHG emissions. That includes the trucking industry, which approaches decarbonization through equipment improvements and use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

[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*



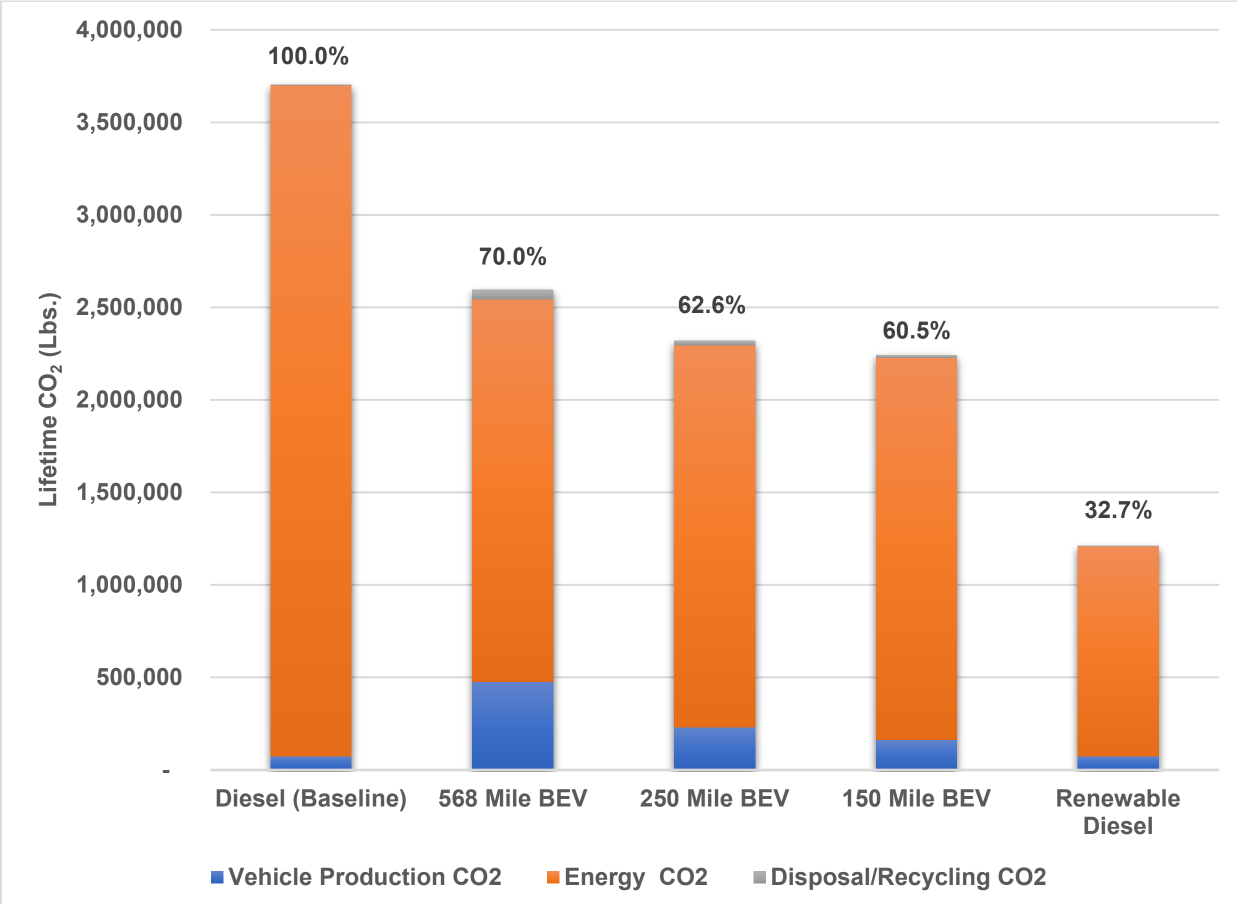
It should be noted that Figures 6 and 7 (below), RD Energy CO_2 encompasses both tailpipe emissions from burning RD and emissions from growing and producing feedstock.

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*

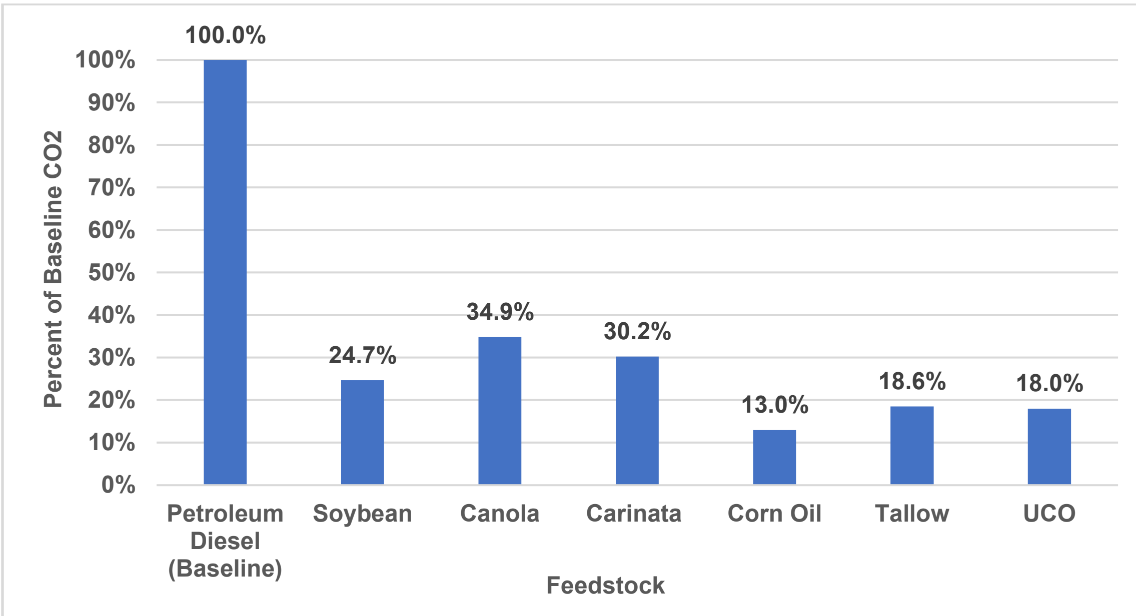


The smaller-range BEV trucks shown in the figure do have up to 13.6 percent lower vehicle CO_2 emissions than the 568-mile BEV that was modeled for the 2022 report. That said, one major caveat is that the smaller-range BEV trucks are modeled with only one battery replacement. It is likely, however, that 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]

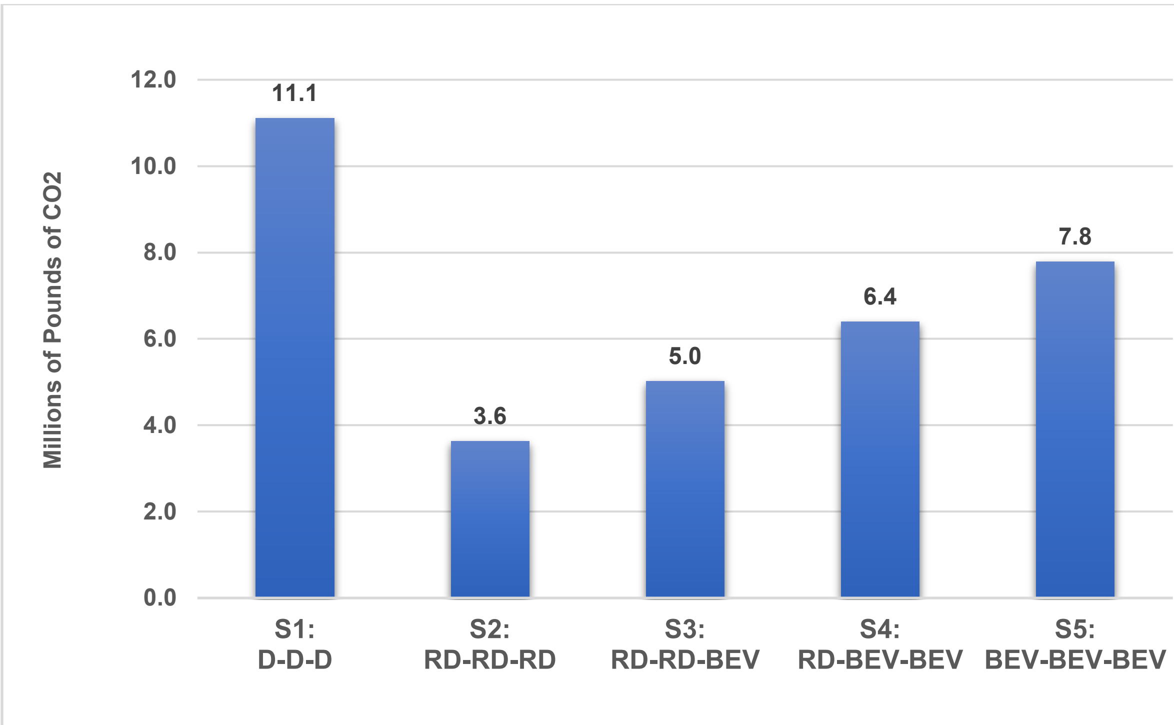
- Scenario 1: In the first scenario (labeled S1) all three trucks in the fleet run strictly on petroleum diesel. The total life-cycle CO_2 emissions are 11.1 million pounds.

[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.

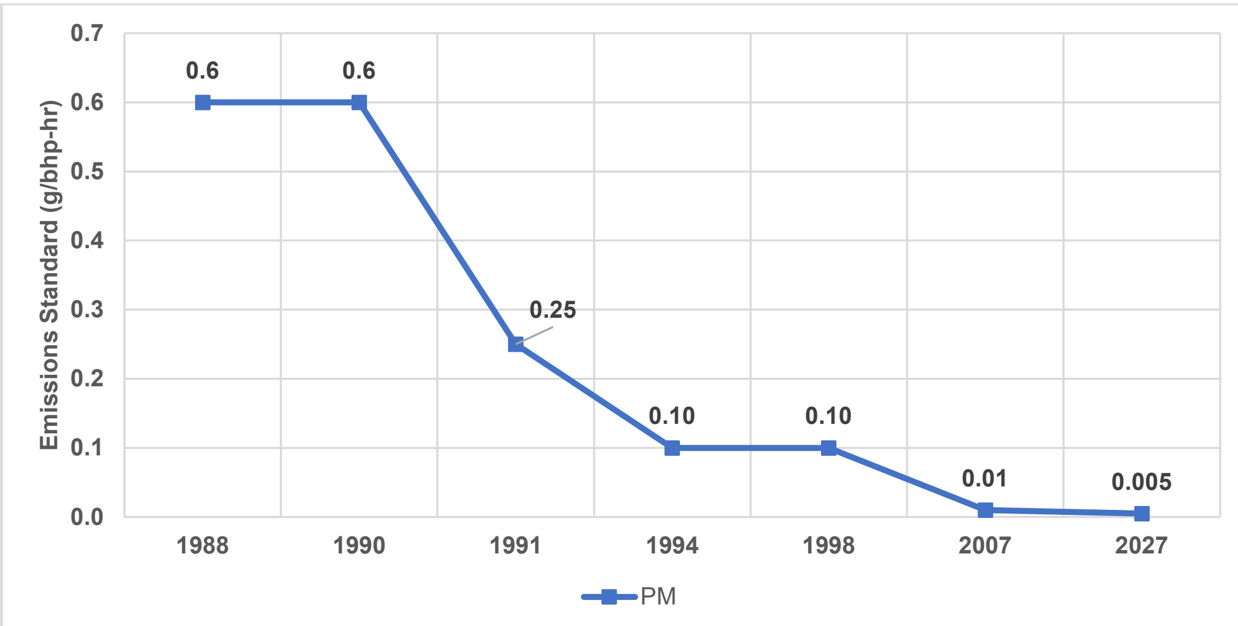
<u>Ambient Air Pollutants.</u> In terms of air pollutants, BEV trucks do not have tailpipe emissions such as particulate matter (PM) or NO_X.[65] Thus, decreasing tailpipe air pollutants is often cited as a rationale for moving from ICE to BEV trucks. While use of RD is still associated with tailpipe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

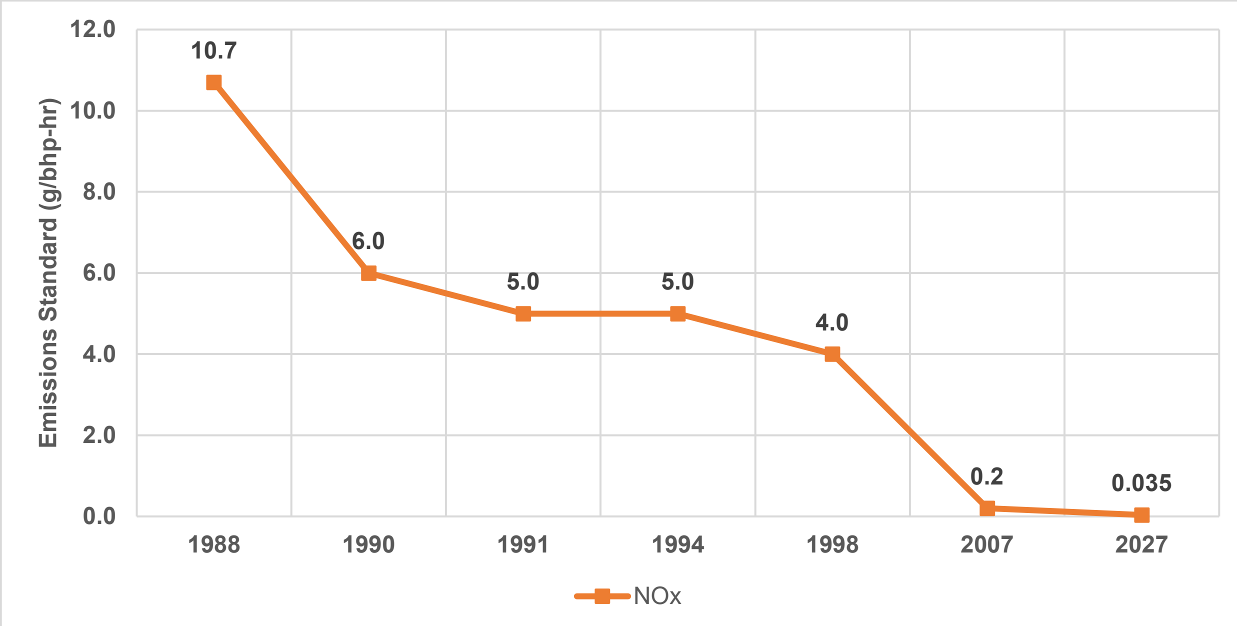
The U.S. EPA engine emission standards for air pollutants on diesel trucks are shown in Figures 10 and 11; both PM and NO_X standards for engines have become significantly more stringent.[66] As an example, reductions associated with EPA's engine emissions standards from 1988 to 2007 decreased PM by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

<u>In summary:</u>

- 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.

<u>Daily Mileage.</u> 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.

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[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.

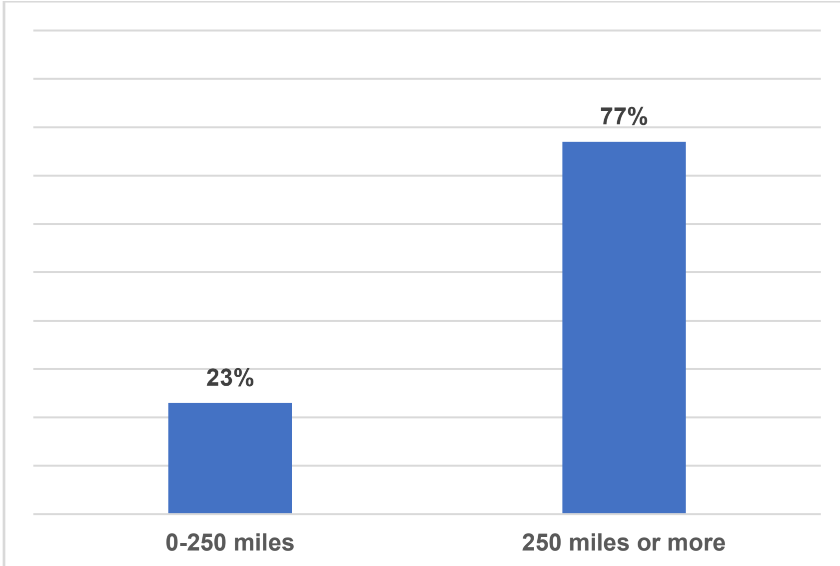
Alternatively, an ICE truck (with or without RD) is able to achieve a range of 1,000 miles or more before refueling is necessary, which is far greater than the BEV's 150- to 250-mile range. Likewise, the ICE range does not decrease with use, while battery capacity degrades with use.

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]

[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]

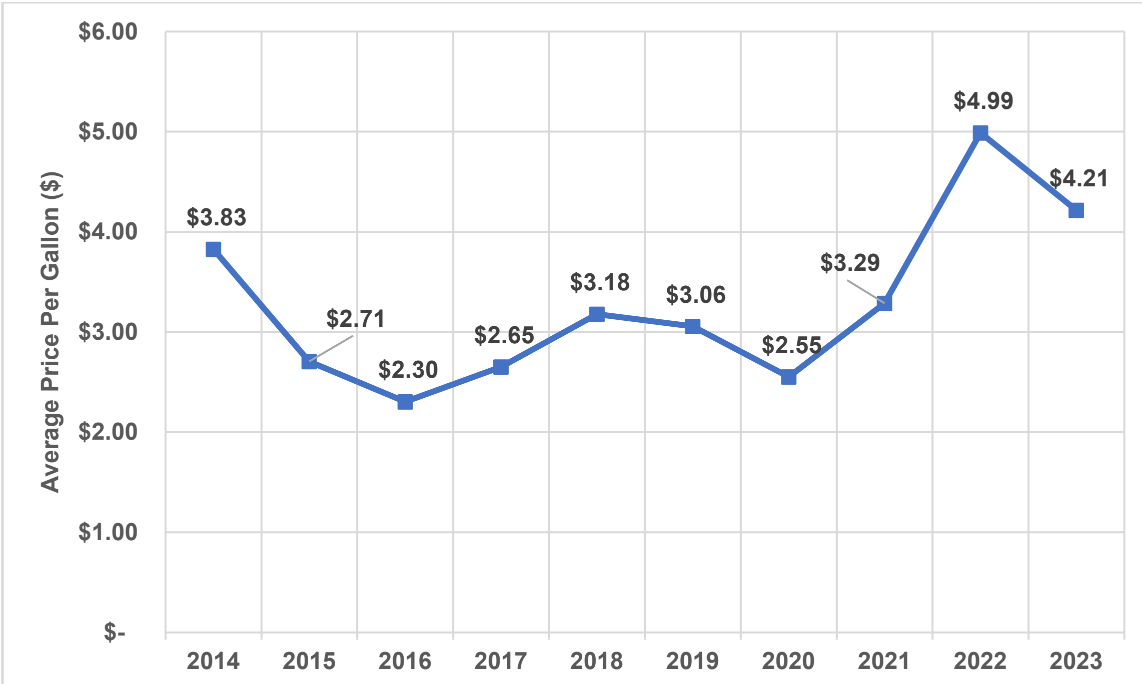
For ICE trucks specifically, there is evidence that maintenance costs for diesel particulate filters and other components are far lower with RD when compared to petroleum diesel.[80]

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]

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.

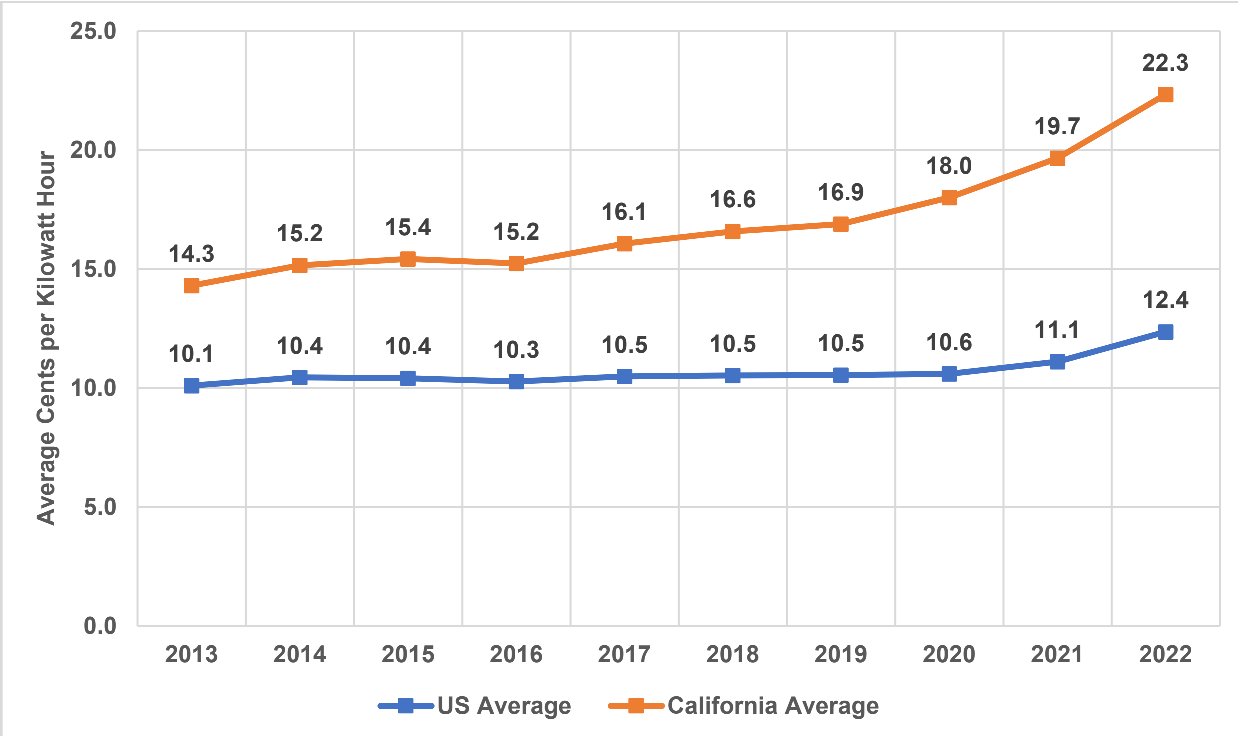
There are many factors that go into the cost of providing electricity. The fuel used for electricity, power plant operations and financing, as well as transmission and distribution lines, are all costs that factor into the price of electricity.[85]

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]

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[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.

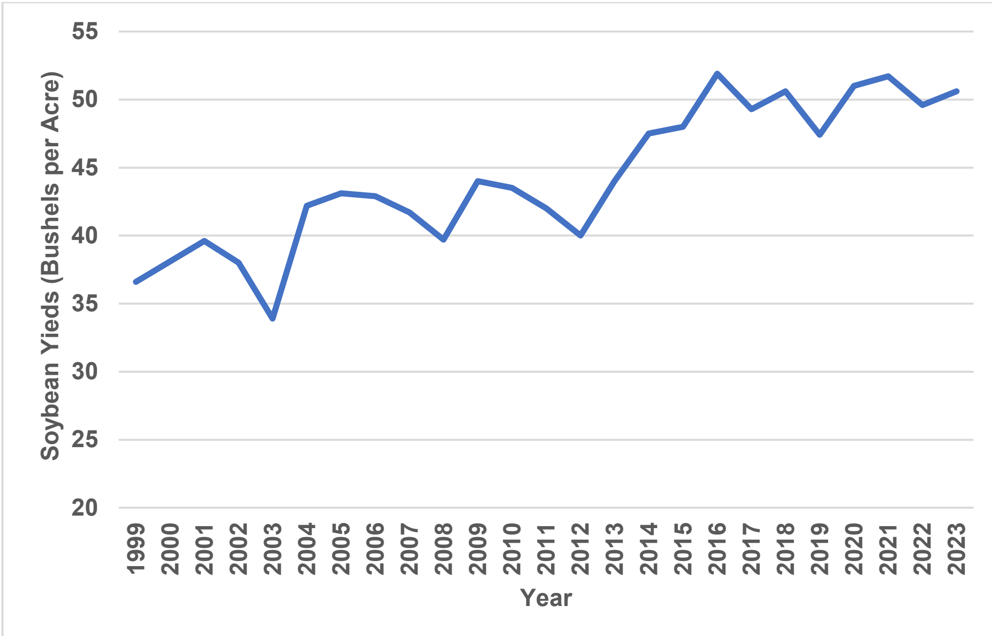
There are also federal programs that provide price supports to farmers (which could lead to overproduction).[92] With such price supports, the impact of additional demand for RD on price is unclear. In theory the additional demand on agriculture commodities provided by RD could help maintain or increase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

[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.

<u>In summary:</u>

- 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]

<u>BEV CO_2 Impacts.</u> 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.

ATRI American Transportation Research Institute

Atlanta, GA • Minneapolis, MN • Washington, DC • Sacramento, CA

(770) 432-0628

ATRI@Trucking.org

TruckingResearch.org