



TRANSPORTATION
ENERGY INSTITUTE

Practical Guide to Cost-Effective Fleet Emissions Reductions

JUNE 2025





The information, concepts, and recommendations expressed in this document are based on information available at the time of the preparation of this document. Action or abstinence from acting based on the opinions and information contained in this document are the sole risk of the reader and Delphi shall have no liability for any damages or losses arising from use of the information and opinions in this document. All information is provided “as is” without any warranty or condition of any kind. The document may contain inaccuracies, omissions, or typographical errors.

All rights reserved. The use of any part of this document, whether it is reproduced, stored in a retrieval system, or transmitted in any form or means (including electronic, mechanical, photographic, photocopying, or recording), without the prior written permission of The Delphi Group and Mobility Futures Lab is an infringement of copyright law. NOTE: Links to United States government resources were accurate and connected to the correct pages as of January 2025.

The Delphi Group
434 Queen St Suite 500
Ottawa, ON, K1R 7V7
Canada
Tel.: (613) 562-2005
Fax: (613) 562-2008
www.delphi.ca

For more information, please contact:

Cara LaRochelle
Director of Sustainable Mobility, Delphi
clarochelle@delphi.ca

Marc Saleh
Lead Consultant, Mobility Futures Lab
msaleh@mobilityfutureslab.ca

©2025 Transportation Energy Institute

Disclaimer: The opinions and views expressed herein do not necessarily state or reflect those of the individuals on the Transportation Energy Institute Board of Directors and the Transportation Energy Institute Board of Advisors or any contributing organization to the Transportation Energy Institute. Transportation Energy Institute makes no warranty, express or implied, nor does it assume any legal liability or responsibility for the use of the report or any product or process described in these materials.

Contents

TERMS & ACRONYMS	6
Glossary of Terms	6
Acronyms Used in This Report.....	7
FOREWORD	8
INTRODUCTION	9
SECTION 1	
DECARBONIZATION ROADMAP	11
SECTION 2	
UNDERSTAND THE OPTIONS	14
Zero-Emission Options	14
Battery Electric Vehicles	15
Hydrogen Fuel Cell Electric Vehicles.....	18
Low-Emission Options	16
Hybrid Electric Vehicles	16
Biodiesel.....	17
Renewable Diesel.....	17
Compressed Natural Gas	18
Renewable Natural Gas.....	19
Other Alternative Fuels.....	21
SECTION 3	
ASSESS THE OPTIONS	24
Operational Viability	25
BEVs.....	25
FCEV	26
Biodiesel and RD	26
CNG/RNG	27
Vehicle Availability	28
BEV and FCEV Model Availability.....	28
HEV Model Availability.....	30
CNG/RNG Model Availability.....	30
Infrastructure Requirements	31
BEV Charging.....	31
FCEV Refueling.....	34
Alternative Fuels.....	35
Maintenance Considerations	37
BEVs and FCEVs.....	37

HEVs.....	38
Biodiesel.....	38
RD.....	39
CNG and RNG.....	40
Impact.....	40
BEV Impacts.....	41
FCEV Impacts.....	43
HEV Impacts.....	45
Biodiesel and RD Impacts.....	45
CNG and RNG Impacts.....	46
Regulatory Landscape.....	49
SECTION 4	
ESTIMATE COSTS	53
Powertrain and Fuels Economics.....	53
BEV Economics.....	53
FCEV Economics.....	54
HEV Economics.....	55
Biodiesel and RD Economics.....	55
CNG and RNG Economics.....	57
Incentives.....	58
Uncertainty in Estimating Alternative Fuel Deployment Costs.....	60
AltFleet Economic Insight Tool.....	61
Powertrain and Market Applications.....	61
How to Use the Tool.....	61
SECTION 5	
TARGET SETTING	64
Targets for ZEV Adoption.....	65
Targets for Low-Emission Options.....	65
Develop a Fleet Decarbonization Plan.....	66
Design Pilot Projects.....	66
SECTION 6	
IDENTIFY ENERGY SUPPLY	68
For BEVs, Connect with Utilities.....	68
For FCEVs, Identify Fuel Producer/Provide.....	69
For Biodiesel and RD, Identify Fuel Producer/Provider.....	71
For CNG/RNG, Identify Fuel Producer/Provider.....	72
SECTION 7	
PLAN FOR CHARGING/REFUELING INFRASTRUCTURE	75
BEV Charging.....	75
Conduct a Facility Assessment.....	75
Charging Infrastructure Planning Study.....	75
FCEV Refueling.....	77
Conduct a Facility Assessment.....	77
Hydrogen Refueling Infrastructure Planning Study.....	79
Biodiesel and RD Refueling.....	79

CNG/RNG Refueling	80
Conduct a Facility Assessment.....	80
CNG/RNG Refueling Infrastructure Planning Study.....	81
SECTION 8	
VEHICLE AND CHARGING/REFUELING INFRASTRUCTURE PROCUREMENT	82
Vehicle and Charging/Refueling Infrastructure Procurement.....	82
Vehicles.....	82
Infrastructure.....	83
Turnkey Solutions for Fleet Operations	84
SECTION 9	
TRAINING	85
Training Drivers.....	85
Training Facility Management Teams.....	87
Training Mechanics.....	87
SECTION 10	
MONITOR AND REPORT ON PERFORMANCE AND COST	91
Establishing a Baseline and Developing Indicators.....	91
Monitoring Telematics, Operational, and Cost Data.....	92
Reporting and Analyzing Data.....	93



GLOSSARY OF TERMS

Battery electric vehicle (BEV): Fully electric vehicle powered by a rechargeable battery pack. These vehicles use an electric motor instead of a traditional internal combustion engine (ICE) and do not produce tailpipe emissions, i.e., they are zero-emission vehicles (ZEVs). Power for BEVs is supplied through external electricity sources (charging stations).

Biodiesel: A renewable fuel produced through the transesterification of plant oils, animal fats, or waste oils that meets the specifications in ASTM D6751. Chemically, it is a fatty acid methyl ester (FAME) and can be blended with petroleum diesel or used in diesel engines designed or modified to operate on higher blends, up to 100% biodiesel.

Carbon dioxide equivalent (CO₂e): A measure of the effect of different greenhouse gases (GHGs) on the climate. By converting emissions of other GHGs such as hydrofluorocarbons, nitrous oxide, methane, and others to the equivalent amount of carbon dioxide (CO₂), their impacts can be compared, reported, and/or discussed using common units.

Carbon intensity (CI): Refers to the amount of greenhouse gas (GHG) emissions measured in grams of carbon dioxide equivalent (CO₂e) emissions per unit of energy or fuel consumed.

Compressed natural gas (CNG): A transportation fuel gas primarily composed of methane and compressed to less than 1% of the volume it occupies at standard atmospheric pressure to facilitate higher-energy-density storage and transportation. CNG must meet the specifications in ASTM D8080-24.

Depot charging: Refers to charging electric vehicles at a central location, such as a fleet's home base or depot. Charging is done when vehicles are not in use (e.g., overnight), allowing for a full charge before daily operations.

Dimethyl ether (DME): A clean-burning synthetic fuel made from natural gas, coal, or biomass that can be used as an alternative to diesel and liquid petroleum gas and meeting ASTM D7901.

Heavy-duty vehicle: In the U.S., this refers to vehicles with a gross vehicle weight rating (GVWR) equal to or greater than 26,001 pounds and includes GVWR Classes 7 and 8.¹

Hybrid electric vehicle (HEV): A vehicle combining one or more electric motors with an internal combustion engine (ICE). HEVs typically use the ICE as the primary power source and supplement it with the electric motor to reduce fuel use.

Hydrogen fuel cell electric vehicle (FCEV): These vehicles use a fuel cell to convert hydrogen gas into electricity that powers an electric motor. These vehicles produce zero tailpipe emissions, with water vapor produced as the only byproduct.

Internal combustion engine (ICE): A type of engine that generates mechanical power via combustion of fuels.

Liquefied natural gas (LNG): A transportation fuel composed of natural gas that has been cooled to - 260 °F, changing it from a gas to a liquid. This reduces the original volume and allows it to be shipped more efficiently and safely. LNG must meet the specifications in ASTM D8080-24.

Medium-duty vehicle: In the U.S., medium-duty vehicles are those with a GVWR between 10,000 pounds and 26,000 pounds, and include GVWR Classes 3, 4, 5, and 6.

On-route charging: Refers to charging electric vehicles while they are on the road (typically vehicles that need to recharge to extend their range during longer trips).

Plug-in hybrid vehicle (PHEV): Vehicles that combine a conventional ICE with a rechargeable battery that can be charged by plugging into an external power source. PHEVs can operate on electric power alone for a limited range before switching to the ICE.

Renewable diesel (RD): A renewable fuel predominantly produced by hydrotreating plant oils, animal fats, or waste oils and meeting the specifications in ASTM D975. Chemically, it is nearly identical to petroleum diesel and can be used in virtually all diesel engines without modifications.

Renewable natural gas (RNG): A pipeline-quality gas derived from organic waste sources (e.g., dairy manure, landfills, wastewater treatment plants) that is processed to high purity standards to be used as a drop-in alternative to CNG as a transportation fuel. RNG must meet the specifications in ASTM D8080-24.

Zero-emission vehicle (ZEV): A vehicle that produces no tailpipe emissions, but might produce emissions on a life cycle basis.

1 Alternative Fuels Data Center. n.d. Vehicle Weight Classes & Categories (table). Accessed March 21, 2025. <https://afdc.energy.gov/data/10380>.

LIST OF ACRONYMS AND ABBREVIATIONS

BEV: battery electric vehicle

CARB: California Air Resources Board

CI: carbon intensity

CNG: compressed natural gas

CO₂e: carbon dioxide equivalent

DCFC: direct current fast charging

DME: dimethyl ether

FCEV: hydrogen fuel cell electric vehicle

GHG: greenhouse gas

GVWR: gross vehicle weight rating

HEV: hybrid electric vehicle

ICE: internal combustion engine

LCFS: low carbon fuel standard

LDV: light-duty vehicle

LNG: liquefied natural gas

MHDBEV: medium- and heavy-duty battery electric vehicle

MHDFCEV: medium- and heavy-duty fuel cell electric vehicle

MHDHEV: medium- and heavy-duty hybrid electric vehicle

MHDV: medium- and heavy-duty vehicle

MHDZEV: medium- and heavy-duty zero-emission vehicle

NGV: natural gas vehicle

NO_x: nitrogen oxides

OEM: original equipment manufacturer

PHEV: plug-in hybrid electric vehicle

PM_{2.5}: fine particulate matter

RD: renewable diesel

RFS: Renewable Fuel Standard

RNG: renewable natural gas

TCO: total cost of ownership

TEI: Transportation Energy Institute

VCM: voluntary carbon market

ZET: zero-emission truck

ZEV: zero-emission vehicle



Foreword

The decarbonization of medium- and heavy-duty vehicles (MHDVs) is critical, given that transportation emissions already represent the largest source of emissions in the U.S. (28% in 2022).² While emissions from light-duty vehicles (LDVs) are declining, the share of emissions represented by MHDVs is increasing year over year.³ Given that the lifespan of these vehicles can be 15 years or longer, it is critical that fleet operators consider implementing lower-emission solutions for new vehicles, but also identify and take advantage of options to reduce emissions from the existing fleet.

A novelty five years ago, medium- and heavy-duty zero-emission vehicles (MHDZEVs) are increasingly common among the options for lower emitting vehicles on U.S. roads and highways. With more than 120 MHDZEV models available from more than 40 vehicle manufacturers, the year-over-year growth of options in this sector is significant. While the existing availability and future promise of these technologies is highly dependent on vehicle class, type, and operational requirements, existing MHDZEV technology can already meet the operational requirements of half to two-thirds of freight routes,⁴ and as deployments of MHDZEVs continue to ramp up, alternative fuels provide an excellent substitute that can be used in existing vehicles with minor, if any, engine modifications required.

The Transportation Energy Institute (TEI) recognizes the importance of supporting fleets in reducing emissions, wherever they are on their decarbonization journey, whether they are pursuing their own environmental objectives, seeking to satisfy demands from their customers, or complying with regulatory requirements.⁵ Fleet owners and operators are encouraged to use this guide and the accompanying AltFleet Economic Insight Tool to better understand and assess the application and impact of the available technologies.

Together, the guide and economic insight tool will arm both private and public fleet owners and operators with the knowledge and resources needed to identify and implement the emissions reduction options that are right for them.

The guide provides a flexible roadmap that can be tailored to the requirements of a variety of fleets, vehicle types, and use cases. Small to large fleet operations can benefit from taking a close look at the options available to reduce emissions and how such options may affect capital and operational expenses. Whether you are starting from scratch or considering the next steps on your existing decarbonization journey, this guide is for you. The accompanying AltFleet Economic Insight Tool helps to support decision-making by providing bespoke cost analysis for your fleet vehicles.

² U.S. Environmental Protection Agency. Updated June 18, 2024. Fast Facts on Transportation Greenhouse Gas Emissions. <https://www.epa.gov/greenvehicles/fast-facts-transportation-greenhouse-gas-emissions>.

³ U.S. Environmental Protection Agency. 2024. *Fast Facts: U.S. Transportation Sector Greenhouse Gas Emissions, 1990–2022*. <https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P101AKR0.pdf>.

⁴ Richard, J., and Kasdan, J. 2024. *Zero-Emission Trucks: The Facts*. Calstart. https://calstart.org/wp-content/uploads/2024/08/ZETs-the-Facts-August-2024_Final.pdf.

⁵ Reducing fuel consumption in existing assets is a valuable first step to any fleet decarbonization strategy. The focus of this guide, however, is on deeper decarbonization

Introduction

Practical Guide to Cost-Effective Fleet Emissions Reductions

In the U.S. transportation ecosystem, MHDVs play a critical role in the freight supply chain, serving as one of the primary modes of transporting goods locally, across the country, and across borders. Non-freight applications include passenger vehicles, municipal/utility vehicles, intercity buses, urban transit, school buses, and specialized vehicles like waste trucks, emergency response vehicles, and work vehicles. Together, these vehicles represent a sizable inventory.

Despite significant improvements over recent years, MHDVs can still be a substantial source of emissions, both criteria air pollutants and greenhouse gases (GHGs), which have been shown to negatively impact public health and the environment. Although much attention has been focused on decarbonizing passenger vehicles, significant effort is needed to continue to reduce emissions from MHDVs. Despite accounting for only 5% of on-road vehicles in the U.S., MHDVs contribute over 20% of the country's transportation emissions.⁶

Since MHDVs are used for a vast array of purposes with very different operating envelope requirements, decarbonizing this sector will require a suite of low- and zero-emission fuels and technology—such as battery electric, hydrogen, and lower-carbon alternative fuels including biodiesel, renewable diesel (RD), natural gas, and renewable natural gas (RNG) solutions—to cover various use cases. (For simplicity, this report uses the term *zero-emission* to refer to solutions that result in zero emissions from a vehicle's tailpipe but that may generate emissions on a life cycle basis.)

Zero-emission technologies like battery electric vehicles (BEVs) and hydrogen fuel cell electric vehicles (FCEVs) are still emerging but have demonstrated effectiveness in applications like transit bus fleets and urban delivery. Some estimate that BEVs could meet the needs of 49–65% of MHDV truck routes, especially for regional delivery fleets.⁷ Meanwhile, FCEVs hold promise for long-haul operations due to their extended range and fast refueling capabilities. Although initial costs are high, advancements in zero-emission vehicle (ZEV) and fuel technologies are projected to bring total-cost-of-driving parity with diesel by 2035, according to the National Renewable Energy Laboratory (NREL).⁸ Transitioning fleet operations to a low- or zero-emission powertrain may result in changes in range, payload, route planning, and refueling and

Strategies including adoption of renewable fuels and battery electric and hydrogen technologies.

6 U.S. Department of Energy. 2023. *The U.S. National Blueprint for Transportation Decarbonization: A Joint Strategy to Transform Transportation*. <https://www.energy.gov/sites/default/files/2023-01/the-us-national-blueprint-for-transportation-decarbonization.pdf>.

7 Richard, J., and Kasdan, J. 2024. *Zero-Emission Trucks: The Facts*. Calstart. https://calstart.org/wp-content/uploads/2024/08/ZETs-the-Facts-August-2024_Final.pdf.

8 Ledna, C., Muratori, M., Yip, A., Jadun, P., and Hoehne, C. 2022. *Decarbonizing Medium- & Heavy-Duty On-Road Vehicles: Zero-Emission Vehicles Cost Analysis*. National Renewable Energy Laboratory. <https://www.nrel.gov/docs/fy22osti/82081.pdf>.

maintenance practices, however, which must all be considered as part of the analysis.

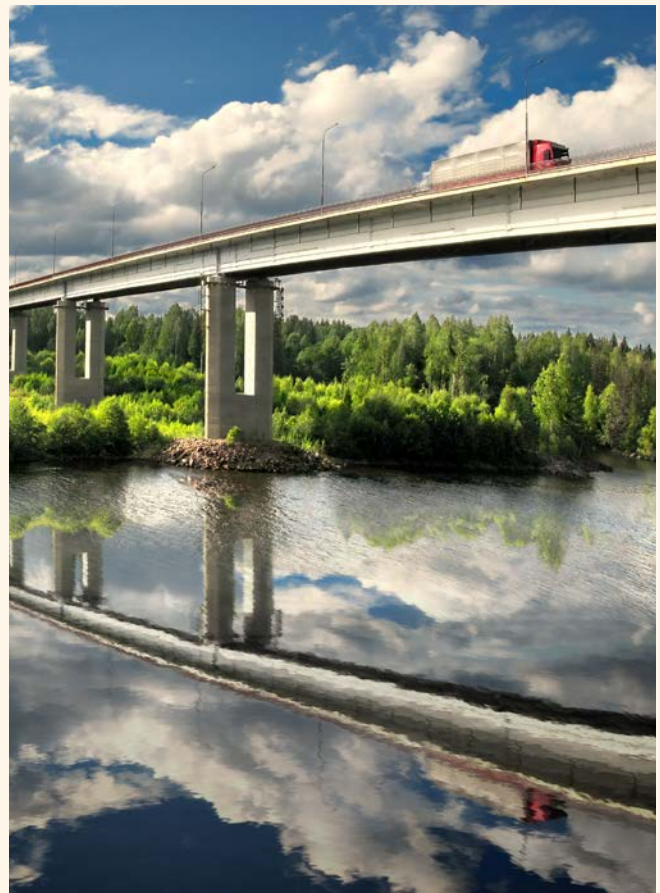
For fleets that are still waiting for technology and cost profiles to serve their operational and economic needs, sustainable fuels provide an excellent interim option, particularly for legacy vehicles relying on internal combustion engines (ICEs).

This guide, along with the AltFleet Economic Insight Tool, provides an introduction to decarbonizing MHDV fleets as well as more detailed guidance such as links to resources to support MHDV fleet owners navigating the transition to alternative low-carbon technologies. Both the guide and the tool also cover low-emission options including alternative fuels and hybrid vehicles. It should be noted that the guide and the economic insight tool are based on well-to-wheel emissions and do not account for the emissions from vehicle or powertrain production.

The information is presented in layers for ease of access, based around the following six steps:

- **Foundation Setting:** Begin by assembling a dedicated project team, developing a comprehensive understanding of the options, securing internal financing, and exploring available incentives.
- **Target Setting:** Establish an overall vision or target, supported by more specific goals. Before full-scale deployment, a pilot program is recommended to gather real-world data on performance, operational adjustments, and ecosystem needs. This step is helpful in identifying potential challenges and making necessary adjustments.
- **Procurement:** Select and procure new vehicles or modify/repower existing fleet vehicles and charging/refueling infrastructure. Plan for charging/refueling, including a facility assessment to ensure that the necessary infrastructure can be accommodated.
- **Installation:** Complete facility upgrades and install charging/refueling infrastructure.
- **Training and Deployment:** Implement comprehensive training programs for drivers, maintenance staff, and first responders. Following successful testing and training, deploy the low-carbon vehicles or fuels into your fleet operations.
- **Monitoring and Scaling:** Continuously monitor the performance and environmental benefits of the low-carbon fleet. Use insights gained to refine practices, share learnings, and plan for scaling across the fleet.

Section 1 presents the first layer: a high-level step-by-step roadmap. Each step in the roadmap is linked to an accompanying section containing three additional layers of information: Overview, Tell Me More, and Learn More (supporting resources).





SECTION 1.

Decarbonization Roadmap

The transition to low- and zero-emission fleets requires a strategic plan that accommodates the diverse considerations of different vehicle types and duty cycles.

Building a roadmap involves not only selecting the right technology for your organization's needs but also understanding the entire ecosystem around your fleet decisions. From setting foundational goals and targets to planning and implementing the necessary charging or refueling infrastructure, each step needs to be carefully tailored to the fleet's vehicle specifications and operations requirements.

The end goal may or may not be adoption of ZEV technology. In cases where commercial readiness, infrastructure, or economics do not yet support the transition to ZEV, meeting overall fleet decarbonization goals may entail the use of alternative fuels or alternative propulsion options such as hybrids, either as interim or more permanent solutions. These possibilities are included in the roadmap.

Each step is linked to a similarly color-coded section containing more detailed information, instruction, and resources.

TABLE 1. ROADMAP TO MHDV DECARBONIZATION

	FOUNDATIONAL STEPS	SECTION
Understand your motivation	Consider what is driving your interest in fleet decarbonization: What do you hope to gain and what are you willing to risk? Is decarbonization a target in and of itself, or is it a means to an end? Are you seeking improved bottom-line operational costs, or are you expecting costs to increase? What are your customers' and other stakeholders' expectations of you? This will inform the level of ambition and internal cost-benefit analysis of the options. <i>(This reflection/internal discussion step is not covered in this guide.)</i>	
Understand the options	Develop an understanding of lower- and zero-emission technology for relevant vehicle classes/vehicle types and the associated market landscape.	2
Assess the options	Based on the composition and operational requirements of your fleet, the commercial availability of the various technology and fuel options, and the possible emissions reductions, assess which low- and zero-emission technologies are feasible and should be considered. Include fueling or charging infrastructure requirements. Note that current feasibility may be limited to a segment of the fleet, to one location or depot, or to a specific route.	3
Estimate costs	Develop an understanding of the economics of low- and zero-emission technologies. Use the AltFleet Economic Insight Tool to estimate costs associated with the ZEV and alternative fuel options you identified in the previous step. Note that the tool is designed to assess a small-scale, one-to-one vehicle replacement pilot deployment. Research additional funding options and available financing if applicable. Consider how new business models and financing options might enable decarbonization plans.	4
	TARGET SETTING	SECTION
Establish goals	Establish a vision or target for fleet decarbonization and set supporting goals. The vision should speak to the end state you are seeking to achieve and therefore represents a longer-term outlook. The goals should be designed as shorter-term milestones that support the longer-term vision. Goals should be "SMART": specific, measurable, achievable, realistic, and time-bound	5
Plan to achieve initial goals	The initial goals are the ones you will be focusing on first and will require in-depth planning to achieve. Based on the learnings from the foundational steps and the steps outlined below, develop a plan to achieve your initial goals and establish a strong foundation for longer-term goals and overall targets. This plan should identify key success factors and potential risks to be assessed via pilot testing. It should name all actors, along with associated roles and responsibilities.	5
Design pilot project(s)	Design a pilot with specific metrics to monitor, including maintenance and energy consumption, focusing on factors that vary locally. The goal of the pilot is to gain a better understanding of the technology's capabilities beyond the averages and best- or worst-case scenarios provided by the original equipment manufacturers (OEMs). The data collected from this pilot will help plan scaling more cost-effectively.	5
	PROCUREMENT OF VEHICLES AND INFRASTRUCTURE	SECTION
Identify energy supply	For BEVs, connect with utilities to assess potential necessary upgrades to electrical infrastructure and the cost and timetable to accommodate vehicle charging at a depot. For application conditions where depot charging is not viable, explore the availability of public charging infrastructure. For FCEVs and alternative fuels, refueling may require installation of fuel storage and refueling infrastructure on-site at an existing facility, depot, or yard. Alternatively, it may be possible to access public or shared fueling infrastructure. Fuel supply must be consistently available throughout your company's timeline defined under your goals. Consider the potential network effect of changes in vehicle range and refueling locations and duration.	6
Plan for charging/refueling infrastructure	Conduct a facility assessment to identify any modifications and/or upgrades that will be required to accommodate the new charging/refueling infrastructure. Identify permitting requirements. In consultation with the utility/fuel and infrastructure providers, determine parameters affecting placement of chargers/refueling equipment and identify supporting requirements.	7
Select and procure vehicles and charging/refueling infrastructure	For new vehicles, repowers, or vehicle modifications, a request for information (RFI) or request for proposal (RFP) may be used to select and procure vehicles and management services, or you may choose to proceed through your regular procurement channels. An RFI or RFP may be used to select and procure chargers, charge management software, or refueling infrastructure and should request information on any low-carbon liquid fuel blending constraints or warranty limits. Consider future-proof elements such as: <ul style="list-style-type: none"> • Modular charging systems that make scaling easier • Energy efficiency upgrades or adding clean energy elements, including on-site solar and bidirectional charging options • Ensuring adequate space for additional charging/refueling infrastructure in future years Consider bundling vehicle and charging/refueling procurement through a turnkey solution, particularly if internal capacity is limited.	8

(CONTINUED)

TABLE 1. ROADMAP TO MHDV DECARBONIZATION (CONTINUED)

	INSTALLATION	SECTION
Upgrade facilities if necessary	Complete facility upgrades to accommodate new electrical infrastructure, vehicle chargers, refueling equipment, and/or parking and operating patterns, or to conform to safety-related standards. <i>(This represents implementation of planning completed in an earlier step and is not covered in this guide.)</i>	
Install charging/refueling infrastructure	Complete installation of vehicle chargers or refueling equipment. <i>(This represents implementation of planning completed in an earlier step and is not covered in this guide.)</i>	
	TRAINING, TESTING, AND DEPLOYMENT	SECTION
Train	Training is typically required for: <ul style="list-style-type: none"> • Drivers (basic safety, on/off, plug-in charging, refueling, maximizing efficiency) • Mechanics (advanced training, preventive maintenance, troubleshooting, diagnostics) • Facilities management and engineering support staff • Dispatch and front-office staff (as required based on your operations) • First responders (as needed/requested by local firefighters, police, paramedics, etc.) 	9
Test and deploy	Examine and test all new equipment to ensure that it meets the specifications within your contract and procurement order and understand performance in real-world conditions. Finalize many of the same steps as for conventional internal combustion vehicles, such as getting insurance and completing inspections. Update standard operating procedures, handbooks, and safety protocols for technology-specific needs. Deploy per pilot testing or strategic fleet plan. <i>(This represents implementation of planning completed in an earlier step and is not covered in this guide.)</i>	
	MONITORING AND SCALING	SECTION
Monitor and report on performance and cost	Gather mechanical and telemetric data to monitor performance toward key performance indicators (KPIs), including operational performance and economics. Use the monitored KPIs to adjust the scaling of your planned deployment, based on lessons learned about the capabilities and technological readiness of both the vehicles and infrastructure.	10
Update roadmap	Incorporate insights from the deployment back into your plan. This is an iterative process that should also account for evolving commercial readiness and the cost of low-carbon technology options.	10





SECTION 2.

Understand the Options

2.1. ZERO-EMISSION OPTIONS

2.1.1 BATTERY ELECTRIC VEHICLES

Overview

BEVs are equipped with electric motors that draw power from a rechargeable battery pack. A battery management system monitors and controls the performance, health, and safety of the battery pack, ensuring optimal energy efficiency and safeguarding against potential issues such as overcharging, overheating, and overall degradation.

Over the past decade, significant cost reductions and technological advancements in batteries, along with the introduction of regulations in various jurisdictions, have led to an increase in commercially available BEV models in the MHDV space. The initial

deployments of this technology were primarily in public transit, with a more recent but growing adoption in trucking and vocational applications.

As of 2024, BEV technology is not yet a viable replacement for all diesel-based applications. Challenges associated with medium- and heavy-duty battery electric vehicles (MHD BEVs) include higher capital costs compared to ICE equivalents, manufacturing constraints impacting delivery times, range limitations, charging times, payload limitations due to weight restrictions, and the availability of charging stations. Deployments of BEVs in the MHDV sector can benefit from a feasibility assessment of local operations to evaluate emissions reductions and operational and financial viability. Some considerations for these assessments are detailed in subsequent sections.

Tell Me More

Overall, BEVs have lower operating and maintenance costs, and some MHD BEVs are already cost-competitive with their ICE equivalents from a total cost of ownership (TCO) perspective for small deployments, especially in urban delivery applications.⁹ These applications typically feature predictable ranges, sufficient daily travel to capitalize on reduced operational costs, and extended downtime that allows fleets to take advantage of low-cost, low-power charging. Existing financial incentives further strengthen the case for scaling electrification in these scenarios, promoting early adoption.¹⁰ As battery costs continue to decrease and production ramps up, it is expected that MHD BEVs will become cost-competitive in more market segments, leading to increased adoption.

As the most mature of the MHD ZEV options, MHD BEVs are increasingly commercially available across all but the heaviest vehicle classes and market segments, and this trend is expected to continue. Reductions in battery costs over the past decade have resulted in overall reductions in vehicle costs, and technology improvements have resulted in performance advantages including increased safety and reliability and an improved driver experience.¹¹

2.1.2 HYDROGEN FUEL CELL ELECTRIC VEHICLES

Overview

FCEVs are powered by electric motors that run on electricity generated by hydrogen fuel cells. (FCEVs also have a battery pack for regenerative braking and power optimization.) In these vehicles, hydrogen gas stored in tanks is fed into a fuel cell stack, where it combines with oxygen from the air to produce

electricity. This electricity then powers the vehicle's electric motor. As a result, FCEVs produce zero tailpipe emissions since the only byproduct of the fuel cell reaction is water vapor.

Medium- and heavy-duty fuel cell electric vehicles (MHDFCEVs) are less mature than their battery electric counterparts. However, significant investments, particularly in hard-to-electrify applications such as long-haul trucking, are narrowing the gap in those areas. A number of companies are developing heavy-duty FCEV trucks for release in 2024/2025, including Daimler and Cummins (collaboration), PACCAR and Toyota (collaboration), Hyundai, and Nikola Motors.

While MHDFCEVs do not present the range limitations and fueling time challenges of BEVs, high capital costs and limited availability of refueling infrastructure are key issues, along with availability of clean hydrogen and low to zero model availability in many market segments.¹² Although hydrogen storage allows for greater range than battery power for electric trucks, its energy density remains lower than diesel, requiring larger tanks, which can impact payload capacity.

Tell Me More

Hydrogen fuel cell technology has grown as a ZEV option due to the ability to produce hydrogen from renewable energy sources and the ability of hydrogen to provide ranges comparable to those of diesel. The most common type of fuel cell for vehicle applications is a proton exchange membrane (PEM) fuel cell. It is composed of an anode and a cathode separated by an electrolyte membrane. Oxygen from the air circulates through the cathode at the same time that hydrogen is introduced to the anode. This triggers an electrochemical reaction that generates electricity, which is the vehicle's power source.

9 Burnham, A., Gohlke, D., Rush, L., Stephens, T., Zhou, Y., Delucchi, M. A., Birky, A., Hunter, C., Lin, Z., Ou, S., Xie, F., Proctor, C., Wiryadinata, S., Liu, N., and Bloor, M. 2021. *Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains*. Argonne National Laboratory. <https://publications.anl.gov/anlpubs/2021/05/167399.pdf>.

10 North American Council for Freight Efficiency. 2018. Medium-Duty Electric Trucks. <https://nacfe.org/research/emerging-technologies/electric-trucks/medium-duty-electric-trucks/#top>.

11 Alternative Fuels Data Center. n.d. Maintenance and Safety of Electric Vehicles. Accessed March 20, 2025. <https://afdc.energy.gov/vehicles/electric-maintenance>.

12 Muratori, M., Borlaug, B., Ledna, C., Jadun, P., and Kailas, A. 2023. "Road to Zero: Research and Industry Perspectives on Zero-Emission Commercial Vehicles." *iScience* 26, no. 5. <https://www.sciencedirect.com/science/article/pii/S2589004223008283>.

MHDFCEV technology is less mature than that of its BEV counterparts, resulting in fewer commercially available models. FCEV technology is seen as particularly promising in long-haul Class 8 trucking operations, where BEVs are expected to face challenges due to range and recharging limitations.

Currently, availability and cost of hydrogen are limiting factors that challenge this technology option. The current lack of clean hydrogen production capacity including limited availability of affordably priced clean hydrogen and the lack of distribution networks and infrastructure pose a significant challenge to wide-scale fleet adoption. Other challenges associated with MHDFCEV adoption include high capital costs and restricted model availability across various market segments. As the clean hydrogen economy is built out across the U.S., the operational and financial viability of MHDFCEVs is expected to improve. This development is pivotal as it aligns with global energy trends toward decarbonization and sustainability. Given these challenges, point-to-point, return-to-base, or route-specific fleets may be best suited to evaluate MHDFCEV opportunities as infrastructure develops.

2.2. LOW-EMISSION OPTIONS

For applications where zero-emission technologies are not yet practical due to cost or operational constraints, several alternative fuel and powertrain solutions offer meaningful pathways to reducing emissions. These include increased use of low-carbon fuels, such as biodiesel or RD, in existing ICE vehicles. Alternative fuel options such as compressed natural gas (CNG) and RNG provide low-emission alternatives but require dedicated engine technology designed for these fuels. Finally, hybrid powertrains like plug-in hybrid electric vehicles (PHEVs) and hybrid ICE vehicles allow for the use of BEV technology combined with a standard ICE. These approaches represent viable alternatives

that can provide tangible emissions reductions in the short to medium term. Dimethyl ether (DME) and hydrogen for ICEs are also promising low-emission fuels. Information on these applications is included in this section; however, as they are not yet commercially available in the U.S., they are not discussed in later sections addressing planning and implementation.

2.2.1 HYBRID ELECTRIC VEHICLES

Overview

Hybrid electric vehicles (HEVs) combine one or more electric motors. HEVs use the ICE as the primary power source and supplement it with the (secondary) electric motor. The electric motor in medium- and heavy-duty hybrid electric vehicles (MHDHEVs) is powered by a smaller battery pack that is charged through regenerative braking. This technology captures energy usually lost during braking and converts it into electricity, which is then stored in the battery. This stored energy is used to power the electric motor.¹³ Some hybrid systems can also actively optimize the engine operation for maximum efficiency, and/or allow engine-off vehicle operation in some situations for further gains in fuel efficiency and emissions.

Tell Me More

HEVs offer flexible and efficient solutions to reduce GHG emissions in many use cases via lower fuel consumption. They are most effective in transient operation cycles (stop-and-go or hilly terrain), which offer greater opportunities to leverage the electrified hybrid system for reduced fuel consumption. While BEVs also feature strong regenerative braking capabilities, HEVs can be more cost-effective in drive cycles where BEVs are not yet viable due to current limitations in range or charging infrastructure—especially in public transit applications with high daily mileage.

¹³ National Academies of Sciences, Engineering, and Medicine. 2020. "Hybrid and Electric Powertrain Technologies." In *Reducing Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two: Final Report*. National Academies Press. <https://nap.nationalacademies.org/read/25542/chapter/9>.

2.2.2 BIODIESEL

Overview

Biodiesel is a diesel substitute fuel derived from organic sources such as plant oils (e.g., canola and soy), animal fats, and other organic feedstock from agricultural processing waste/byproducts and forest biomass through a transesterification process.^{14,15} Biodiesel must meet ASTM D6751 to be considered a legal fuel that is fit for purpose. Biodiesel has lower overall life cycle emissions and carbon intensity (CI) than the petroleum diesel it displaces. It is typically blended with petroleum diesel in blends of 5% (B5) to 20% (B20) and used to power existing ICEs. Given that these low blends of biodiesel require little or no modification to vehicles or refueling infrastructure, they are an effective fuel blend, particularly for market segments that are challenging to decarbonize or where the infrastructure and underlying ecosystem to support decarbonization are not yet well established. Upgrades to new and existing diesel trucks are growing in availability and allow for use of 100% biodiesel (B100).

Tell Me More

Biodiesel is versatile and suitable for use in MHDVs. Blending offers a practical approach to integrating biodiesel into current fuel infrastructure. Since model year (MY) 1994, most MHDV engines have been manufactured to be compatible with biodiesel blends of up to B20 with little or no modification. While not required, it is recommended to refer to equipment manuals and/or consult the manufacturer to understand recommended fuels and implications for your vehicles and use-case.

In colder climates, biodiesel has a tendency to gel more quickly than petroleum diesel, which can cause filter plugging.¹⁶ This is easily addressed via blending with low-cloud-point diesel and/or the use

of low-temperature flow additives for use in cold temperatures. Keep in mind that cold flow improvers for diesel fuel differ from those used when biodiesel is in the mix.

Fleet owners across the U.S. can expect to encounter different biodiesel pricing strategies influenced by regional regulatory landscapes, incentives, and market conditions.

2.2.3 RENEWABLE DIESEL

Overview

Although biodiesel and RD have similar feedstocks, their production, availability, and engine behavior differ. RD is typically produced using an isomerization and hydrogenation process, resulting in a hydrocarbon that is chemically equivalent to petroleum diesel and satisfies the ASTM D975 specification defining traditional diesel fuel. Thus, it can typically be used in higher blends than biodiesel (up to 100%) and can replace petroleum diesel in MHDV ICEs as a drop-in fuel.

Tell Me More

Because RD is nearly chemically identical to petroleum diesel, it is fully compatible with most existing diesel engines and fueling infrastructure. The exception is that RD has fewer to no aromatics, and as such may require additives to enhance lubricity.

It can be used neat (R100 or R99) but is often blended with petroleum diesel and/or biodiesel. Similar to biodiesel, it is identified by the letter R followed by a number indicating the percentage of RD in the blend (e.g., R80 is a blend of 80% renewable diesel mixed with petroleum diesel, biodiesel, or a combination).

RD typically performs better in cold weather than biodiesel due to its branching molecular structure.

¹⁴ Veolia North America. 2021. "Biodiesel vs. Renewable Diesel: Are They the Same?" <https://blog.veolianorthamerica.com/biodiesel-vs.-renewable-diesel-are-they-the-same>.

¹⁵ U.S. Energy Information Administration. 2024. Biofuels Explained. <https://www.eia.gov/energyexplained/biofuels/biodiesel-rd-other-basics.php>.

¹⁶ Nowatzki, J., Shrestha, D., Swenson, A., and Wiesenborn, D. P. 2019. Biodiesel Cloud Point and Cold Weather Issues. Farm Energy. <https://farm-energy.extension.org/biodiesel-cloud-point-and-cold-weather-issues/>.

It does not gel as readily as biodiesel and its cloud point can be as low as -40°C . Its higher cetane number provides better ignition characteristics (shorter ignition delay) but can be an issue in older engines. Insufficient isomerization during the RD production process may cause fuel quality issues, including gelling, for end users.

As with biodiesel, regional economic and regulatory factors affect the price of RD. It has historically been higher priced than either petroleum diesel or biodiesel due to supply constraints, increased demand, and production costs. However, state and federal policy and regulatory factors have combined to bring RD very close to cost parity with diesel at the point of purchase in some places.

2.2.4 COMPRESSED NATURAL GAS

Overview

CNG is a form of natural gas primarily composed of methane, a potent greenhouse gas, and is used as an alternative fuel. Despite being a nonrenewable resource, natural gas presents a cleaner-burning option than diesel, reducing GHG emissions and air pollutants. CNG, produced by compressing natural gas at high pressure, requires relatively low energy for conversion.

CNG fuel requires different engine technology than its diesel counterpart, as the combustion process and fuel characteristics differ. CNG engines use a spark-ignition system rather than the compression-ignition system used in diesel engines. The fuel system must also be adapted to handle CNG, which involves different fuel injectors, regulators, and storage systems.

CNG MHDVs have now been deployed commercially for more than two decades in public transit, refuse, and trucking applications, undergoing numerous

iterations and improvements from OEMs that have increased their reliability. Engine specifications have also evolved to expand the range of trucking applications where the technology is viable. These advances have been coupled with growing infrastructure supporting its use. CNG vehicles can be fueled at two types of natural-gas stations, fast-fill and time-fill stations. Fast-fill stations use fuel from a local utility line converted to high-pressure gas using an on-site converter and stored in tanks on the property. This enables drivers to fuel their vehicles in almost the same time as it takes them to refuel with gasoline/diesel. Alternatively, time-fill stations fuel vehicles directly from the compressor over longer periods of time.

Tell Me More

MHDVs may be dedicated CNG, bi-fuel, or dual-fuel vehicles. Dedicated CNG vehicles operate solely on CNG or RNG. Bi-fuel CNG vehicles have two separate fueling systems that enable them to run on either natural gas or gasoline. These are available in the aftermarket; conventional diesel vehicles are modified using conversion kits that add CNG fuel storage components including fuel cylinders, supply lines, and CNG-specific injectors.¹⁷ Dual-fuel vehicles primarily run on natural gas but rely on diesel fuel for ignition assistance, providing flexibility for long-haul and heavy-duty applications.¹⁸ The fuel is stored in multiple high-pressure tanks, often located behind the cab, and is delivered through a pressure regulator to ensure compatibility with the engine's injection system. This setup allows natural gas vehicles (NGVs) to maintain performance and efficiency comparable to traditional ICEs.¹⁹ However, the requirement for multiple tanks, necessary due to CNG's lower energy density compared to diesel, can reduce payload capacity and require more frequent refueling in some applications. This has been

¹⁷ Alternative Fuels Data Center. n.d. Natural Gas Vehicle Availability. Accessed March 20, 2025. <https://afdc.energy.gov/vehicles/natural-gas-availability>.

¹⁸ Virginia Clean Cities. n.d. Renewable Natural Gas. Accessed December 4, 2024. <https://vacleancities.org/cleaner-transportation/natural-gas/>.

¹⁹ Alternative Fuels Data Center. n.d. How Do Compressed Natural Gas Class 8 Trucks Work? Accessed December 4, 2024. <https://afdc.energy.gov/vehicles/how-do-natural-gas-class-8-trucks-work>.

offset by some local weight allowance increases to accommodate the additional weight of CNG/RNG equipment.

While CNG-powered vehicles have higher initial costs due to specialized engines and fuel storage systems, they can offer significant operational savings. CNG engines do not require the complex exhaust gas aftertreatment systems mandated for diesel vehicles, making their aftertreatment systems simpler than those of diesel engines.²⁰ Maintenance costs for CNG vehicles vary and can fall within the range of diesel vehicle costs, with some applications reporting higher or lower expenses. However, CNG fuel prices are lower than diesel on a per-unit-of-energy basis and are generally more stable, with monthly rather than daily price adjustments shielding fleet operators from the market volatility that frequently impacts diesel prices.



2.2.5 RENEWABLE NATURAL GAS

Note that *RNG* and *biomethane* are terms often used interchangeably, but they have specific distinctions based on their production processes and end uses. While RNG is a broader term that denotes the larger concept of developing renewable natural gas from biomass, biomethane specifically refers to high-purity methane produced from biogas, highlighting its biomass origin. In this guide, the term RNG will be used.

Overview

RNG is produced from biogas that is generated through the fermentation of organic materials such as cow manure, sewage sludge, or landfill organic waste. The production process not only generates a renewable energy source but also captures methane—a potent GHG—preventing its release into the atmosphere. RNG has a significantly lower CI than traditional fossil natural gas and diesel and has the potential to reach a negative CI when sourced from certain feedstocks, such as dairy manure or landfill gas.²¹

RNG is fully interchangeable with conventional natural gas and can be used as a transportation fuel in the form of CNG or liquefied natural gas (LNG). It is compatible with existing CNG or LNG vehicle engines and fueling infrastructure. While RNG offers significant environmental benefits, its production costs are higher than those of conventional natural gas due to the complexities of biogas upgrading and distribution, which can generally be offset by incentives or credits for renewable fuels.

Tell Me More

RNG destined for use in transportation is processed to a very high purity standard through a method that increases the methane content and transforms it into pipeline-quality gas. This allows RNG to be distributed through existing natural gas pipeline

20 Noregon. n.d. CNG and RNG vs. Diesel Trucks. Accessed December 2, 2024. <https://www.noregon.com/cng-rng-vs-diesel-trucks/>.

21 FreightWaves. 2022. RNG Is Decarbonizing Trucking Today. <https://www.freightwaves.com/news/rng-is-decarbonizing-trucking-today>.



networks,²² which makes it a reliable fuel option. As a result, RNG now represents 69% of the natural gas used in transportation in North America.²³

RNG provides operational advantages for fleets, offering driving ranges comparable to conventional natural gas, making it viable for long-haul trucking. Although diesel typically delivers more power at lower engine revolutions than RNG, many fleet owners still prefer RNG due to its overall mileage capabilities, cost-effectiveness, and significant emissions reduction potential. RNG uses the same infrastructure as CNG, allowing fleets to leverage existing fueling stations. For detailed information on RNG fueling infrastructure, refer to the CNG section (2.2.4) above. It is important to note, however, that RNG is available at fewer fueling stations, and its availability varies by location, depending on regional production capacity, distribution infrastructure, and policy support.²⁴ The majority of RNG, however, is accessed through book-and-trade transactions.

This allows for access to RNG at any point along the fungible natural gas pipeline.

RNG also provides many environmental benefits. Since the fuel is derived from renewable organic waste sources, it is both renewable and often achieves a negative CI. For heavy-duty vehicles that travel long distances, RNG can lower life cycle emissions substantially.²⁵ Studies have found that replacing just 25% of a fleet's diesel trucks with negative-CI RNG from dairy manure feedstocks can reduce a fleet's GHG emissions by 100%.²⁶

Despite these benefits, RNG faces challenges from feedstock availability and high production costs when compared to conventional fuels.²⁷ These limitations, along with the need for infrastructure expansion, create scalability concerns. However, policies like California's Low Carbon Fuel Standard (LCFS) and U.S. EPA's Renewable Fuel Standard are helping offset costs and incentivizing production and use.

22 Alternative Fuels Data Center. n.d. Renewable Natural Gas Production. Accessed December 2, 2024. <https://afdc.energy.gov/fuels/natural-gas-renewable>.

23 Menzies, J. 2024. NACFE Report Gives Fresh Take on Natural Gas as Trucking Fuel. Trucknews.com. <https://www.trucknews.com/sustainability/nacfe-report-gives-fresh-take-on-natural-gas-as-trucking-fuel/1003183330/>.

24 Noregon. n.d. CNG and RNG vs. Diesel Trucks. Accessed December 4, 2024. <https://www.noregon.com/cng-rng-vs-diesel-trucks/>.

25 Xiao, H. 2024. Fuelling the Transition: Low-Carbon Fuel Choices for Road Freight (revised). Pembina Institute. https://www.pembina.org/sites/default/files/2024-08/Fuelling_the_Transition-revised.pdf.

26 FreightWaves. 2022. RNG Is Decarbonizing Trucking Today. <https://www.freightwaves.com/news/rng-is-decarbonizing-trucking-today>.

27 Menzies, J. 2024. NACFE Report Gives Fresh Take on Natural Gas as Trucking Fuel. Trucknews.com. <https://www.trucknews.com/sustainability/nacfe-report-gives-fresh-take-on-natural-gas-as-trucking-fuel/1003183330/>.

2.2.6 OTHER ALTERNATIVE FUELS

PLUG-IN HYBRID ELECTRIC VEHICLES

Overview

Like HEVs, PHEVs combine an electric motor with an ICE. The vehicles can switch between both power sources or use them simultaneously. PHEVs differ from HEVs in that they have a battery pack that can be charged externally (i.e., plugged in). Unlike their light-duty counterparts, PHEVs in MHDV classes are not widely commercially available at this time.

Tell Me More

PHEVs offer flexible and efficient solutions to reduce GHG emissions, particularly in applications where BEVs' range and charging needs are not yet cost-effective. PHEVs are particularly well-suited for two MHDV applications: urban delivery/service tasks and vocational vehicles that travel to job sites and perform stationary operations, often requiring substantial range. For example, bucket trucks used by electric utility services may travel to a site and operate for hours; the use of electric power will significantly reduce fuel consumption.²⁸

DIMETHYL ETHER

Overview

DME is a synthetically produced alternative to diesel, designed for use in compression-ignition engines with specialized fuel systems. At normal atmospheric conditions, DME is a colorless gas,

requiring pressurization to ~75 psi to remain in liquid form. Its storage and handling requirements are similar to propane, utilizing pressurized storage tanks at ambient temperature.²⁹ DME is known for its clean combustion properties, producing virtually no soot and reduced nitrogen oxide (NO_x) emissions compared to diesel while offering comparable energy efficiency and engine performance.^{30,31}

DME can be synthesized from a variety of feedstocks, including biomass, methanol, and fossil fuels. Natural gas is considered the most likely large-scale production feedstock in the U.S. due to its availability and cost effectiveness.^{32,33} Despite its potential, DME is not yet commercially available in the U.S., although renewable DME production has begun on a small scale.³⁴ Demonstrations have shown that it is possible for diesel engines to operate on 100% DME with significant modifications or on DME-diesel blends with minimal retrofitting.³⁵

Tell Me More

DME's high cetane number allows the fuel to perform efficiently in compression-ignition engines, closely matching the power output and energy efficiency of diesel.³⁶ However, to fully utilize DME as a fuel, engines require technical adaptations. These include modifications to the fuel injection system, combustion process, exhaust treatment, and storage tanks.³⁷ Despite these challenges, over 90% of the engine components are the same as those in traditional diesel engines. This compatibility

28 National Academies of Sciences, Engineering, and Medicine. 2020. "Hybrid and Electric Powertrain Technologies." In *Reducing Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two: Final Report*. National Academies Press. <https://nap.nationalacademies.org/read/25542/chapter/9>.

29 Alternative Fuels Data Center. n.d. Dimethyl Ether. Accessed December 2, 2024. <https://afdc.energy.gov/fuels/emerging-dme>.

30 National Academies of Sciences, Engineering, and Medicine. 2020. "Hybrid and Electric Powertrain Technologies." In *Reducing Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two: Final Report*. National Academies Press. <https://nap.nationalacademies.org/read/25542/chapter/9>.

31 TEC4FUELS. 2023. Dimethyl Ether as an Alternative Fuel. <https://www.tec4fuels.com/dimethyl-ether-as-an-alternative-fuel/?lang=en>.

32 National Academies of Sciences, Engineering, and Medicine. 2020. "Hybrid and Electric Powertrain Technologies." In *Reducing Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two: Final Report*. National Academies Press. <https://nap.nationalacademies.org/read/25542/chapter/9>.

33 Aiello, A. 2024. Dimethyl Ether as a Diesel Fuel Replacement. Power Progress. <https://www.powerprogress.com/news/dimethyl-ether-as-a-diesel-fuel-replacement/8034296.article>.

34 National Academies of Sciences, Engineering, and Medicine. 2020. "Hybrid and Electric Powertrain Technologies." In *Reducing Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two: Final Report*. National Academies Press. <https://nap.nationalacademies.org/read/25542/chapter/9>.

35 Alternative Fuels Data Center. n.d. Dimethyl Ether. Accessed December 2, 2024. <https://afdc.energy.gov/fuels/emerging-dme>.

36 National Academies of Sciences, Engineering, and Medicine. 2020. "Hybrid and Electric Powertrain Technologies." In *Reducing Fuel Consumption and Greenhouse Gas Emissions of Medium- and Heavy-Duty Vehicles, Phase Two: Final Report*. National Academies Press. <https://nap.nationalacademies.org/read/25542/chapter/9>.

37 TEC4FUELS. 2023. Dimethyl Ether as an Alternative Fuel. <https://www.tec4fuels.com/dimethyl-ether-as-an-alternative-fuel/?lang=en>.

makes DME a feasible option for manufacturers to consider as part of a transition strategy toward decarbonization of the sector.

Bringing DME-ready engines to market still falls under the responsibility of OEMs and engine manufacturers, as the development of DME-compatible components, such as injectors and storage systems, is critical for adoption. However, DME's ability to leverage existing liquid petroleum gas infrastructure for storage and transport offers significant cost and handling advantages.³⁸ With continued advancements in production and vehicle compatibility, DME shows promise as an alternative fuel for MHDV vehicles. At this time, however, DME remains an emerging technology and is not yet a viable large-scale solution.



HYDROGEN INTERNAL COMBUSTION ENGINES

Overview

Hydrogen ICE technology represents a modification of traditional ICEs to use hydrogen as a fuel instead of gasoline or diesel. These engines produce lower emissions compared to conventional gasoline or diesel engines, although they are not as clean as FCEVs. Hydrogen ICE vehicles emit some NO_x and may produce trace amounts of carbon emissions depending on the combustion process. However, they are generally considered very low carbon or approaching zero carbon at the vehicle level, as recognized by the U.S. Environmental Protection Agency (EPA).

Hydrogen ICE vehicles are anticipated to play a role in long-haul applications where range and weight limitations are critical. These engines may offer a more cost effective alternative for long-distance freight transportation compared to FCEV and BEV technologies, addressing the need for lower emissions while leveraging existing ICE technology. However, while hydrogen ICE powertrains are less costly than those for FCEVs, they are expected to have modestly lower efficiency, resulting in greater fuel consumption. The production of commercially available hydrogen ICE Class 8 trucks is unclear at this stage, with estimates of production start dates in 2028 or beyond.

Tell Me More

Hydrogen ICE vehicles are designed to burn hydrogen in a modified ICE, using the same basic mechanics as traditional diesel engines but with significant adaptations to accommodate hydrogen's properties. However, they are expected to be more similar to spark-ignited natural gas engines in terms of combustion characteristics. This similarity means the learning curve for technicians working on hydrogen ICE vehicles is expected to be less

³⁸ TEC4FUELS. 2023. Dimethyl Ether as an Alternative Fuel. <https://www.tec4fuels.com/dimethyl-ether-as-an-alternative-fuel/?lang=en>.

steep than for those working on FCEVs. Technicians familiar with diesel and natural gas engines will find many aspects of hydrogen ICE technology familiar, making the transition smoother and potentially less costly.

In terms of emissions, while hydrogen ICE vehicles do produce lower greenhouse gases compared to diesel engines, they are not entirely emission free. NO_x emissions are still a concern, and depending on the specifics of the combustion process, there may also be some carbon emissions. However, these emissions are generally lower than those from traditional fossil fuel engines.

Hydrogen ICE technology is seen by some as an interim step toward fully zero-emission vehicles. As the cost of hydrogen decreases, hydrogen ICE

vehicles could become a cost-effective option before hydrogen fuel cell technology becomes more economically viable. The projected cost differential between hydrogen ICE vehicles and diesel vehicles is expected to be smaller than that between FCEVs and diesel vehicles, making hydrogen ICE a potentially attractive option for fleet operators as an interim solution. If hydrogen ICE vehicles become more viable in the near term, their deployment could help spur the development of hydrogen fueling infrastructure, which in turn would support and accelerate the adoption of FCEVs.



UNDERSTAND THE OPTIONS

Learn More

TOOLS

- **[Alternative Fueling Station Locator:](#)** Detailed U.S. Department of Energy (DOE) map showing public refueling stations and fuel corridors for all alternative fuels addressed in this guide.

ADDITIONAL RESOURCES

- **[U.S. National Blueprint for Transportation Decarbonization:](#)** Created by the DOE in collaboration with other federal agencies, the blueprint outlines a comprehensive strategy to reduce GHG emissions across the transportation sector.
- **[A Trucking Fleet Primer for Commercial Truck Electrification:](#)** The North American Council for Freight Efficiency (NACFE) discusses the

collaboration between the trucking industry and utilities to facilitate the adoption of electric vehicles (EVs), outlines the challenges and opportunities in establishing necessary infrastructure, and offers strategic insights for fleets transitioning to EVs.

- **[Hybrid and Electric Powertrain Technologies:](#)** Chapter from a larger study on decarbonization options by the National Academy of Sciences.
- **[Zero-Emissions Technology for Freight: Heavy-Duty Trucks:](#)** This document provides clearly expressed background information and statistics on ZEV technologies.
- **[Medium- and Heavy-Duty Vehicle Decarbonization:](#)** A hub of journal articles, reports, and public testimony on various topics and challenges in the MHDV decarbonization sector, from Resources for the Future.



SECTION 3.

Assess the Options

The decision to choose a low-carbon technology will depend on a number of factors, such as:

- **Operational viability** (e.g., drive cycle analysis, cargo limitations, downtime, climate)
- **Vehicle availability** (current and projected)
- **Infrastructure requirements**
- **Maintenance considerations**
- **Impact** (GHG reduction potential)
- **Regulatory landscape**
- **Cost, including availability of incentives** (see Section 5)

Depending on the company's goals, fleet size and composition, operational profile, region where the fleet operates, depot size(s) and location(s), and other characteristics, the relative importance of each of the assessment categories will vary.

This section will walk fleet owners through the key elements of each of the factors to help them assess which low-carbon options have the potential to generate emissions reductions while also maintaining favorable operation and capital (operating expenses and capital expenditures) cost profiles.

3.1. OPERATIONAL VIABILITY

3.1.1 BEVS

Range is a key factor in the operational viability of MHD BEVs. Range heavily depends on battery size, which also impacts payload capacity. Larger batteries extend vehicle range but reduce payload due to their weight requirements, presenting a critical trade-off for many fleet operators. For instance, the batteries required to power long-haul trucks can weigh between 7,000 and 14,000 pounds, which would prevent BEVs from carrying the same payload as diesel-fueled trucks due to federal weight restrictions limiting trucks to 80,000 pounds on interstate highways.³⁹

Additionally, MHD BEV range is affected by auxiliary power loads, extreme weather, and route conditions. BEV technology benefits from regenerative braking, which allows vehicles to recoup energy in stop-and-go conditions. The combination of daily driving range and the amount of time available for charging, or dwell time, determines the required charging speed to ensure operational viability for BEVs. Charging stations are available at different power levels, which charge at different rates. Faster charging stations are more expensive and often require costly upgrades at the deployment site, impacting the financial viability of the project. Therefore, the most cost-effective applications for electrification at this stage involve scenarios where vehicles are parked predictably for extended periods, allowing the use of the lowest charging power/speed. Further, scaling this technology will require extensive infrastructure development, particularly for long-haul freight. To meet the demands of existing fleets, experts estimate that at least 600,000 high-capacity truck chargers will be needed by 2030. In response, major manufacturers like Daimler Truck North America, Volvo, and Navistar, which together

represent around 70% of the U.S. MHDV market, are collaborating to accelerate the development of charging networks.⁴⁰

MHDV fleets span a diversity of applications with varying operational characteristics, including distance traveled, dwell time, and route predictability.⁴¹ Introducing BEVs first requires a detailed analysis to evaluate which technologies are currently viable within typical fleet operations. Fleet operators should refer to the resources provided in this guide and consult with their dealership or OEMs to assess the range and payload capabilities of commercially available options. Depending on your operations and the size of deployment, hiring a consultant to assess your routes and charging infrastructure needs and determine your deployment size based on existing BEV capabilities may be beneficial. Ideally, this would involve deploying pilot applications to assess the capabilities of the technology under local operational conditions.

Public transit, school bus, and urban delivery applications of BEVs are growing, with deployments on carefully assessed routes that are within range. The NACFE has published numerous guidance reports analyzing the technological feasibility of BEVs in the trucking industry. These reports suggest that BEVs are a practical solution for Class 3 to 6 vehicles, particularly for urban stop-and-go and regional-haul activities, including return-to-base operations and daily travel distances of less than 200 miles. However, for heavier truck classes, challenges associated with cost, range, and weight restrictions currently prevent battery electric trucks from being a feasible option for routes exceeding 200 miles, especially for duty cycles that operate near the maximum allowable weight. These challenges don't preclude BEVs but may limit the use cases

39 Maynard, M. February 28, 2024. "The Challenge of Decarbonizing Long-Haul Trucking." *Time*. <https://time.com/6766439/electric-long-haul-trucking/>.

40 Maynard, M. February 28, 2024. "The Challenge of Decarbonizing Long-Haul Trucking." *Time*. <https://time.com/6766439/electric-long-haul-trucking/>.

41 Transportation Energy Institute. 2022. *The Easiest and Hardest Commercial Vehicles to Decarbonize*. <https://www.transportationenergy.org/research/reports/decarbonizing-medium-and-heavy-duty-vehicles>.

or require more trips for a given amount of freight. In some cases, HEVs may be considered as an alternative for routes where BEVs are not yet viable and HEVs are available, particularly in applications with long-distance or high-duty cycles that limit full electrification.



3.1.2 FCEV

FCEVs are anticipated to play a crucial role in long-haul applications where range and weight limitations are critical, overcoming some of the challenges currently presented by BEV technology. However, these vehicles also face specific weight limitations compared to diesel, primarily due to the weight and size of the required hydrogen tanks. (This issue arises because hydrogen has a significantly lower volumetric energy density compared to diesel.) Class 8 hydrogen fuel cell electric trucks are typically about 7,750 pounds heavier than ICE trucks because of the high-pressure hydrogen tanks. As production scales up, this weight penalty is expected to drop to around 4,000–5,000 pounds thanks to lighter components.⁴² Beyond heavy trucking, FCEVs are also making inroads in public transit, particularly in high-range and low-dwell-time applications.

FCEVs additionally have the advantage of faster refueling. The DOE has set goals for heavy-duty trucks to reach fill rates of 8 kg H₂/min by 2030 and 10 kg H₂/min by 2050, envisioning a six-minute fill time for a truck with a range of 745 miles. Meanwhile, ongoing research aims to validate proposed fueling standards and equipment. These advancements suggest that FCEVs could achieve fueling times comparable to diesel vehicles in the future, providing a significant advantage for long-haul applications where quick refueling is essential.

3.1.3 BIODIESEL AND RD

The transition from regular diesel to alternative fuels like B20 and R99 has minimal impact on operational viability. B20 offers a nearly seamless shift, requiring no engine modifications for most engines, and fuel economy impacts can vary—some fleets report a negligible 1–2% reduction, while others have observed improved efficiency depending on factors like driver behavior, duty cycle, and engine calibration. R99, on the other hand, provides

⁴² North American Council for Freight Efficiency. 2020. *Making Sense of Heavy-Duty Hydrogen Fuel Cell Tractors*. <https://nacfe.org/wp-content/uploads/2020/12/NACFE-Guidance-on-Hydrogen-Fuel-Cell-Tractors-FINAL-121620.pdf>.

identical performance and fuel efficiency to regular diesel, making it a drop-in solution that integrates effortlessly into most operations. This provides an excellent opportunity to reduce emissions from existing fleet vehicles and to decarbonize new vehicles for operations where ZEVs are not currently technologically viable.

Biodiesel has a higher cloud point than conventional diesel, meaning it can become thick and gel-like in cold temperatures. This gelling can clog fuel filters and lines, hindering engine performance. Fleets should use lower blends of biodiesel (up to B20) in colder months and restrict the usage of higher biodiesel blends to warmer months. Companies specializing in alternative fuels can help fleets establish best practices for this seasonal fuel transition.

Alternatively, companies specializing in conversion kits can help fleet owners convert their existing fleet into dual-fuel systems, allowing for the use of higher biodiesel blends, up to B100. These create a separation within the vehicle's fuel storage, one for biodiesel and one for petroleum diesel or RD. This small change ensures that the first 30 seconds of start-up uses petroleum diesel or RD to flush the system and create residual heat, allowing the vehicle to then switch to biodiesel without issue. Similarly, there is a 30-second shutdown procedure, where petroleum diesel is again flushed through the system, ensuring that there is no residual biodiesel fuel that could cause cold-start issues.

RD does not require any vehicle modifications to be operationally viable. While RD generally has lower cloud and pour points than biodiesel—making it less prone to gelling in cold temperatures—performance can vary depending on the specific formulation. Some RD blends are optimized for cold weather and perform similarly to petroleum diesel, but others may not be as well suited for winter conditions.

3.1.4 CNG/RNG

From an operational perspective, CNG and RNG are equivalent fuels. The only difference is in the decarbonization potential, as further described in Section 3.5.5, which addresses impacts. Fleet operators need to evaluate several operational considerations when assessing viability of these fuels. Natural-gas-powered trucks may have a shorter driving range compared to their diesel counterparts due to lower energy density, but they are lighter weight, enabling larger payloads. To extend the range, additional storage tanks can be incorporated for trucking. However, this method increases the vehicle's weight, leading to a reduction in the payload capacity for carriers operating at the maximum legal weight limit. For long-haul applications, CNG/RNG trucks have typically been used on routes without strict weight limitations, known as non-weight-sensitive routes. To address this, the Federal Highway Administration (FHWA) implemented a 2,000-pound increased weight allowance for natural-gas-powered trucks operating on the Interstate Highway System. This allowance helps mitigate payload capacity concerns and allows fleets to operate more efficiently while still adhering to regulatory requirements.⁴³ Local weight allowance increases for CNG/RNG trucks can offset the added weight of the CNG/RNG systems, allowing fleets to maintain their payload capacity.

Historically CNG/RNG vehicles can experience a decrease in power compared to their diesel counterparts, particularly on steep roads or during highway driving. The next generation of CNG/RNG engines, such as the recently released 15-liter CNG engine, is expected to address power concerns. These advancements will be particularly crucial for long-haul applications, where trucks often carry heavier loads.

⁴³ Transport Project. 2019. *Natural Gas Vehicle Weight Allowance Guidance: 23 USC 127(s)*. <https://transportproject.org/wp-content/uploads/2020/01/NGV-Weight-Allowance-Guidance.pdf>.

3.2. VEHICLE AVAILABILITY

3.2.1 BEV AND FCEV MODEL AVAILABILITY

[Figure 1](#) represents the availability of MHDBEVs in the U.S. as of November 2024, and [Figure 2](#) the availability of MHDFCEVs.

There were 173 MHDBEV models available, spanning 10 vehicle types, with significant representation across all market segments. However, higher-weight-class BEV applications, such as Class 8 tractors, are typically designed for regional-haul operations with limited distances, as the high cost and payload impacts of larger batteries constrain their feasibility for longer routes. For light- and medium-heavy-duty vehicles (Classes 2b–6), manufacturers commonly offer the same model with varying battery sizes, which can significantly impact the purchase price. This makes it critical for purchasers to assess their routes and operational needs carefully to select a battery size that meets their requirements without overdesigning, thereby optimizing cost and efficiency.

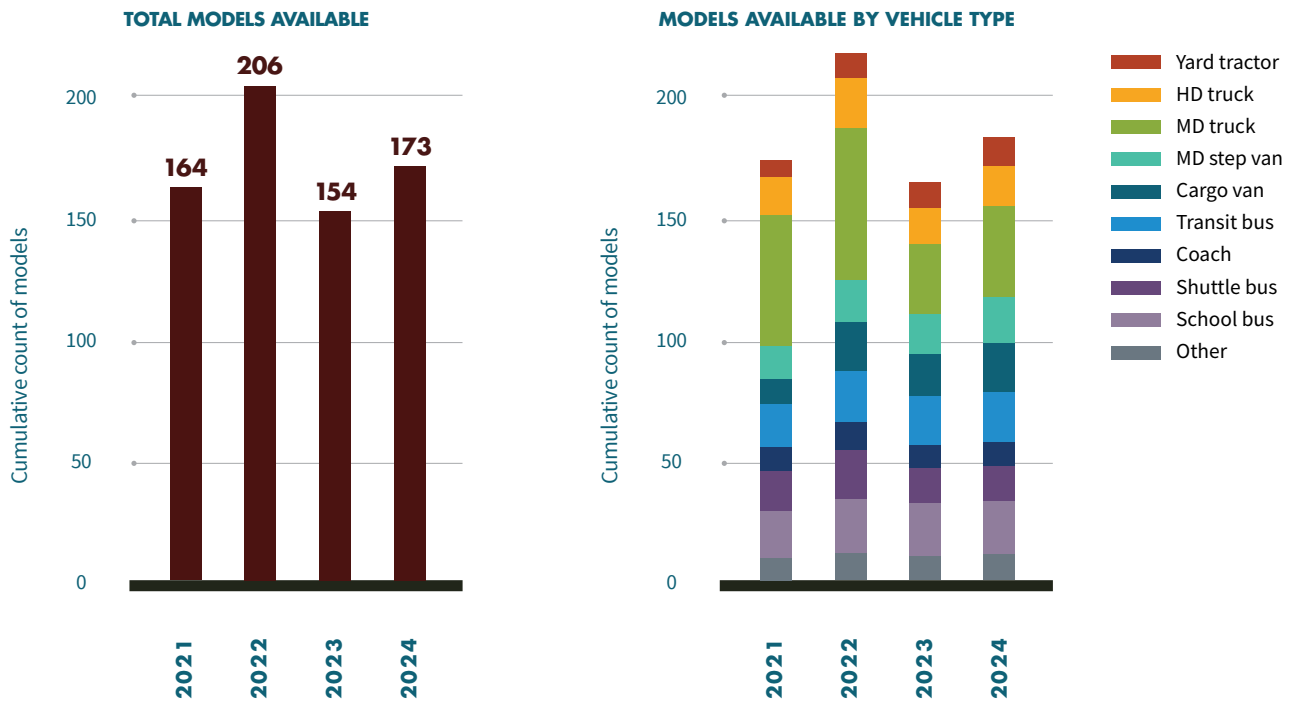
In contrast, MHDFCEV models are more limited, with only 21 models available across seven vehicle types, and are primarily concentrated in Class 8 tractor and public transit applications. This reflects the current focus of FCEV technology on segments that are anticipated to face challenges in achieving technological and economic readiness with BEVs, such as long-haul transportation and high-utilization transit operations.

Overall, this is an evolving landscape, as evidenced by the significant growth from 2021 to 2024 illustrated in these figures, so users of this guide are encouraged to consult the ZETI Data Explorer Tool⁴⁴ for updated statistics over time.

44 See Global Drive to Zero's ZETI Data Explorer at <https://globaldrivetozero.org/tools/zeti-data-explorer/>.

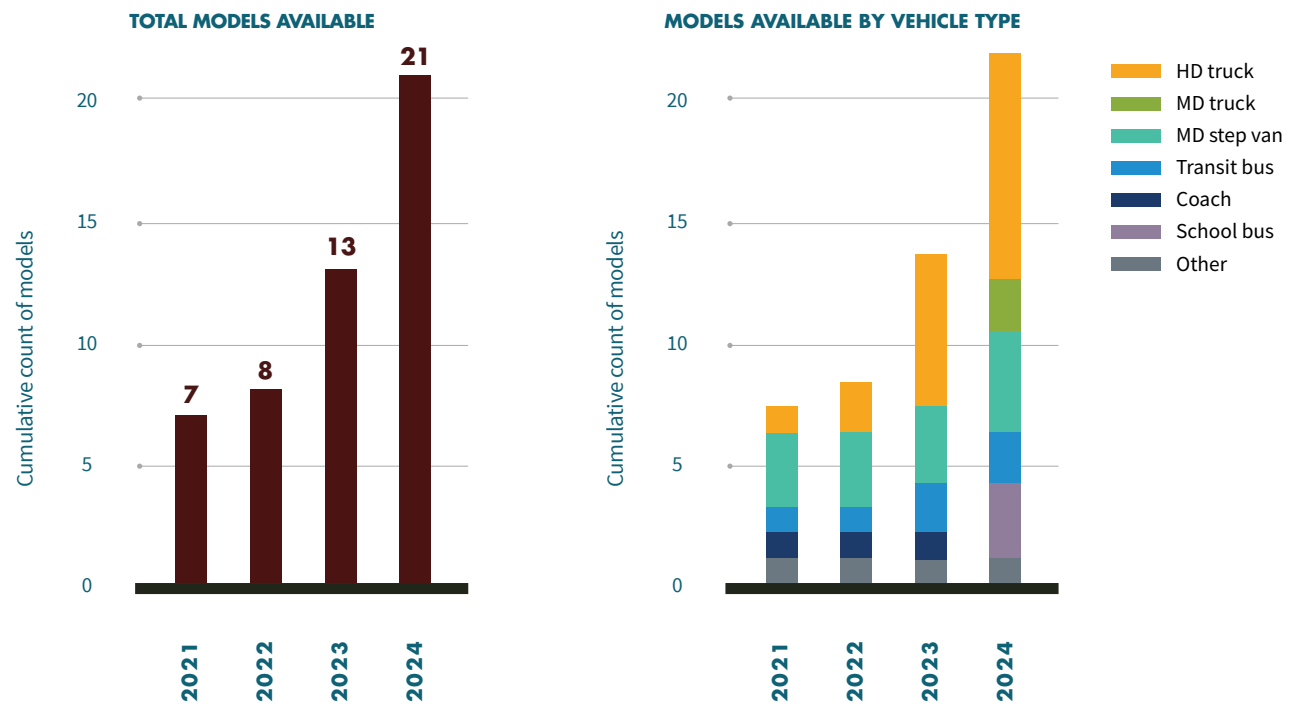


FIGURE 1: AVAILABILITY OF MHDBEV MODELS IN THE U.S., 2024



Source: ZETI Data Explorer Tool

FIGURE 2: AVAILABILITY OF MHDFCEV MODELS IN THE U.S., 2024



Source: ZETI Data Explorer Tool



3.2.2 HEV MODEL AVAILABILITY

MHDHEVs are most widely available in public transit, with multiple models offered by New Flyer, Gillig, and Nova Bus. Beyond transit, hybrid technology has also been applied in vocational vehicle segments, including refuse trucks, delivery vehicles, bucket trucks, and emergency service vehicles.

Diesel HEVs first gained traction in the early 2000s, primarily in transit and municipal fleets, as manufacturers sought to reduce fuel consumption and emissions without the infrastructure challenges of full electrification. Early deployments focused on high-idling, stop-and-go applications, where regenerative braking could maximize efficiency. However, as battery technology improved and electrification policies advanced, industry focus shifted toward fully battery electric and hydrogen fuel cell vehicles. As a result, new diesel hybrid model development has slowed, with manufacturers prioritizing zero-emission alternatives to align with regulatory targets and fleet decarbonization goals.

Unlike BEVs and FCEVs, which have seen expanding model availability, HEV offerings remain more limited and are primarily concentrated in urban and municipal applications. Publicly available data on the exact number of HEV models is less

comprehensive than for BEVs and FCEVs, as HEVs are often developed as optional configurations within existing diesel platforms rather than stand-alone models.

3.2.3 CNG/RNG MODEL AVAILABILITY

CNG is used in refuse, regional-haul, public transit, and vocational trucks, and increasingly in long-haul transportation. Existing CNG engines, typically ranging from 6 to 12 liters in size, cater to a variety of applications. Larger engines, such as those around 12 liters, are designed for regional-haul and long-haul operations, offering robust performance suitable for heavy-duty needs. Mid-sized engines are commonly used in transit and refuse trucks, while smaller engines are ideal for school buses and vocational vehicles. RNG can be used interchangeably with conventional natural gas in CNG-compatible engines.

As of mid 2024, the 12-liter engine remains the industry standard for regional- and long-haul NGVs.⁴⁵ For long-haul operations, the highly anticipated launch of the Cummins X15N 15-liter engine in early 2024 marks a significant milestone, promising substantial improvements in payload capacity, power, and efficiency, further enhancing the competitiveness of NGVs against diesel alternatives.⁴⁶

⁴⁵ Ragon, P.-L., Kelly, S., Egerstrom, N., Brito, J., Sharpe, B., Allcock, C., Minjares, R., and Rodríguez, F. 2023. *Near-Term Infrastructure Deployment to Support Zero-Emission Medium- and Heavy-Duty Vehicles in the United States*. International Council on Clean Transportation. <https://theicct.org/wp-content/uploads/2023/05/infrastructure-deployment-mhdv-may23.pdf>.

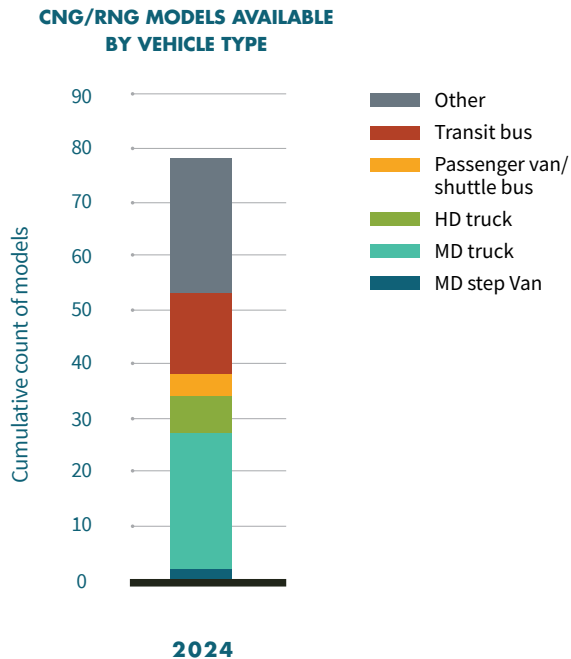
⁴⁶ Seger, J., Otto, K., Phillips, S., Roeth, M., and Mihelic, R. 2024. *Confidence Report: Natural Gas' Role In Decarbonizing Trucking*. North American Council for Freight Efficiency. <https://nacef.org/wp-content/uploads/2024/03/Nat-Gas-2024-Confidence-Report.pdf>.

Early in 2024, Kenworth delivered the industry’s first 15-liter natural-gas-powered truck, a Kenworth T680 equipped with the new X15N engine, to UPS. Kenworth has announced plans to begin production of both the T680 and T880 Class 8 truck models featuring the X15N engine in the third quarter of 2024.⁴⁷ Similarly, Peterbilt and Freightliner have confirmed the inclusion of the X15N engine in one or more of their upcoming Class 8 models.⁴⁸

Overall, the availability of CNG/RNG vehicles has expanded significantly, with leading manufacturers including Kenworth, Freightliner, Peterbilt, Volvo, and Mack offering medium- and heavy-duty models compatible with both fuels.⁴⁹

Figure 3 depicts the number of CNG/RNG models available by vehicle type in the U.S. as of 2024.⁵⁰

FIGURE 3: CNG MODELS BY VEHICLE TYPE



3.3. INFRASTRUCTURE REQUIREMENTS

The focus of this section is charging and refueling requirements. More detailed information on infrastructure installation is available in Section 8.

The MHDZEVs that are currently commercially available tend to operate within cities or regionally. Hence, most charging/refueling can be done at private fleet depots. Some public charging/refueling infrastructure for low- and zero-emission MHDVs is available, and more is being phased in. As of 2024, relying entirely on public charging infrastructure to charge MHD BEVs is not feasible in most regions. Electrical utilities in certain jurisdictions are, however, exploring participating in infrastructure development specifically for MHDVs. Public charging infrastructure will be particularly critical for long-haul trucking applications on freight corridors.

For information on public charging and fueling facilities in the U.S., the DOE’s Alternative Fueling Station Locator⁵¹ is a useful resource.

3.3.1 BEV CHARGING

The deployment of BEV technology typically necessitates the installation of charging infrastructure at the depot and possibly in other locations. For ranges under about 200 miles, depot charging is usually sufficient. “Opportunity charging”—for example, while loading and unloading—can provide additional power when required for longer routes. Public on-route charging is typically only required for long-haul applications. However, depending on the drive cycles, parking locations of MHDVs, and the cost of deploying charging infrastructure at a depot, public charging infrastructure may become necessary for a wider

47 Kenworth. 2024. Kenworth Announces Production Schedule for Class 8 Trucks Specified with New Cummins X15N Engine. <https://www.kenworth.com/about-us/news/kenworth-announces-production-schedule-for-class-8-trucks-specified-with-new-cummins-x15n-engine/>.

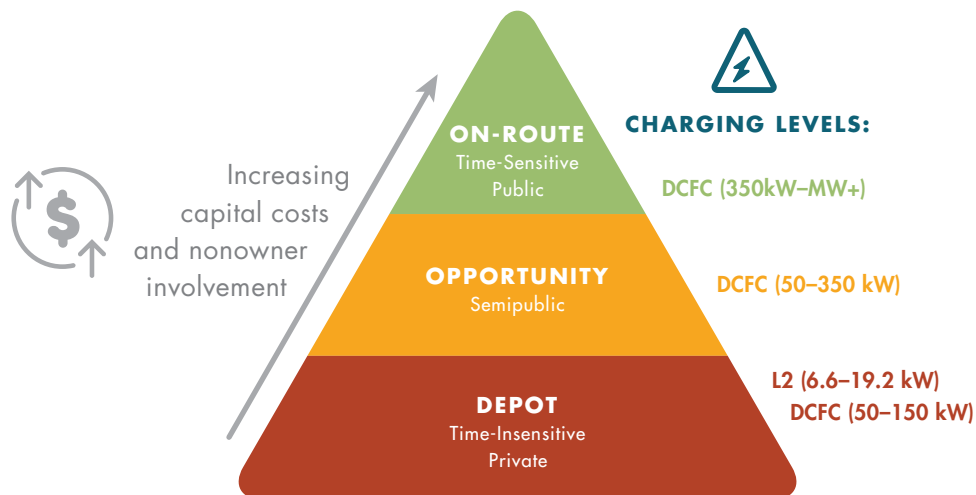
48 Ragon, P.-L., Kelly, S., Egerstrom, N., Brito, J., Sharpe, B., Allcock, C., Minjares, R., and Rodríguez, F. 2023. *Near-Term Infrastructure Deployment to Support Zero-Emission Medium- and Heavy-Duty Vehicles in the United States*. International Council on Clean Transportation. <https://theicct.org/wp-content/uploads/2023/05/infrastructure-deployment-mhdv-may23.pdf>.

49 Transport Project. n.d. Start Now. RNG Is How! Accessed December 2, 2024. <https://transportproject.org/rng-is-how/>.

50 Alternative Fuels Data Center. n.d. Alternative Fuel and Advanced Vehicle Search. Accessed December 2, 2024. <https://afdc.energy.gov/vehicles/search>.

51 Alternative Fuels Data Center. n.d. Alternative Fueling Station Locator. Accessed December 2, 2024. <https://afdc.energy.gov/stations#/find/nearest>.

FIGURE 4: CHARGING POWER REQUIREMENTS BY USE CASE



range of applications, particularly for unpredictable routes or when drivers keep the vehicle with them, reducing returns to a centralized depot.

For fleets without a dedicated depot, those leasing depots with restrictive landlords, those lacking space or unable to afford capital expenditure for charging infrastructure, or those requiring redundancy and on-route charging, public and shared charging solutions are increasingly available. Examples include Electric Island’s truck charging hub in Portland, Oregon, the Port of Long Beach’s truck charging hub in Los Angeles, and TruckNet’s Otay Mesa location near the Port of San Diego, all of which offer accessible electric truck charging. Charging-as-a-service (CaaS) providers like WattEV and Forum Mobility are opening shared charging sites in California, with further expansions planned. OEMs like Volvo and Daimler Trucks North America are investing in public charging networks, and companies like Tesla are seeking subsidies to build charging infrastructure along key corridors. The International Council on Clean Transportation

(ICCT) has estimated that 85% of the projected energy consumption from electric long-haul trucks will concentrate on the National Highway Freight Network (NHFN), which would require charging stations every 50 miles, in alignment with federal standards. This highlights the need for targeted public infrastructure planning to support BEV needs.⁵²

The power level of charging infrastructure dictates the possible rate of recharge (the actual rate of power received by the vehicle is determined primarily by the configuration of the vehicle, the state of charge, and the temperature of its battery), which is also largely determined by the vehicle’s duty cycle, size of the battery, and recharging session dwell time. Charging solutions vary in power levels, commonly referred to as Level 2 and Level 3, or direct current fast charging (DCFC). [Figure 4](#) outlines the typical charging power required for each of these three charging scenarios.⁵³

52 Ragon, P.-L., Kelly, S., Egerstrom, N., Brito, J., Sharpe, B., Allcock, C., Minjares, R., and Rodríguez, F. 2023. *Near-Term Infrastructure Deployment to Support Zero-Emission Medium- and Heavy-Duty Vehicles in the United States*. International Council on Clean Transportation. <https://theicct.org/wp-content/uploads/2023/05/infrastructure-deployment-mhdv-may23.pdf>.

53 Muratori, M., and Borlaug, B. 2021. *Perspectives on Charging Medium- and Heavy-Duty Electric Vehicles*. National Renewable Energy Laboratory. <https://www.nrel.gov/docs/fy22osti/81656.pdf>.

For vehicles with smaller batteries and longer dwell times, such as those traveling short distances daily, low-power chargers (9–19 kW, Level 2 AC) at depots may suffice. Applications involving higher daily distances with larger batteries or more limited dwell times for charging typically require higher-power chargers (50–350 kW, Level 3 DC). The heaviest long-haul trucking vehicles with longer range will require chargers of 1 MW or greater. A new Megawatt Charging Standard is expected to be released soon, aiming to provide a power level of 1000–3700 kW (1–3.7 MW) to enable charging speeds comparable to refueling diesel vehicles.

The use of higher-power chargers and the scaling of a BEV deployment may require upgrading the facility's electrical grid connection and/or integrating stationary battery storage to optimize the use

of a lower grid capacity. Sections 7.1 and 8.1, respectively, delve into the specifics of connecting with local electrical utilities to understand their rate structure and timelines and determining charging infrastructure needs.

Electrification of MHDVs is expected to increase daily electricity consumption in the U.S. by approximately 140,000 MWh by 2030. While this adjustment represents just 1% of total electricity retail sales in 2021, counties with high energy demand may face localized spikes in areas where fleets are concentrated. These impacts are expected to be more pronounced in states adopting the Advanced Clean Trucks (ACT) regulation.⁵⁴

⁵⁴ Ragon, P.-L., Kelly, S., Egerstrom, N., Brito, J., Sharpe, B., Allcock, C., Minjares, R., and Rodríguez, F. 2023. *Near-Term Infrastructure Deployment to Support Zero-Emission Medium- and Heavy-Duty Vehicles in the United States*. International Council on Clean Transportation. <https://theicct.org/wp-content/uploads/2023/05/infrastructure-deployment-mhdv-may23.pdf>.



3.3.2 FCEV REFUELING

In the U.S., while hydrogen supply is abundant, hydrogen refueling infrastructure is currently limited, mainly serving private fleets in the light-duty or public transit sectors, with the only public refueling stations in California. This current lack of infrastructure complicates hydrogen truck pilot programs. Existing pilots have relied on mobile hydrogen refueling solutions, which result in higher costs and slower refueling times. This issue has been identified and is being addressed via the development of regional clean hydrogen hubs that will form the basis of a national hydrogen network. These will be used to power not only clean transportation but also community and industrial needs.

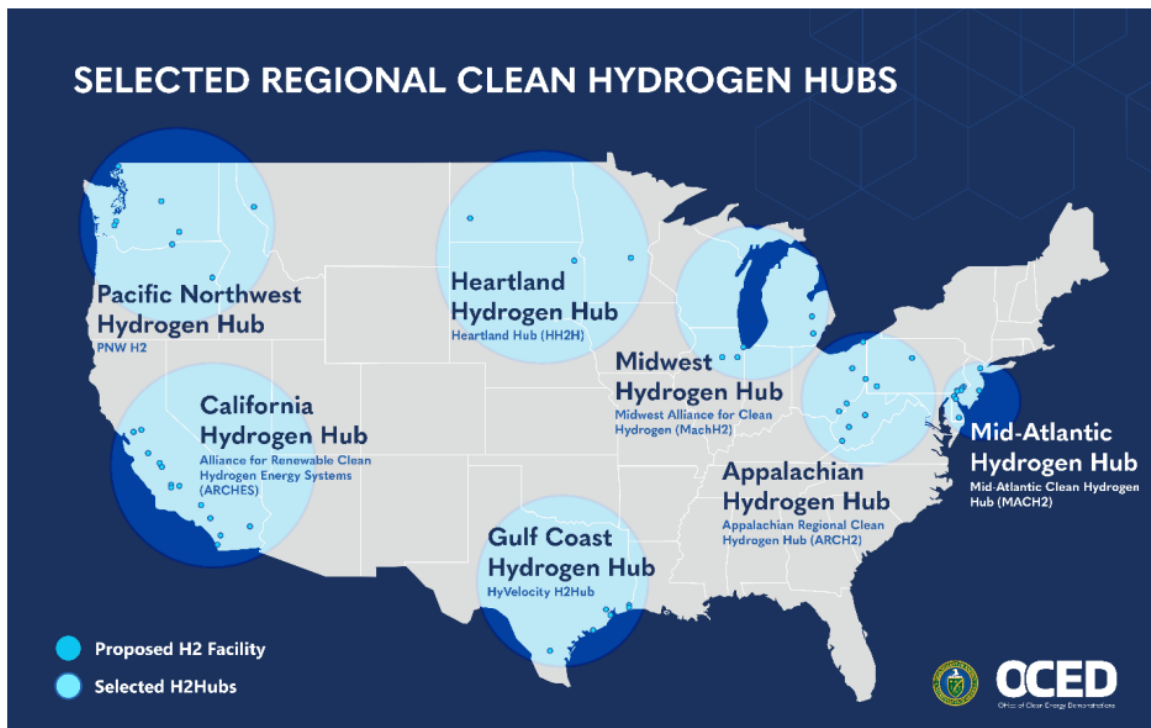
Unlike BEV technology, which is already being installed extensively at fleet depots, hydrogen

fueling infrastructure is limited to depots for public transit applications and large operators in the Class 8 regional-haul space. The remaining infrastructure is expected to be developed along long-haul corridors to serve Class 8 long-haul trucks.

The pressures at which hydrogen is stored in the vehicle vary: 700 bar for most vehicles, or 350 bar for buses and lift trucks. Necessary refueling infrastructure includes compressors to achieve the required pressure, metering equipment (which currently presents one of the greatest challenges to commercial refueling infrastructure), and dispensers that can refuel vehicles. These vary in speed but can be up to 10 kg/min. Like the vehicles themselves, these technologies are all relatively nascent.⁵⁵

Section 8 expands on the considerations of assessing refueling needs.

FIGURE 5: PLANNED LOCATIONS OF HYDROGEN HUBS AND FUELING FACILITIES



Source: Center for Climate and Energy Solutions, <https://www.c2es.org/2023/10/hydrogen-hubs-look-to-build-on-regional-u-s-strengths/>

55 U.S. Department of Energy, n.d. Hydrogen Delivery. Accessed March 21, 2025. <https://www.energy.gov/eere/fuelcells/hydrogen-delivery>.

3.3.3 ALTERNATIVE FUELS

Biodiesel and RD

The infrastructure for biodiesel and RD involves storage and fueling facilities. These fuels typically use similar storage and dispensing systems as petroleum diesel, necessitating the use of a UL listed storage tank and some type of secondary containment system. Depending on the specific needs and circumstances of the fleet, some fleet owners and operators may choose to have fuels delivered preblended, while others may choose to blend fuels on-site.

Biodiesel can be prone to gelling in cold temperatures, so infrastructure in colder regions may need additional features like heated storage tanks or blending facilities to mix biodiesel with petroleum diesel in winter months. Biodiesel blends up to B20 are compatible with existing fueling infrastructure and typically require no modifications or upgrades. B100 requires separate storage tanks, which are typically heated, insulated, or both. RD, on the other hand, can generally be stored and used like petroleum diesel, though performance can depend on the base stock and processing. In colder climates, RD should be stored above its cloud point to avoid gelling, which may require similar infrastructure adjustments as biodiesel.

Discuss fuel quality best practices with your supplier to prevent vehicle downtime. Proper fuel filter type and storage and handling practices will improve your success.

CNG

CNG infrastructure has seen significant development over the past decade, with a network gradually being established along long-haul freight corridors and fleet operator depots across the U.S. There are currently more than 1,300 CNG fueling stations, 738 of which are public, with more planned for future

development. Many fleets also install CNG/RNG fueling capability at their depots, either through owned infrastructure tied into utility supply or as a provided service similar to wet hosing diesel.

This infrastructure includes both time-fill and fast-fill stations, each catering to different operational needs. Time-fill stations allow vehicles to be refueled gradually, typically overnight, making them ideal for fleets with predictable downtime. Time-fill stations fill vehicles directly from a compressor, which reduces the heat of compression and allows for a fuller and more energy-efficient fill. This makes them particularly suited for fleets operating on fixed schedules, as they can refuel over several hours at dedicated locations. However, their slower fueling process limits their use to fleets with sufficient downtime. On-site refueling is only possible if your location has a natural gas line nearby.

Fast-fill stations, on the other hand, compress and store CNG in tanks at a pressure of 4300 psi, allowing for a quick refuel comparable to diesel fueling times—approximately 15 minutes. This quick fill can offer a range of 700–800 miles, making them suitable for fleets requiring rapid turnarounds, especially in long-haul operations. This option is commercially available at nearly all (734 of the 738 public CNG stations) across the U.S. Some stations combine fast-fill and time-fill capabilities to cater to diverse fleet needs.⁵⁶

The CNG fueling network across the U.S. has expanded significantly, with hub-and-spoke providers playing a crucial role in offering distributed natural gas delivery to fleet depots. Many fleet operators have partnered with local CNG distribution companies to deploy refueling infrastructure tailored to their operational requirements. These partnerships often involve long-term commitments to purchasing CNG in exchange for the installation of either time-fill or fast-fill refueling stations on-site,

⁵⁶ Menzies, J. 2024. "Decarbonizing Trucking Begins with Today's Diesel and Natural Gas Engines." Trucknews.com. <https://www.trucknews.com/features/decarbonizing-trucking-begins-with-todays-diesel-and-natural-gas-engines/>.

enhancing the availability and accessibility of CNG for various fleet operations. This allows for increased operational efficiency, as on-site infrastructure can seamlessly integrate with fleet schedules, especially for time-fill options in larger vehicles. On-site refueling infrastructure can reduce long-term costs, support the unique needs of the fleet, and are more consistently reliable than public fueling stations. Where the local availability of utility natural gas may not be available or in limited supply, fleet operators can partner with virtual pipeline companies to provide gas supply on a temporary or long term basis.

For those relying entirely or in part on public refueling stations, tools such as the DOE’s Alternative Fueling Station Locator (see Learn More at the end of this section for more information on this resource) allows fleet operators to plan routes along designated corridors, ensuring reliable access to fueling infrastructure.

Figure 6 highlights the existing CNG fueling corridors across the US.

FIGURE 6: AVAILABLE AND PENDING CNG FUEL CORRIDORS ACROSS THE U.S.



Source: DOE Alternative Fueling Station Locator, Fuel Corridors, https://afdc.energy.gov/stations#/corridors?state=AL&fuel=CNG&show_corridor_stations=false

RNG

The RNG fueling landscape is similar to that of CNG. RNG is fully interchangeable with conventional natural gas, and thus can be distributed through existing gas pipelines and natural gas fueling station infrastructure.⁵⁷ Currently, the U.S. has a network of 305,000 miles of natural gas transmission pipelines, with an additional 2.2 million miles of distribution pipes that transport gas within utility service areas. Over half the country’s natural gas refueling stations already supply RNG.⁵⁸ However, it is important to note that natural gas pipelines

57 Alternative Fuels Data Center. n.d. Renewable Natural Gas Production. Accessed December 2, 2024. <https://afdc.energy.gov/fuels/natural-gas-renewable>.

58 Traugott, J. 2024. “RNG-Fueled Trucks ‘Most Compelling Carbon Reduction Strategy,’ Says Hexagon Agility VP.” Cleantrucking.com. <https://www.cleantrucking.com/alt-fuels/natural-gas/article/15677359/rngfueled-trucks-most-compelling-carbon-reduction-strategy-says-hexagon-agility-vp>.

are fungible, meaning that they do not physically deliver RNG versus CNG to specific fueling stations; rather, the fuel may be a variable blend of both. To achieve the carbon benefits of RNG, fleet operators need an offtake agreement with an RNG provider to ensure that the environmental attributes of RNG are allocated to their fleet.⁵⁹ Additionally, book-and-claim systems are increasingly being used, allowing fleets to purchase RNG credits while physically receiving conventional natural gas.

The rapid expansion of RNG production facilities across the country highlights its rising demand, with 311 production facilities now operational across the U.S. and another 489 in the planning stages or under construction.⁶⁰ The number of RNG production facilities increased by 44% from 2023 to 2024, and ambitious targets have been set for the coming decades.⁶¹ These developments align with efforts to decarbonize transportation, where RNG provides an immediate and scalable solution.



3.4. MAINTENANCE CONSIDERATIONS

3.4.1 BEVS AND FCEVS

Vehicles

BEVs and FCEVs generally require less maintenance than ICE vehicles due to their simpler mechanical design. The battery, motor, and associated electronics require little to no regular maintenance, and there are fewer fluids, such as engine oil, to replace. Additionally, regenerative braking reduces brake wear, and fewer moving parts lower the likelihood of mechanical failure. These factors contribute to an estimated 20–60% reduction in maintenance costs compared to ICE vehicles.⁶²

Battery degradation, represented by the expected charge cycles of a battery over its lifetime, is an important consideration when transitioning to electric powertrains. The lifespan and performance of a battery depend on its chemistry, with two prevalent types in commercial BEVs being lithium-ion nickel manganese cobalt (NMC) and lithium iron phosphate (LFP). NMC batteries typically offer higher energy density but may degrade more quickly than LFP batteries, which are known for their longer cycle life and greater thermal stability. OEMs commonly recommend operating batteries within a state of charge range of 20–80% to optimize long-term performance and reduce degradation. While these guidelines can vary based on the battery chemistry, adhering to them can extend the useful life of the battery.

Charging practices also play a critical role in maintaining battery health. Frequent use of high-power fast charging (e.g., 300 kW) can accelerate battery degradation due to the additional heat and

59 Xiao, H. 2024. *Fuelling the Transition: Low-Carbon Fuel Choices for Road Freight* (revised). Pembina Institute. https://www.pembina.org/sites/default/files/2024-08/Fuelling_the_Transition-revised.pdf.

60 Traugott, J. 2024. "RNG-Fueled Trucks 'Most Compelling Carbon Reduction Strategy,' Says Hexagon Agility VP." Cleantrucking.com. <https://www.cleantrucking.com/alt-fuels/natural-gas/article/15677359/rngfueled-trucks-most-compelling-carbon-reduction-strategy-says-hexagon-agility-vp>.

61 Biomass Magazine. September 10, 2024. "North American RNG Surpasses 400 Operational Facilities." <https://biomassmagazine.com/articles/north-american-rng-surpasses-400-operational-facilities>.

62 Burnham, A., Gohlke, D., Rush, L., Stephens, T., Zhou, Y., Delucchi, M. A., Birky, A., Hunter, C., Lin, Z., Ou, S., Xie, F., Proctor, C., Wiryadinata, S., Liu, N., and Bolor, M. 2021. *Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains*. Argonne National Laboratory. <https://publications.anl.gov/anlpubs/2021/05/167399.pdf>.

stress placed on the cells. However, the extent of this impact depends heavily on the vehicle's battery management system, which regulates charging rates, monitors cell temperatures, and implements safeguards to mitigate degradation.⁶³ Slower charging methods, such as 50 kW or Level 2 charging, are generally less impactful on battery longevity. Looking ahead, advancements in battery technology, such as solid-state batteries, promise to improve energy density, thermal management, and overall lifespan.

Recharging/Refueling Infrastructure

While vehicle maintenance for BEVs and FCEVs is minimal, the supporting infrastructure—charging stations for BEVs and hydrogen refueling stations for FCEVs—requires regular upkeep to ensure reliability. Routine inspections, software updates, and on-site repairs are essential to maintaining functionality, particularly as higher-power chargers and hydrogen systems become more prevalent. Maintenance costs can vary based on usage patterns, climate, and station complexity. For instance, additional upkeep might be necessary in cold climates to mitigate freezing temperatures' impact on both vehicles and infrastructure, while high-utilization chargers may require more frequent servicing of connectors and cables. Fleet operators should ask equipment providers to include a service level agreement prior to ordering equipment. If one is not available, the operator may have to engage with an independent service provider that is familiar with the equipment.

As the adoption of BEVs and FCEVs accelerates, predictive maintenance and smart monitoring solutions are emerging to enhance reliability and reduce downtime. These technologies can identify potential issues early, optimizing costs and improving efficiency. A number of business models have also been developed around providing maintenance services for charging stations,

offering solutions such as routine inspections, software updates, and on-site repairs to ensure high uptime and efficiency, particularly as the deployment of higher-power chargers increases.

3.4.2 HEVS

Maintenance routines for MHDHEVs are similar to those for diesel vehicles but require additional attention to battery systems, regenerative braking, and hybrid powertrain components. While HEVs still rely on an ICE, the electric motor reduces engine load and brake wear, leading to lower maintenance costs compared to conventional diesel models.

Regenerative braking significantly extends brake life, reducing replacement intervals, particularly in stop-and-go applications like transit and refuse collection. Battery maintenance involves periodic monitoring for degradation, cooling performance, and software updates. Battery lifespans vary depending on chemistry, with some fleets reporting battery replacements after 7–10 years, though warranties help offset costs.

Like BEVs and FCEVs, HEVs and their electric motors, inverters, and power electronics require specialized diagnostic tools and trained technicians but generally experience less wear than conventional drivetrain components. The diesel engine and exhaust system still require oil changes, diesel particulate filter (DPF) regeneration, and selective catalytic reduction (SCR) maintenance, though the reduced engine load extends service intervals.

3.4.3 BIODIESEL

The use of higher blends of biodiesel (over 20%) typically entails additional maintenance requirements, particularly at higher blends.⁶⁴ While tracking fuel use is important, overemphasizing blend levels to drivers and maintenance crews can sometimes lead to perceived issues unrelated

⁶³ Bhagavathy, S. M., Budnitz, H., Schwanen, T., and McCulloch, M. 2021. "Impact of Charging Rates on Electric Vehicle Battery Life." Transport Findings. <https://findingspress.org/article/21459-impact-of-charging-rates-on-electric-vehicle-battery-life>.

⁶⁴ McCormick, Robert, 2023. "Biodiesel Handling and Use Guide, Sixth Edition." NREL. <https://docs.nrel.gov/docs/fy23osti/86939.pdf>

to the fuel itself. Fleet operators should focus on routine maintenance and performance monitoring and confirm recommended fuels and maintenance practices with vehicle and engine manufacturers to ensure optimal operation.

Note that biodiesel blends up to B5 are fungible and considered the same as ultra-low sulfur diesel via ASTM D975. Therefore, suppliers/retailers may supply diesel containing up to 5% biodiesel without disclosure. Fleet operators and fuel procurement staff should work with suppliers to determine the biodiesel content prior to further blending.

Material Compatibility

Although most engine manufacturers only endorse blends up to B5 for older engines, research and work from the NREL indicate that blends between B6 and B20 may require only minor or no modifications to engines designed to run on standard petroleum diesel. Research over the last 30 years has shown that sensitive materials such as elastomers and nitrile rubber can withstand B20 blends effectively. For vehicles older than MY 1994 or those designed before the widespread adoption of B20, fleet owners should verify compatibility with biodiesel blends beyond B5, as these engines were not always tested with higher blends. Higher-blend biodiesels may be incompatible with some elastomeric materials in older engines. The degradation of such materials can cause operational issues, though most of these original elastomeric parts in older engines have already been cycled out through routine maintenance.

Strong Solvent Properties

When used at high blending rates, biodiesel can act as a solvent that can dissolve varnish and sediments in fuel tanks and systems. When transitioning from diesel to B20, fleets typically employ a shorter fuel filter change interval for one or two maintenance cycles. Normal intervals are then resumed.



Temporary or occasional diesel use does not require any change to normal maintenance intervals.

Cold Weather Issues

Biodiesel has a higher cloud point than petroleum diesel, which can lead to challenges in many parts of North America. Like with petroleum diesel, cold weather additives are available to help improve the cold weather operability of B100 and biodiesel blends. In addition, fleet operators in colder regions should consider heated storage and fuel lines to prevent gelling. The cold flow properties vary with the biodiesel blend percentage, so specific temperature management strategies may be needed depending on the biodiesel blend and season. Improved vehicle fuel filter technology, specifically for biodiesel blends, exists and should be used to reduce the impacts of cold flow issues.

Lubricity Benefits

Biodiesel blends of as little as 2% have been shown to improve lubricity of the fuel to the extent that additional lubricity additives are not needed.⁶⁵

3.4.4 RD

Similarity to Petroleum Diesel

RD typically does not require specialized equipment and can use existing diesel infrastructure.

⁶⁵ McCormick, R., and Moriarty, K. 2023. *Biodiesel Handling and Use Guide*. 6th ed. National Renewable Energy Laboratory. https://afdc.energy.gov/files/u/publication/biodiesel_handling_use_guide.pdf.

3.4.5 CNG AND RNG

CNG and RNG burn more cleanly than diesel fuel, reducing certain maintenance needs. For example, unlike diesel vehicles, CNG vehicles do not require DPFs or SCR systems, which require regular maintenance.⁶⁶ While natural gas engines eliminate some diesel-specific maintenance requirements, their recommended maintenance intervals are generally shorter than those of comparable diesel engines. However, manufacturers are working to extend these intervals, with Cummins' latest X15N engine expected to have longer maintenance cycles.⁶⁷ Despite some reduced maintenance needs, the overall maintenance costs of natural gas engines remain comparable to diesel engines due to the higher cost of specialized parts and training requirements.

Although maintenance practices for CNG and RNG vehicles are becoming standardized, CNG/RNG-compatible facilities often require upgrades to manage natural gas operations, particularly for ventilation and gas detection equipment. These upgrades, while increasing up-front costs, are essential for ensuring compliance and safety.⁶⁸

3.5. IMPACT

The transition to low- and zero-emission MHDVs brings varying environmental and air quality impacts, influenced by the fuel type, production method, and the fleet's location. The AltFleet Economic Insight Tool associated with this guide quantifies well-to-wheel emissions reductions for various fuels and technologies, using the best available data from individual states to inform deployment strategies. The tool estimates reductions in GHG emissions measured in carbon dioxide equivalents (CO₂e), as well as criteria air pollutants, including NO_x and fine particulate matter (PM_{2.5}).

In this section, GHG emissions from alternative fuel and technology options are compared against diesel fuel based on CI, which refers to the amount of GHG emissions measured in grams of CO₂e emissions per unit of energy or fuel consumed. A lower CI means the fuel or energy source produces fewer GHGs. Additionally, we examine the impact of these technologies on NO_x and PM_{2.5} emissions, which are key contributors to air pollution and have significant implications for public health.



66 Freeze, M. 2024. "RNG Seen as Near-Term Answer to Trucking's Emission Hurdles." Transport Topics. <https://www.ttnews.com/articles/rng-panel-mce-2024>.

67 Seger, J., Otto, K., Phillips, S., Roeth, M., and Mihelic, R. 2024. *Confidence Report: Natural Gas' Role In Decarbonizing Trucking*. North American Council for Freight Efficiency. <https://nacfe.org/wp-content/uploads/2024/03/Nat-Gas-2024-Confidence-Report.pdf>.

68 Kelly, K., and Melendez, M. 2017. *Compressed Natural Gas Vehicle Maintenance Facility Modification Handbook*. U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. https://afdc.energy.gov/files/u/publication/cng_maintenance_facility_mod.pdf.

3.5.1 BEV IMPACTS

The GHG benefits of BEVs are closely linked to the CI of the local electricity grid used for charging. In regions where the grid relies on cleaner energy sources, such as renewables and nuclear, BEVs can achieve low or nearly zero well-to-wheel emissions. Conversely, in areas dominated by coal-based grids, the emissions reductions from BEVs are reduced and may even be negated by the high emissions intensity of the grid.

The emissions reduction benefits of BEVs will continue to increase over time as the grid continues to improve its CI.

The emission intensity of states’ grids varies, as illustrated in [Figure 7](#).

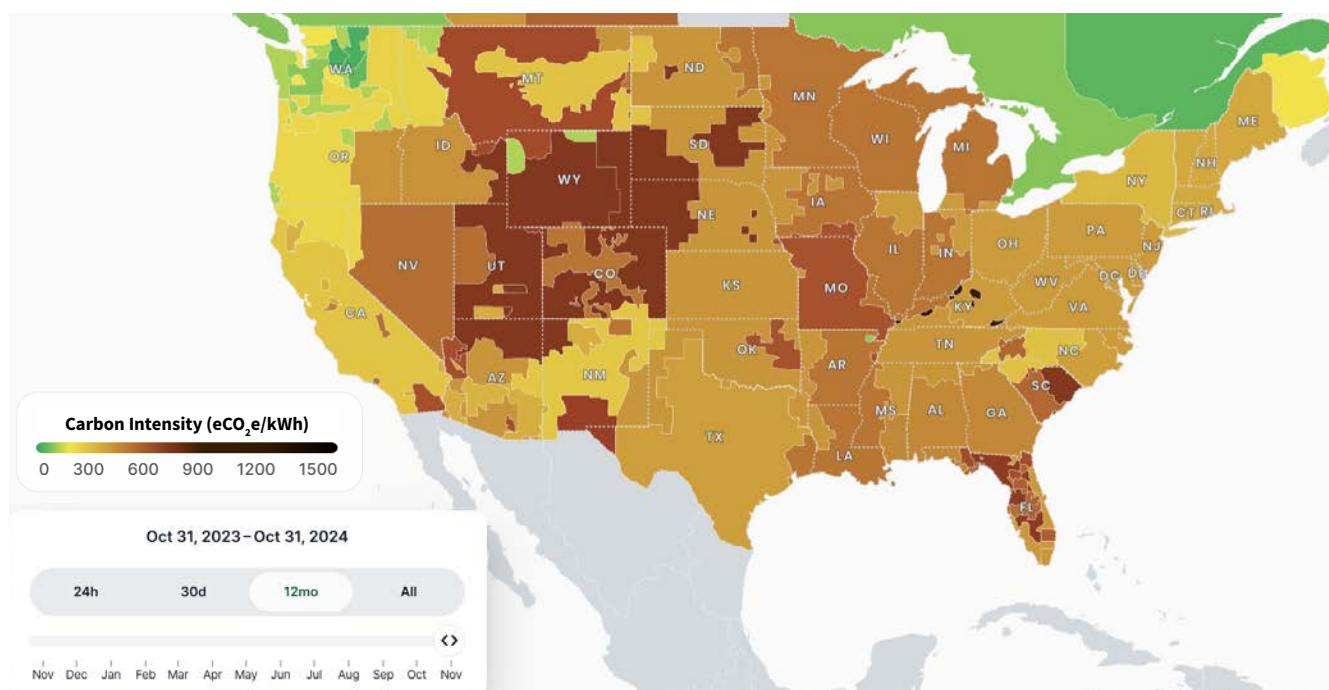
Overall, fossil fuels remain the most common fuel type for electricity production in the U.S., accounting for approximately 60% of generation. That is beginning to change as nuclear and renewables grow in popularity, as illustrated in [Figure 8](#).



This trend is also apparent in the average CI of electricity generation in the U.S., which has steadily declined since about 2005, as illustrated in [Figure 9](#).

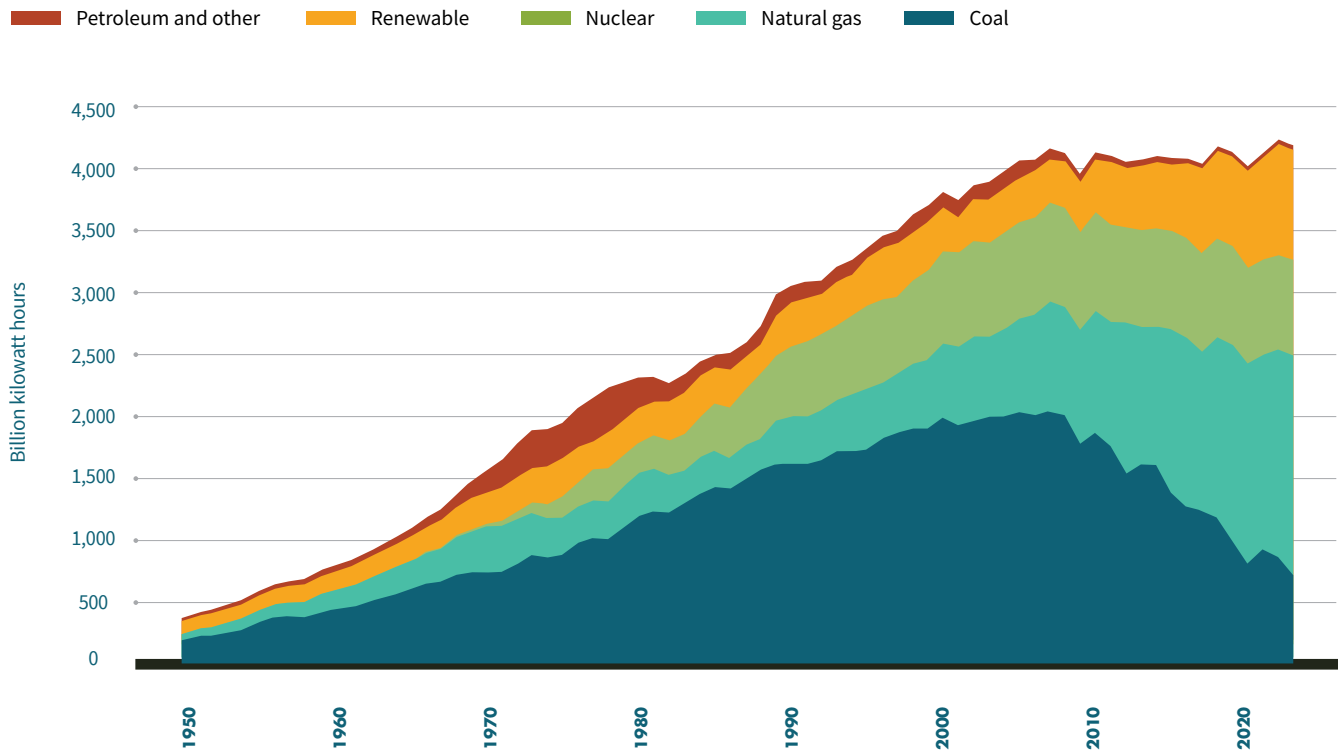
In terms of criteria air pollutants, BEVs completely eliminate tailpipe emissions of NO_x and PM_{2.5}, both of which are major contributors to urban air pollution and respiratory illnesses. Unlike combustion engines, BEVs do not require exhaust aftertreatment systems.

FIGURE 7: 12-MONTH AVERAGE CI OF ELECTRICITY CONSUMED, BY STATE



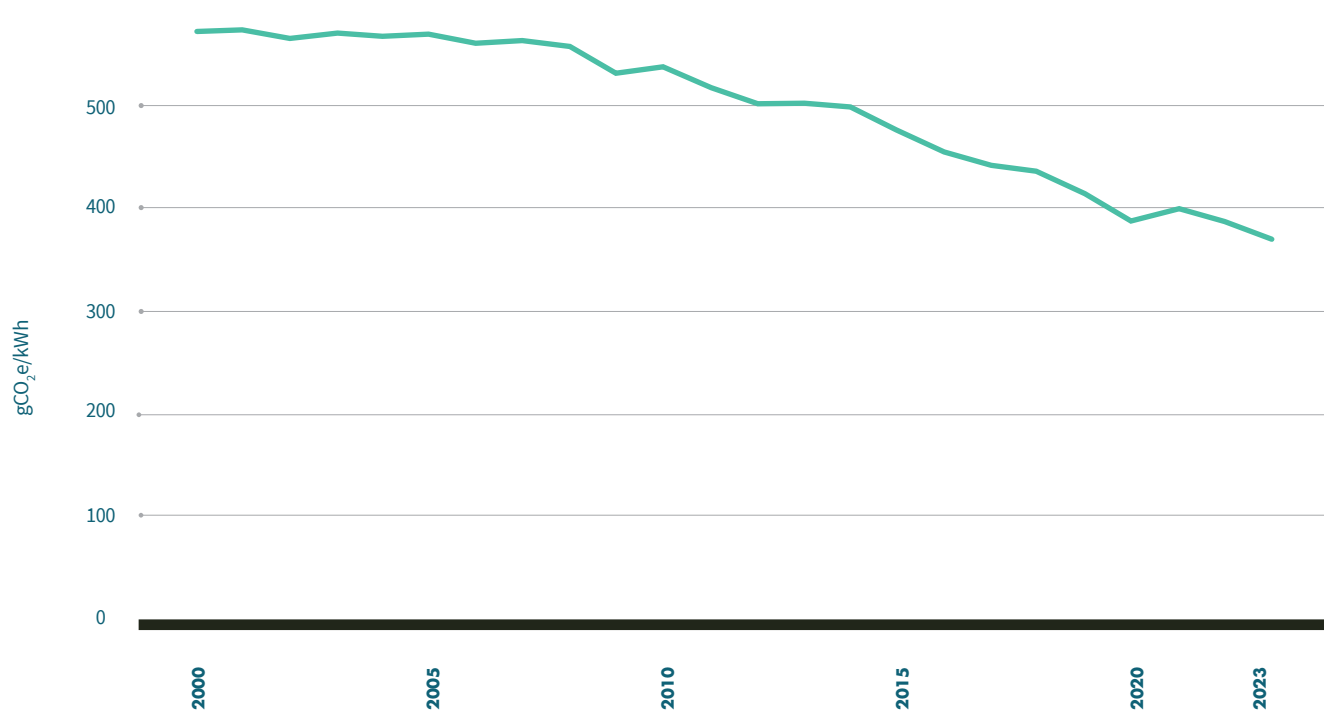
Source: Electricity Maps, <https://app.electricitymaps.com/map/12mo>

FIGURE 8: U.S. ELECTRICITY GENERATION BY MAJOR ENERGY SOURCE, 1950-2023



Source: U.S. Energy Information Administration, <https://www.eia.gov/energyexplained/electricity/electricity-in-the-us.php>

FIGURE 9: AVERAGE CI OF ELECTRICITY GENERATION IN THE U.S., 2000-2023



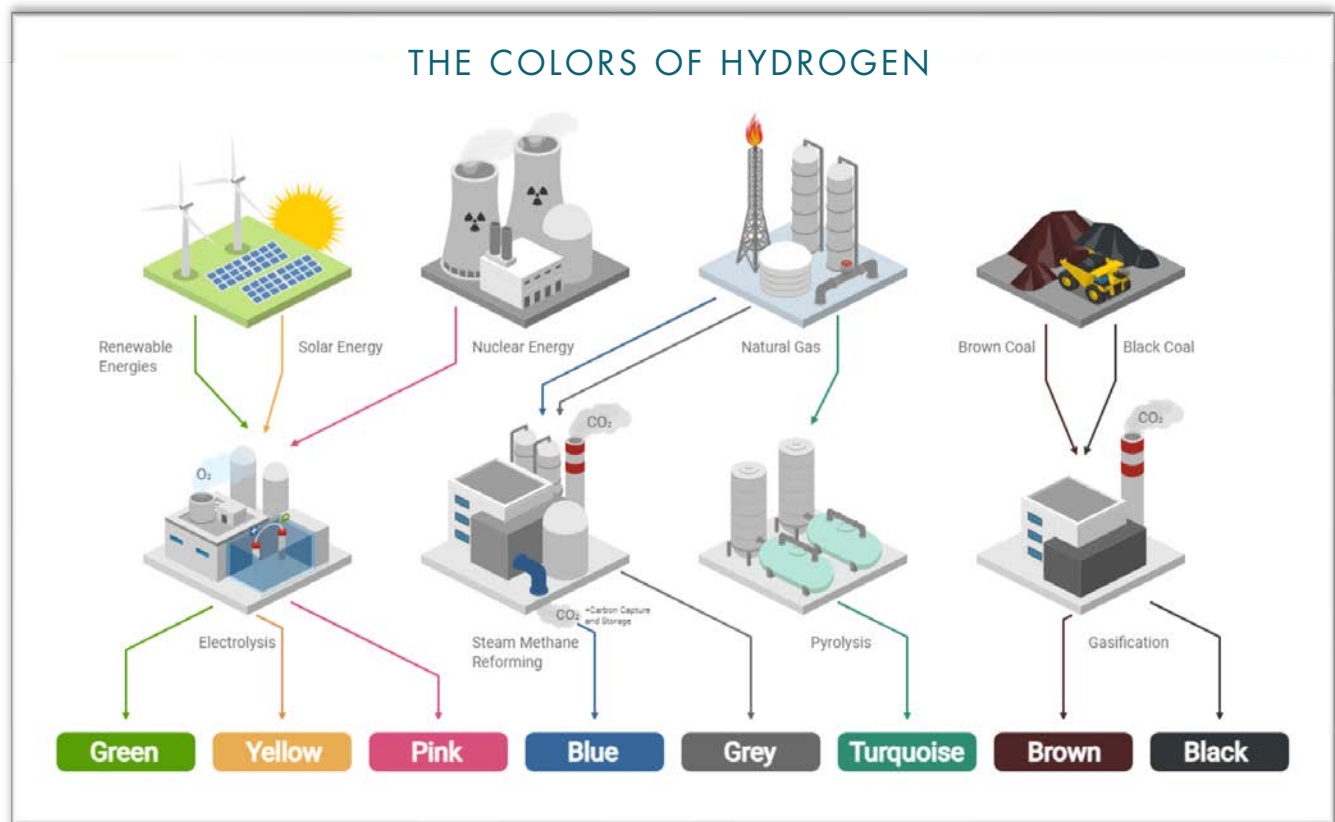
Source: Our World in Data, <https://ourworldindata.org/grapher/carbon-intensity-electricity?tab=chart&country=~USA>

3.5.2 FCEV IMPACTS

The GHG impact of FCEVs largely depends on the method of hydrogen production. While hydrogen is a colorless gas, the popular naming convention uses different colors to distinguish between production methods and feedstocks. [Figure 10](#) shows all the colors, but the most common are green, gray, and blue hydrogen. Green hydrogen, produced via electrolysis of water using renewable energy sources, offers the most significant emissions reductions but is currently limited in production and is the costliest of the options. Gray and blue hydrogen are both produced from natural gas using steam methane reforming; however, blue hydrogen adds carbon capture and storage to reduce the net processing emissions.

While production of green hydrogen is increasing (including through the development of regional green hydrogen hubs—see Section 3.3.2), currently about 95% of the hydrogen produced in the U.S. is gray hydrogen.⁶⁹

FIGURE 10: TYPES OF HYDROGEN



Source: *Icograms*, <https://icograms.com/templates/infographics/hydrogen-production>

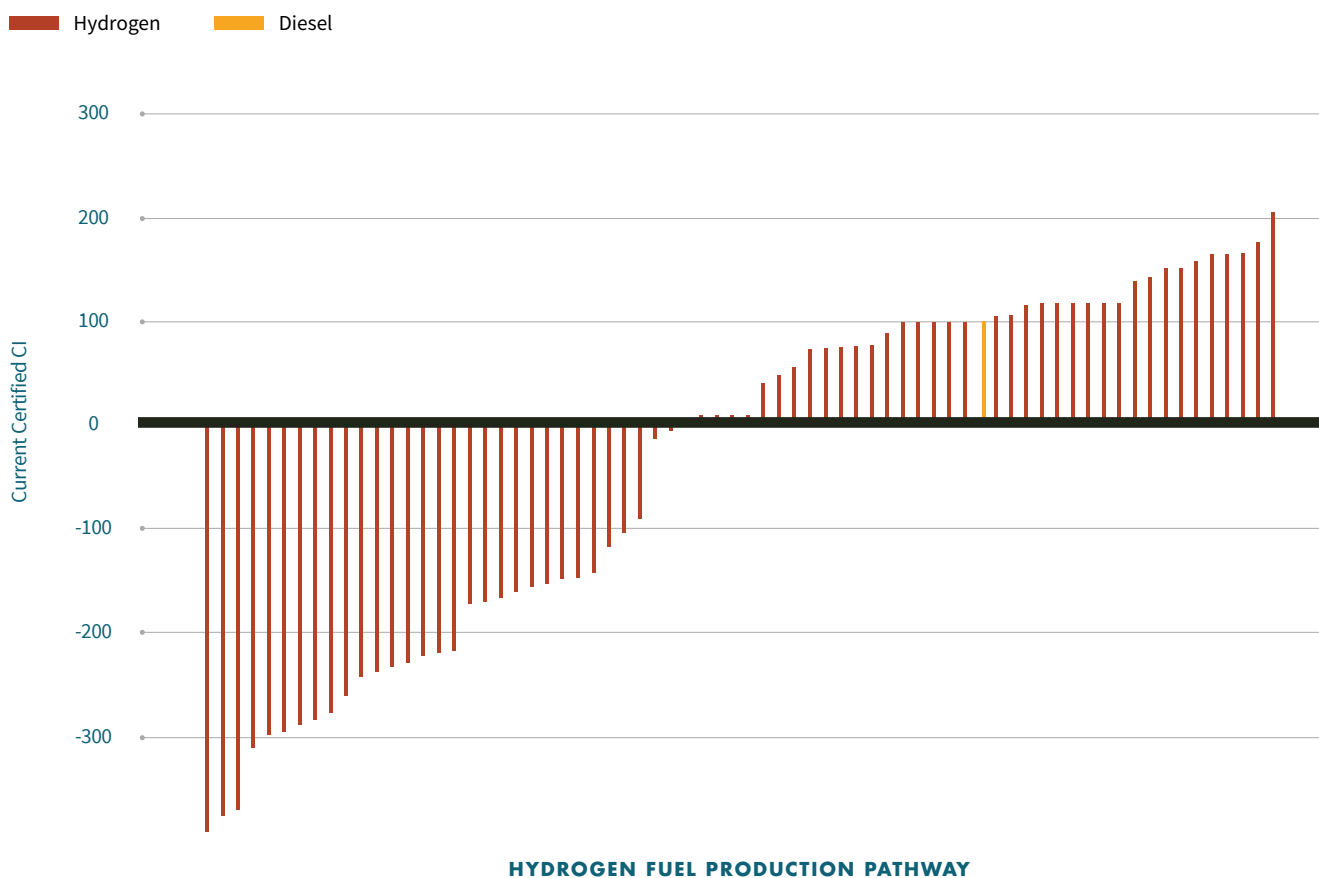
69 Hydrogen Interagency Task Force. 2024. *Introduction to Clean Hydrogen: The Potential Roles, Benefits, and Challenges of Clean Hydrogen*. <https://www.hydrogen.energy.gov/docs/hydrogenprogramlibraries/pdfs/hit-introduction-to-clean-hydrogen.pdf>.

The broad range of environmental impacts of different production methods of hydrogen is apparent based on the range of CIs of hydrogen fuels certified by the California Air Resources Board (CARB) for use in California, summarized below in [Figure 11](#). Each line represents a hydrogen fuel production pathway consisting of an associated fuel producer and facility, production method, feedstock, transportation method, and dispensing location.

FCEVs, like BEVs, produce zero tailpipe NO_x and PM_{2.5} emissions, making them a clean alternative for reducing local air pollution. Unlike diesel engines, hydrogen fuel cells do not involve combustion, meaning they do not generate NO_x emissions from high-temperature fuel burning.



FIGURE 11: CI RANGE OF HYDROGEN VS. PETROLEUM DIESEL (gCO₂e/MJ)



Source: California Air Resources Board

3.5.3 HEV IMPACTS

Diesel HEVs reduce GHG emissions by improving fuel efficiency, but they do not generally provide measurable reductions in NO_x or PM_{2.5} emissions relative to diesel in ICE vehicles equipped with modern emissions controls.

HEVs achieve 10–30% reductions in CO₂ emissions by lowering fuel consumption through engine optimization and regenerative braking. These reductions are most pronounced in stop-and-go applications, such as transit, refuse, and delivery vehicles, where hybrid systems reduce idling and improve fuel economy.

Despite lower fuel consumption, HEVs do not significantly reduce NO_x or PM_{2.5} emissions in vehicles equipped with advanced aftertreatment systems. Since HEVs still rely on diesel combustion, their NO_x and PM_{2.5} levels remain similar, and they require the same emissions control technologies as conventional diesel vehicles. Unlike BEVs and FCEVs, HEVs do not operate in zero-emission mode for extended periods, which limits their impact on air quality improvements. However, older HEVs without state-of-the-art emissions controls may offer some reductions in NO_x and PM by lowering overall fuel usage and optimizing engine performance.

3.5.4 BIODIESEL AND RD IMPACTS

The use of biodiesel and RD offer reductions in GHG emissions compared to petroleum diesel, though the exact reduction levels depend on the feedstocks and production processes used.

Note that while RD is often used at 100%, the use of B100 is becoming more common, with aftermarket conversion options. Biodiesel is still more commonly used in lower blends (up to B20), so actual GHG emissions reductions depend on the blend rate. On average, B20 provides around a 13.5% carbon reduction, while B100 offers an average 74% reduction in emissions.⁷⁰

California's LCFS Pathway Certified Carbon Intensities demonstrate that RD offers a significant environmental benefit, reducing carbon intensity by an average of 65% compared to conventional petroleum diesel. However, the carbon intensity of RD varies depending on the production process and feedstock used, as illustrated in Figure 12. For instance, RD produced from waste fats, oils, and greases generally achieves a lower CI compared to that derived from agricultural feedstocks like soy or canola oil. These differences reflect the variability in feedstock sourcing, production efficiency, and supply chain logistics, highlighting the importance of optimizing production pathways to maximize environmental benefits.

Common blend levels of biodiesel, represented in Figure 12, can be assessed using U.S. national averages of carbon intensity. While actual carbon intensities may vary, understanding the blend level differences is often most useful for fleet operators.

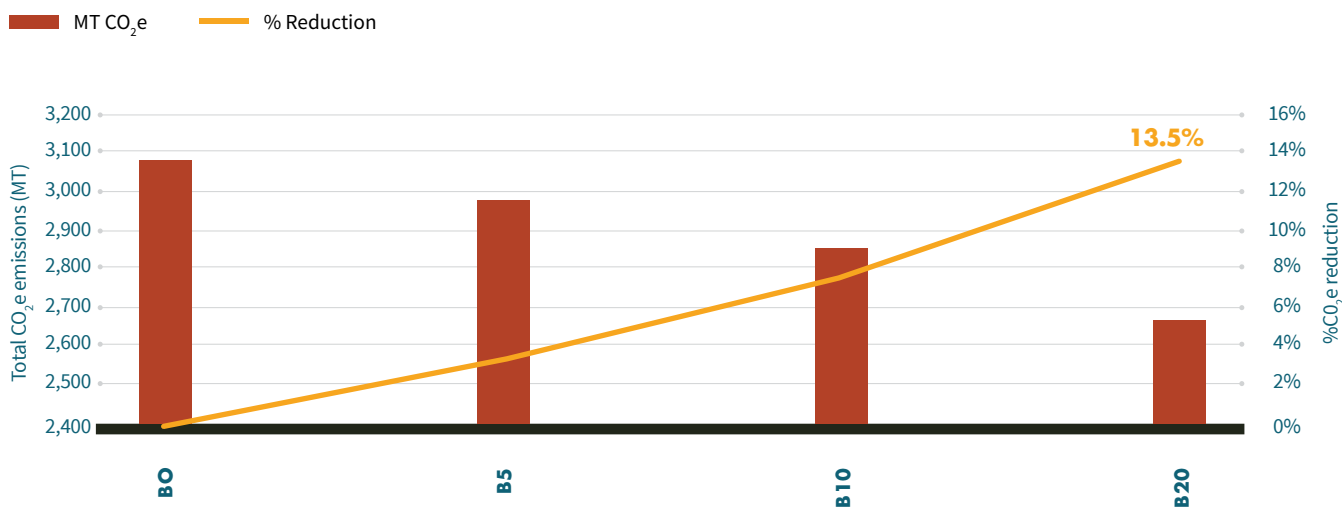
The air quality benefits of biodiesel and RD depend on whether the vehicle is equipped with modern emissions controls. While neither fuel provides measurable reductions in NO_x or PM_{2.5} emissions compared to petroleum diesel in vehicles with advanced aftertreatment systems, RD can offer significant NO_x and PM_{2.5} reductions in older heavy-duty engines and vehicles that lack state-of-the-art emissions controls.⁷¹

Biodiesel, especially in lower blends like B20, has also been shown to consistently reduce PM_{2.5} emissions

⁷⁰ Alternative Fuels Data Center. n.d. Biodiesel Vehicle Emissions. Accessed March 21, 2025. <https://afdc.energy.gov/vehicles/diesels-emissions#:~:text=Life%20cycle%20analysis%20completed%20by>.

⁷¹ University of Toronto. 2019. *Evaluation of the Impact of Using Biodiesel and Renewable Diesel to Reduce Greenhouse Gas Emissions in City of Toronto's Fleet Vehicles: Final Report*. <https://www.toronto.ca/legdocs/mmis/2019/ie/bgrd/backgroundfile-130965.pdf>.

FIGURE 12: CARBON MITIGATION WITH BIODIESEL (EXAMPLE: 250,000 GALLONS DIESEL AND BLENDS)



Source: TEI's Carbon Avoidance Tracker

compared to petroleum diesel in older or less technologically advanced engines. However, the effect on NO_x emissions can vary—blends up to B20 are typically considered neutral, while higher blends (B100) may increase NO_x emissions by up to 10%, depending on factors such as engine type and duty cycle.⁷²

3.5.5 CNG AND RNG IMPACTS

CNG and RNG provide environmental advantages over diesel due to their cleaner combustion, emitting fewer GHGs and air pollutants like NO_x. Although natural gas engines provide a decrease in PM_{2.5} emissions, this reduction may not be significant due to the effectiveness of well-maintained DPFs on modern diesel engines.

Natural gas produces approximately 27% less CO₂ per unit of energy compared to No. 2 diesel fuel.⁷³ Despite the lower CO₂ emissions per unit of energy, the overall efficiency of a heavy-duty natural gas engine is less than that of a comparable diesel engine,⁷⁴ and the need to compress natural gas for storage on vehicles must be considered.⁷⁵ Methane leakage during the upstream process in the natural gas supply system (pipelines and local distribution systems) also affects the net CO₂ benefit. The EPA estimates methane leakage to be 1.4%, although some estimates are higher. Efforts are ongoing to limit leakage and ensure equipment integrity, with certification available through organizations like MiQ.⁷⁶ Taking engine efficiency, upstream methane leakage, and gas compression into account, conventional natural gas use results in CO₂ savings of approximately 13–18% compared to standard diesel trucks.⁷⁷

72 U.S. Department of Energy. 2017. Biodiesel Basics. https://afdc.energy.gov/files/u/publication/biodiesel_basics.pdf?642b65deb7.

73 U.S. Energy Information Administration. 2024. Carbon Dioxide Emissions Coefficients. https://www.eia.gov/environment/emissions/co2_vol_mass.php.

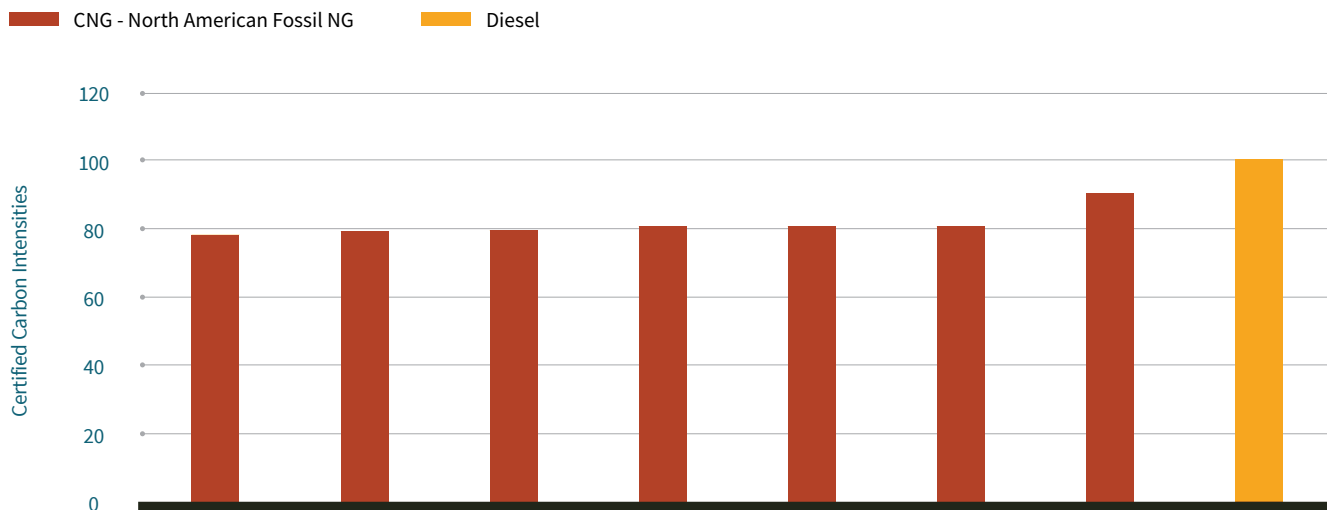
74 California Air Resources Board. n.d. Low Carbon Fuel Standard Regulation. Unofficial electronic version. Accessed March 21, 2025. https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcf_s_fro_oal-approved_unofficial_06302020.pdf.

75 North American Council for Freight Efficiency. n.d. Natural Gas And Greenhouse Gas Reduction. Accessed December 3, 2024. <https://nacfe.org/research/technology/powertrain/natural-gas-role-in-decarbonizing-trucking/>.

76 <https://miq.org/>

77 North American Council for Freight Efficiency. n.d. Natural Gas And Greenhouse Gas Reduction. Accessed December 3, 2024. <https://nacfe.org/research/technology/powertrain/natural-gas-role-in-decarbonizing-trucking/>

FIGURE 13: CI RANGE OF CNG VS. DIESEL (gCO₂e/MJ)



Source: California Air Resources Board

Figure 13 depicts a comparison of CNG and diesel based on the CI data from CARB’s LCFS Pathway Certified Carbon Intensities.⁷⁸ Diesel presents the highest CI, at over 100 gCO₂e/MJ. The CIs of CNG are consistent across each production pathway, as there is only one feedstock considered and one process for production. Each line in Figure 13 represents a fuel production pathway consisting of an associated fuel producer and facility, production method, feedstock, transportation method, and dispensing location. The CI of diesel fuel in the table represents the average crude oil supplied in California refineries and average California refinery efficiencies.

RNG enhances these GHG benefits even further by using feedstocks composed of organic waste. RNG derived from dairy manure can have CI values lower than -300 gCO₂e/MJ, compared to diesel’s 100 gCO₂e/MJ,⁷⁹ while RNG from landfill or wastewater sources typically ranges from 35 to 55 gCO₂e/MJ. Replacing only a quarter of a fleet’s diesel trucks

with trucks powered by RNG produced from dairy manure can reduce a fleet’s carbon emissions by 100%.⁸⁰

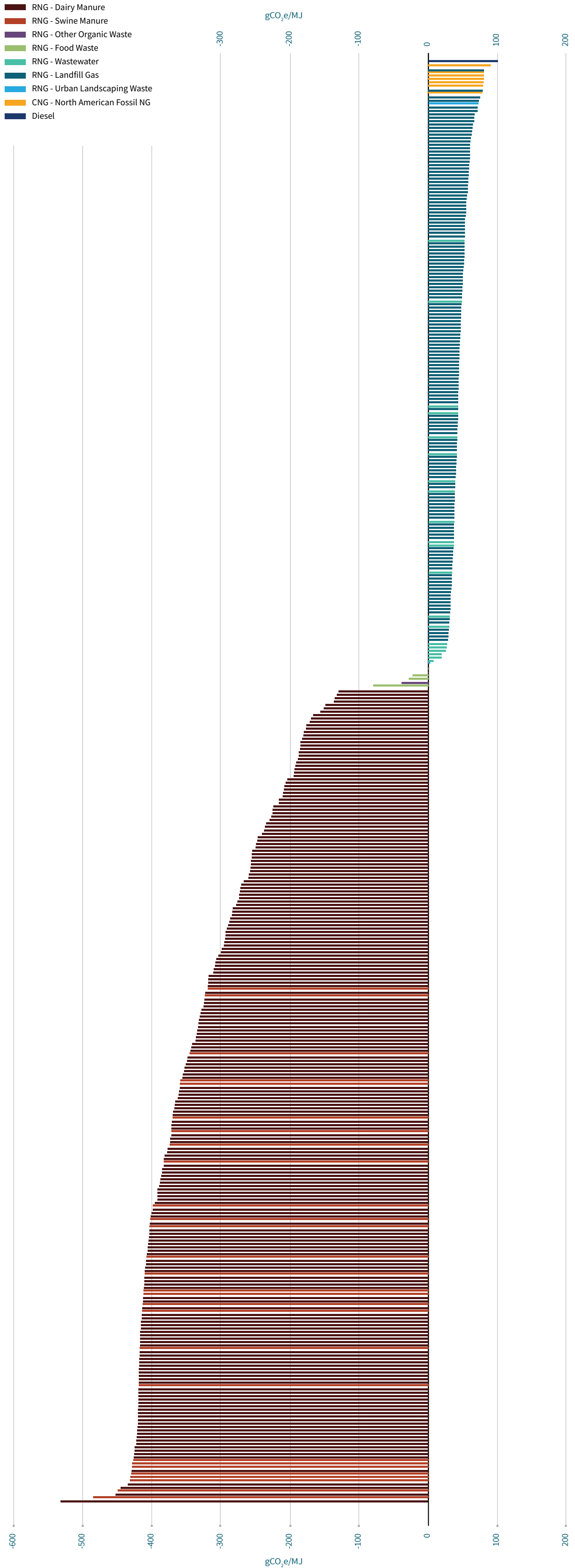
Figure 14 depicts the variability of CIs across commercially available feedstocks, ranging from -500 to 100 gCO₂e/MJ. Each line represents a fuel production pathway consisting of an associated fuel producer and facility, production method, feedstock, transportation method, and dispensing location. The CI of diesel fuel in the table represents the average crude oil supplied in California refineries and average California refinery efficiencies.

78 California Air Resources Board. Updated March 7, 2025. LCFS Pathway Certified Carbon Intensities. <https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities>.

79 FreightWaves. 2022. RNG Is Decarbonizing Trucking Today. <https://www.freightwaves.com/news/rng-is-decarbonizing-trucking-today>.

80 Burnham, A., Gohlke, D., Rush, L., Stephens, T., Zhou, Y., Delucchi, M. A., Birky, A., Hunter, C., Lin, Z., Ou, S., Xie, F., Proctor, C., Wiryadinata, S., Liu, N., and Boloor, M. 2021. Comprehensive Total Cost of Ownership Quantification for Vehicles with Different Size Classes and Powertrains. Argonne National Laboratory. <https://publications.anl.gov/anlpubs/2021/05/167399.pdf>.

FIGURE 14: CI RANGES OF RNG BY FEEDSTOCK VS. PETROLEUM DIESEL (gCO₂e/MJ)



Source: California Air Resources Board

3.6. REGULATORY LANDSCAPE

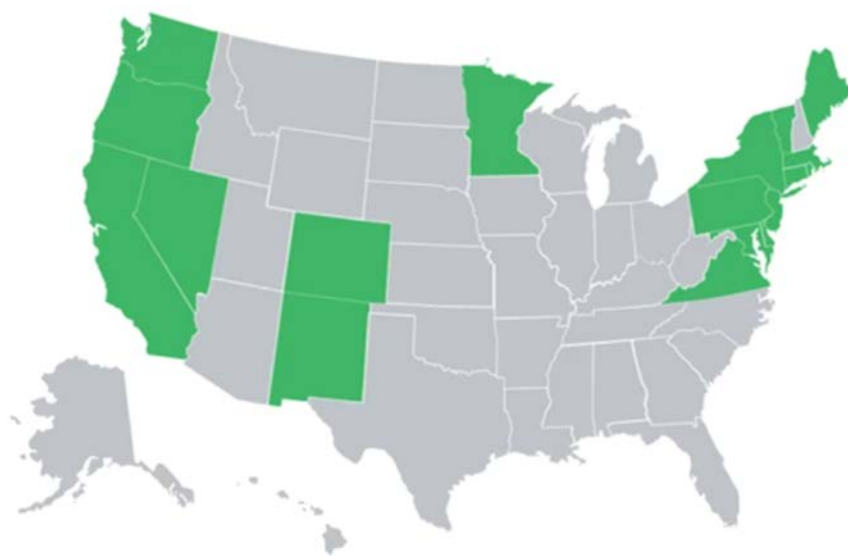
The regulatory landscape for MHDVs in the U.S. is rapidly evolving, with federal- and state-level initiatives shaping the path toward reduced GHG emissions and the widespread adoption of zero-emission technologies. While federal regulations set the national baseline, states like California have introduced more ambitious standards that are influencing nationwide trends.

The regulatory framework for MHDVs in the U.S. at the federal level is driven by the EPA and the NHTSA under the Clean Air Act (CAA) and the Energy Independence and Security Act of 2007 (EISA). The EPA’s Phase 1 and Phase 2 GHG emissions standards, implemented in 2014 and 2019, respectively, established baseline fuel efficiency and emissions reduction targets for medium- and heavy-duty trucks. These standards encouraged advancements in various areas, including engine, tire, and idle-reduction technologies. Additionally, Phase 2

established “technology-advancing standards,” which considered technologies that were currently being developed to further promote adoption. On March 29, 2024, the EPA issued the final ruling on Phase 3, introducing more stringent standards for model years 2028 through 2032 and targeting further GHG reductions in heavy-duty vocational vehicles and tractors.⁸¹ The regulation also proposed new performance standards for criteria air pollutants such as PM_{2.5} and sulfur dioxide (SO₂). The evolution of these standards reflects a sector-wide push for decarbonization and fuel efficiency improvements.⁸²

In California, federal emission regulations still apply; however, under the Clean Air Act of 1970, CARB was granted the authority to establish its own, stricter, emissions standards. Since then, CARB has been the leader in standards surrounding air quality, pollution, and GHG emissions. Seventeen other states have already adopted CARB emissions standards in full or in part (see [Figure 15](#)).

FIGURE 15: STATES THAT HAVE ADOPTED CARB EMISSIONS STANDARDS



Source: Calstart, https://calstart.org/wp-content/uploads/2024/05/ZIO-ZET-May-2024-Market-Update_Final.pdf

81 U.S. Environmental Protection Agency. Updated February 19, 2025. Regulations for Greenhouse Gas Emissions from Commercial Trucks & Buses. <https://www.epa.gov/regulations-emissions-vehicles-and-engines/regulations-greenhouse-gas-emissions-commercial-trucks>.

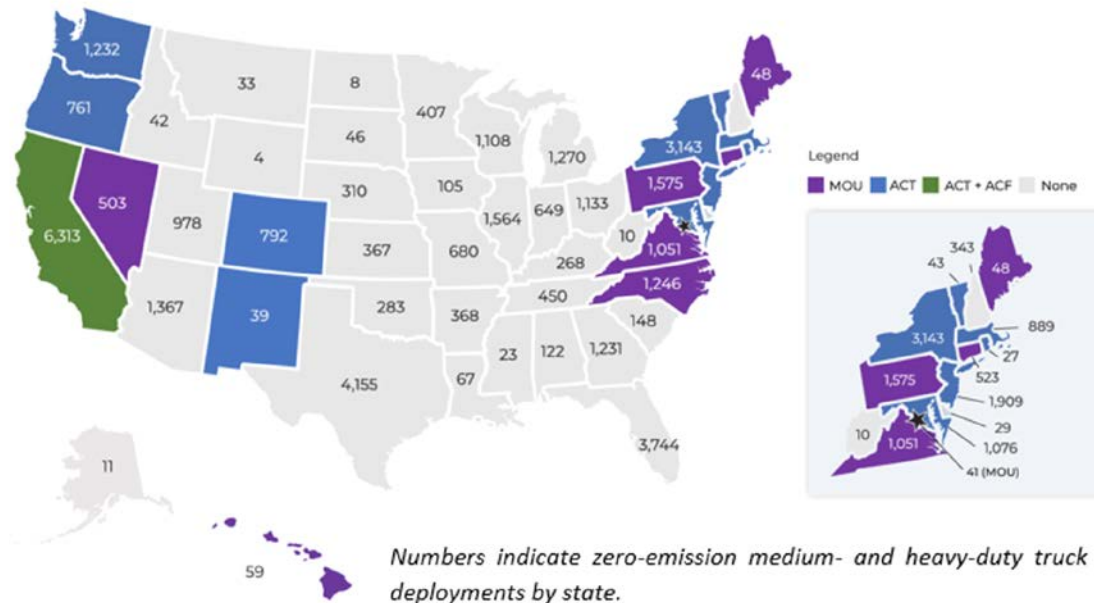
82 U.S. Environmental Protection Agency. Updated March 12, 2025. Final Rule: Greenhouse Gas Emissions Standards for Heavy-Duty Vehicles – Phase 3. <https://www.epa.gov/regulations-emissions-vehicles-and-engines/final-rule-greenhouse-gas-emissions-standards-heavy-duty>.

Additionally, in 2020, CARB passed the ACT rule, which requires manufacturers to meet an increasing percentage of MHDZEV sales beginning in 2024. CARB released sales targets for manufacturers, by vehicle class, to promote adoption and drive costs down long-term. These sales targets range from 5% in 2024 to over 40% in 2035 and beyond. The ACT rule has already been adopted by eleven states, accounting for 37% of all zero-emission truck (ZET) deployments nationwide despite these states representing only 27% of truck registrations. ACT requires manufacturers to sell an increasing number of ZEVs as a percentage of their overall truck sales to meet long-term adoption goals. Figure 16 below depicts which states have adopted ACT (blue), which states have signed the memorandum of understanding (MOU) indicating intent to adopt ACT (purple), and which states have not signed on (gray), as of June 2024.⁸³

CARB’s Advanced Clean Fleets (ACF) rule was intended to phase in the use of ZEVs for targeted fleets that are well suited for electrification; however, the state’s request to the EPA for a CAA waiver was withdrawn in January 2025. The regulation now applies only to government fleets, both state and local.

Deployment of ZETs has steadily increased, with over 42,500 deployed in the U.S. since January 2017. This represents less than 1% of the country’s 12.95 million trucks.^{84, 85} States vary significantly in their policy approaches, as seen in Figures 15 and 16. This variation highlights differing levels of policy ambition and commitment to decarbonization. The numbers in Figure 16 indicate deployments of medium- and heavy-duty ZETs by state. (Note that buses are excluded from these counts.)

FIGURE 16: STATES THAT HAVE ADOPTED CARB’S ACT REGULATIONS



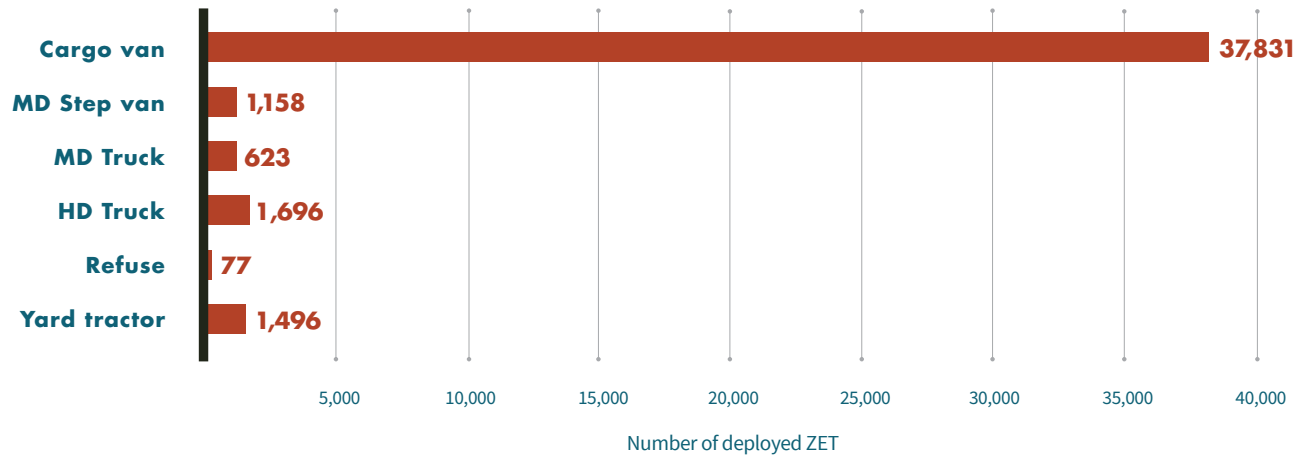
Source: Calstart, https://calstart.org/wp-content/uploads/2024/05/ZIO-ZET-May-2024-Market-Update_Final.pdf and <https://calstart.org/calstart-releases-january-2025-zero-emission-truck-market-update/>

83 Richard, J. 2024. *Zeroing In on Zero-Emission Trucks: January 2025 Market Update*. Calstart. https://calstart.org/wp-content/uploads/2025/01/January2025_ZIO-ZET_MarketUpdate_Final.pdf.

84 Al-Alawi, B., and Richard, J. 2024. *Zeroing In on Zero-Emission Trucks: Market Update, May 2024*. Calstart. https://calstart.org/wp-content/uploads/2024/05/ZIO-ZET-May-2024-Market-Update_Final.pdf.

85 Calstart. 2025. CALSTART Releases January 2025 Market Update on Zero-Emission Trucks. <https://calstart.org/calstart-releases-january-2025-zero-emission-truck-market-update/>.

FIGURE 17: CUMULATIVE U.S. ZET DEPLOYMENTS BY SEGMENT, 2017–2024



Source: Calstart, https://calstart.org/wp-content/uploads/2025/01/January2025_ZIO-ZET_MarketUpdate_Final.pdf CNG and RNG engines are positioned as transitional technologies within this framework. The EPA’s new Phase 3 criteria pollutant regulations will add cost and complexity to diesel engines, but natural gas engines have the capability to easily meet them. This advantage is expected to reduce the initial cost difference between natural gas and diesel options, improving the competitiveness of natural gas engines. Additionally, natural gas engines can be used as a tool to help OEMs meet the GHG Phase 3 regulations, as the net CO₂ benefit of natural gas is approximately 13–18% less than diesel counterparts. Despite these advantages, natural gas engines do not qualify under the ZEV mandates. However, paired with hybrid technology, they can qualify as near-zero-emission vehicles (NZEVs), allowing fleets to fulfill up to 50% of their ZEV purchase requirements with a hybrid or natural gas product.⁸⁴

As illustrated in [Figure 17](#), the majority of these are cargo vans. The popularity of ZEVs in this segment is largely due to their advantageous features including smaller batteries, high production volumes from multiple OEMs, favorable duty-cycle capability, and reduced up-front costs relative to other vehicle segments. Deployments of heavy-duty ZETs are increasing rapidly, likely driven by increased incentives for this thriving vehicle segment.

There are also nuances in the regulatory landscape for biodiesel. The fuel is regulated federally, under the EPA’s new production mandate. Tied to the Renewable Fuel Standard (RFS) program, the final rule requires refiners to blend 20.94 billion gallons in renewable fuel, which is a 120-million-gallon increase from the previous renewable volume obligations.⁸⁷ Further, new sustainable

agriculture rules, under the IRS’s section 45Z Clean Fuel Production Credit, will likely reduce the CI of agriculture-based biofuels over the coming years by providing a tax credit for U.S. production of clean transportation fuel that prioritizes sustainable agricultural practices.



⁸⁶ Seger, J., Otto, K., Phillips, S., Roeth, M., and Mihelic, R. 2024. *Confidence Report: Natural Gas’ Role in Decarbonizing Trucking*. North American Council for Freight Efficiency. <https://nacf.org/wp-content/uploads/2024/03/Nat-Gas-2024-Confidence-Report.pdf>.

⁸⁷ Melvin, J. (2023). US EPA ‘Lowers Ambitions’ to Chagrin of Biofuel Producers in Final RFS Rule for 2023–2025. S&P Global. <https://www.spglobal.com/commodity-insights/en/news-research/latest-news/crude-oil/062123-us-epa-finalizes-biofuel-blending-mandates-for-next-three-years>.



ASSESS THE OPTIONS Learn More

TOOLS

- **[Carbon Avoidance Tracker \(CAT\)](#)**: TEI's CAT program provides tailpipe, life cycle, and biogenic emissions results that calculate the metric tons of CO₂e avoided and overall percentage reductions of metric tons of CO₂e, and separates out biogenic emissions from fuels blended with biofuels.
- **[The Zero-Emission Technology Inventory \(ZETI\)](#)**: Searchable compendium of MHDZEVs available in the U.S. (and elsewhere), including both commercial and projected availability.
- **[Alternative Fueling Station Locator](#)**: The DOE's detailed map showing public refueling stations and fuel corridors for all alternative fuels addressed in this guide.
- **[Federal and State Laws and Incentives](#)**: Searchable database from the DOE of federal and state laws and incentives for alternative fuels and vehicles, air quality, fuel efficiency, and other transportation-related topics.

ADDITIONAL RESOURCES

- **[Zero-Emission Trucks: The Facts](#)**: A 2024 overview from Calstart of the state of zero-emission freight vehicles in the U.S., including supply and demand. It also summarizes progress being made on charging and hydrogen refueling infrastructure deployment and utilities' ability to serve the new electricity demand created by truck electrification.
- **[Zeroing In on Zero-Emission Trucks](#)**: Calstart's 2024 report provides a comprehensive overview of the current state of the U.S. market. This

includes a summary of the current market, as well as a summary of the current state incentive programs and utility make-ready programs available across the country.

- **[The Messy Middle](#)**: A Time for Action: NACFE explored the myriad powertrain options available to fleets in fleet operations. This report contains an analysis of the benefits and challenges of each option and lays out the factors fleet managers need to consider when deciding which technologies to deploy in their operations.
- **[Amping Up](#)**: Charging Infrastructure for Electric Trucks: This 2019 report from NACFE highlights the key factors influencing charging infrastructure planning decisions for commercial BEVs.
- **[A Trucking Fleet Primer for Commercial Truck Electrification](#)**: This NACFE primer provides fleet owners with the resources needed to transition to electric trucks. It covers key considerations, including where electric trucks are best suited, cost of ownership, and infrastructure requirements.
- **[Biodiesel Handling and Use Guide](#)**: NREL's sixth edition of this guide for those who blend, distribute, and/or use biodiesel and biodiesel blends.
- **[Road to Zero: Research and Industry Perspectives on Zero-Emission Commercial Vehicles](#)**: A comprehensive overview of MHDZEVs from research (NREL) and industry (Volvo Group North America) professionals.
- **[Exploring Hydrogen's Role in Heavy-Duty Trucking](#)**: Primer on what is required to deploy hydrogen-fueled heavy-duty vehicles, from Resources for the Future.



SECTION 4.

Estimate Costs

Understanding the costs associated with deploying alternative powertrain vehicles requires a detailed, market-segment-specific, and region-specific analysis. The **AltFleet Economic Insight Tool** is available on the TEI's website to support fleet operators in estimating overall costs and comparing options.

4.1. POWERTRAIN AND FUELS ECONOMICS

4.1.1 BEV ECONOMICS

For MHD BEVs, higher capital costs are typically offset by lower operational expenses for charging and maintenance over the vehicle's lifetime. Prices of MHD BEVs are expected to continue coming down due to improvements in battery technology and evolving regulations that are leading to increased production volumes.

Electricity pricing for charging can vary across jurisdictions depending on the utility rate structure. Charging costs are typically measured in kilowatt-hours (kWh), and some jurisdictions offer time-of-use pricing, where electricity is cheaper during off-peak hours when the utility has excess capacity. In addition to the cost of electricity consumed in kWh, utilities often charge a monthly fee called a demand charge. This fee is based on the highest power load (in kW) consumed during any 15-minute interval in the month.

The demand charge incentivizes consumers to stagger their power consumption to avoid peak loads. For EV fleets, this means it is cost-effective to spread charging throughout the day rather than charging all vehicles simultaneously over a short period using high-power chargers. In other words, fleet owners can minimize costs by charging at lower power levels, which reduces both operational costs (via a lower demand charge) and capital costs (by lowering the expense of charging stations and grid upgrades). The AltFleet Economic Insight Tool allows users to select the number of chargers at different power levels required for deployment, as well as the costs of charger installation and any necessary grid upgrades.

As of 2024, financial incentives are crucial to making BEV technology economically viable for most MHDV applications, especially in large deployments requiring significant grid upgrades. In the U.S., operators can access both federal and state incentives where available (see Section 4.2). This financial support can greatly reduce the costs associated with vehicle purchases and the deployment of charging infrastructure. States with LCFS programs allow for the generation of compliance credits for BEV charging. Outside of LCFS states, credits may also be generated under the expanding voluntary carbon market (VCM) programs.

Depending on the MHDV application, incentive programs, and the regulatory structure of local utilities, fleets are financially responsible for different portions of grid upgrades. These upgrade costs can vary significantly between states, necessitating a thorough assessment by fleet operators. This topic is explored in greater detail in Section 8.1.

4.1.2 FCEV ECONOMICS

MHDFCEVs currently face high capital costs due to the early stage of fuel cell technology and lower production volumes. These costs are expected to decrease as the technology advances and economies of scale are realized, following a trajectory similar to BEVs.

Hydrogen fuel, particularly green hydrogen produced from renewable sources, remains too expensive to compete with diesel at present, though production costs are expected to decline with increased investment in hydrogen infrastructure and technology. The U.S. is aiming to reduce the cost of clean hydrogen to \$1 per kilogram within a decade.⁸⁸ Some states play a larger role in hydrogen production than others, but pump prices vary based on the type of hydrogen produced (i.e., green, blue, or gray) and distribution costs. Public hydrogen prices in California have ranged between \$9 and \$15, reaching as high as \$30 in 2024. The AltFleet Economic Insight Tool uses default average costs from the limited number of public hydrogen stations in the U.S. to estimate fleet fuel expenses, though actual prices may differ regionally and should be confirmed with a fleet's fuel provider.

Like BEVs, MHDFCEVs are expected to benefit from lower maintenance expenses at maturity due to fewer moving parts in the drivetrain. Federal and state incentives help reduce both vehicle acquisition costs and the expenses related to refueling infrastructure, improving the feasibility of MHDFCEVs

⁸⁸ Dodd, D. 2024. "Could Clean Hydrogen Become Affordable at Scale by 2030?" Harvard Business School Working Knowledge. <https://www.library.hbs.edu/working-knowledge/could-clean-hydrogen-become-affordable-at-scale-by-2030>.

for pilot projects and larger-scale operations. For fleets installing depot refueling infrastructure, the AltFleet Economic Insight Tool allows users to input total costs and apply subsidies to limit infrastructure expenses. This topic is explored further in Section 8.2.

4.1.3 HEV ECONOMICS

Hybrid electric MHDVs offer a middle ground between traditional diesel vehicles and fully electric alternatives, balancing fuel savings with operational flexibility. While capital costs for diesel HEVs are higher than those of conventional diesel trucks—due to the addition of battery packs, electric motors, and power electronics—they remain lower than the costs of BEVs or FCEVs. Depending on duty cycles, MHDHEVs can achieve fuel efficiency improvements of 10–30%, leading to significant lifetime fuel savings. Additionally, hybrid powertrains reduce wear on components such as brakes, lowering maintenance expenses compared to standard diesel models.

Unlike BEVs, HEVs do not require dedicated charging infrastructure, making them easier to integrate for fleets without depot charging capabilities. However, the economic viability of HEVs depends on the application, with the greatest benefits seen in stop-and-go urban operations such as refuse collection, delivery, and transit, or in undulating or hilly terrain, where regenerative braking can be maximized.

State and federal incentives for hybrid MHDVs are more limited than those available for BEVs or MHD FCEVs. However, some regional programs offer support through fuel efficiency grants and low-emission vehicle incentives, improving the financial outlook for fleets adopting HEV technology. The AltFleet Economic Insight Tool incorporates default values for HEV fuel savings, maintenance reductions, and component lifespans, enabling fleet operators to compare cost-effectiveness across regions and applications.



4.1.4 BIODIESEL AND RD ECONOMICS

The cost of vehicles using biodiesel (B20) and RD (R99) is generally the same as for those running on conventional diesel. The key difference in overall economics comes from the cost of the fuel itself, which can vary based on several factors. Higher biodiesel blends may also require additional investments in vehicle upgrades and fueling infrastructure, further impacting overall costs.

The cost of producing biodiesel and RD is directly influenced by the price of feedstocks, such as soybean oil, canola oil, and animal fats. Additionally, production and distribution costs play a significant role, with regional production capacity and transportation logistics impacting the fuel prices paid by operators across different states. Government policies are another key factor in shaping these costs.

Federal programs like the RFS establish nationwide volumetric blending standards for refiners and importers (obligated parties) of gasoline and diesel. Nonobligated parties (downstream fuel blenders) may opt in to the RFS and become incentivized to blend high levels of biofuels via the renewable identification number (RIN) credit. The RINs can then be sold to obligated parties so they can meet their federal requirements.

State-level initiatives—such as California’s and Oregon’s LCFSs—provide carbon-based compliance credits and broader incentives that extend beyond blending requirements. Additionally, the VCM has emerged as a system where companies and organizations voluntarily buy and sell carbon credits to offset their GHGs. Unlike compliance programs, the VCM operates independently of regulatory mandates and is particularly relevant in regions without LCFS programs. While VCM credits cannot be stacked with compliance credits like RINs or LCFS credits due to regulatory restrictions, they can provide an alternative revenue stream for projects that generate measurable carbon reductions outside regulated programs.

It is important to note that compliance-based credits—such as RINs under RFS and LCFS credits—can be stacked with the IRS’s new Clean Fuel Production Credit (45Z) to further reduce the price of low-carbon fuels. The recently introduced 45Z credit, set to replace the Biodiesel Blenders Tax Credit (BTC) in 2025, is another federal incentive aimed at rewarding low-carbon fuel production. Unlike compliance-based incentives, VCM credits function separately from these regulatory programs and cannot be combined with RFS or LCFS credits for the same emissions reductions.

Market supply and demand also affect pricing. For example, during periods of oversupply, biofuel prices can drop significantly, while limited supply can drive prices up. The AltFleet Economic Insight Tool developed to complement this report uses historical market trends to set default prices for biodiesel and RD across states.

As of June 2024, with the market oversupplied for RD and various compliance incentives in place, biofuels are reaching price parity with diesel in certain states. This allows fleet operators to access biodiesel and RD at prices similar to those of conventional diesel, making these fuels a cost-effective option. However, the expiration of the federal BTC at the end of 2024 introduces uncertainty in long-term pricing, as the loss of this incentive could lead to price increases depending on market conditions and future policy decisions. While the BTC is currently set to be replaced by the performance-based Clean Fuel Production Credit (45Z), there is ongoing discussion in Congress about extending the BTC, further adding to the policy uncertainty. Users of the tool can override these default values with prices provided by their fuel provider.



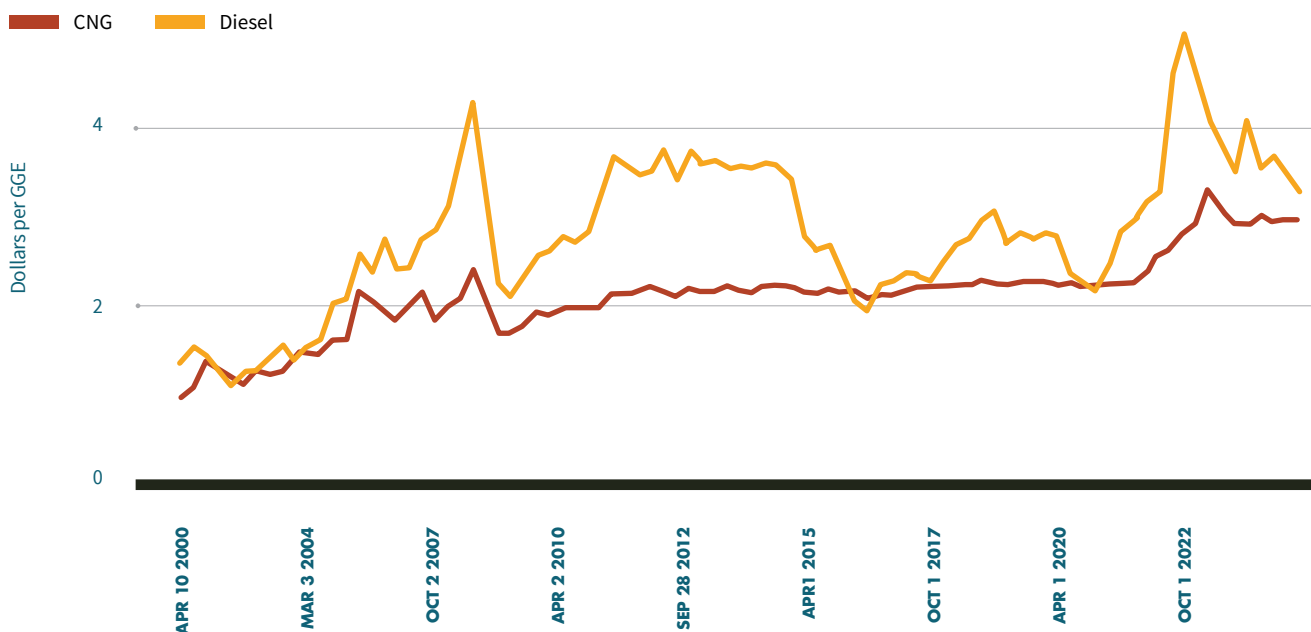
4.1.5 CNG AND RNG ECONOMICS

For CNG vehicles, capital costs are typically higher than those for diesel vehicles, but these expenses can be offset by fuel savings over the vehicle’s lifetime.⁸⁹ One significant advantage of CNG is its lower cost compared to gasoline or diesel, with CNG historically 30–50% cheaper than diesel per gasoline gallon equivalent (GGE).⁹⁰ Additionally, CNG fuel prices have historically been less volatile than diesel, as a smaller share of pump prices is driven by commodity price swings. This can provide fleets with more predictable long-term fuel costs.⁹¹

However, historical pricing trends show that CNG’s price advantage has fluctuated over time, particularly in response to major shifts in crude oil prices. For instance, the sharp decline in crude oil prices around 2014–2016 led to lower diesel prices, reducing the cost advantage of CNG and slowing adoption. Some analysts argue that the real driver of CNG’s decline in the past decade was not its own price volatility but rather the collapse in diesel prices. [Figure 18](#) illustrates historical CNG prices versus diesel prices, highlighting key market shifts. While CNG has generally remained lower than diesel, concerns remain about whether CNG prices could spike above diesel again. Current pricing outlooks for natural gas vary, with some industry experts remaining cautious due to past market disruptions.

Maintenance costs for NGVs vary: Some reports show similar or slightly lower costs compared to diesel, while others indicate slightly higher costs.

FIGURE 18: AVERAGE RETAIL FUEL PRICES IN THE U.S., 2000–2024



Last update: December 2024

Source: DOE Alternative Fuels Data Center, <https://afdc.energy.gov/fuels/prices.html>

89 FreightWaves. 2024. RNG Is Decarbonizing Trucking Today. <https://www.freightwaves.com/news/rng-is-decarbonizing-trucking-today>.

90 North Carolina Clean Energy Technology Center. 2015. Alternative Fuel Tool Kit—How to Implement: Compressed Natural Gas. <https://nccleantech.ncsu.edu/wp-content/uploads/2018/06/CNG-Chapter3.pdf>.

91 Transport Project. n.d. Start Now. RNG Is How! Accessed December 3, 2024. <https://transportproject.org/rng-is-how/>.

For MHDV fleets operating in regional or urban duty cycles, return-to-base fueling is the most common approach, as vehicles can refuel at a central location rather than relying on public stations. However, successful depot fueling depends on high utilization to offset infrastructure costs. The cost of installing CNG fueling stations varies widely, ranging from \$10,000 for a basic time-fill station to over \$2 million for a fast-fill station. Major cost drivers for CNG fueling infrastructure include compression equipment, storage vessels, and installation labor, with compression equipment costs ranging from \$20,000 to over \$100,000, and high-pressure storage vessels adding \$50,000 to \$100,000, depending on capacity. Additional site-specific factors, such as land preparation, utility upgrades, and permitting, can represent 10–30% of the total project cost.⁹²

To mitigate these infrastructure costs, fleets can enter into partnerships with fuel providers, where the provider shares in the capital investment of building fueling infrastructure in exchange for a long-term fuel supply commitment. Such agreements can help fleets reduce up-front costs while ensuring reliable access to CNG or RNG at stable pricing over the contract period. For fleets with dispersed operations or long-haul duty cycles, access to a reliable public CNG fueling network remains a key consideration. Public station availability and fuel pricing structures vary by region, influencing the overall cost-effectiveness of CNG adoption for different fleet applications.

Transitioning to NGVs is often a long-term strategy, with a more than 10-year investment horizon needed to recover the initial costs, particularly for fleets investing in depot refueling infrastructure. For fleets intending to install depot refueling

infrastructure, the AltFleet Economic Insight Tool allows users to input the total cost along with subsidies that can help limit these infrastructure costs.

RNG, which can use the same infrastructure as CNG, generally faces higher production costs and supply constraints, making the price three to five times higher than conventional natural gas.⁹³ However, government subsidies and compliance credits, such as RINs under the RFS and state-level programs like California’s LCFS, help narrow this cost gap by supporting RNG production and driving demand, significantly offsetting the difference in effective pricing. RNG production is expanding across the U.S. and is expected to more than double by 2030 despite high production costs, feedstock availability, and the complexity of regulatory approvals contributing to significant up-front investment requirements and financing difficulties for RNG projects.^{94,95} Further, the book-and-claim system, where environmental attributes of RNG can be sold separately from the physical gas, provides flexibility to move RNG attributes.

4.2. INCENTIVES

Before exploring state-specific incentives, it’s important to understand the federal programs that support capital costs for both vehicle purchases and infrastructure across various alternative powertrains, including ZEVs and low-emission vehicles. The federal tax credit for commercial clean vehicles under Internal Revenue Code (IRC) section 45W offers up to \$40,000 in tax credits for new ZEVs with a GVWR of 14,000 pounds or more (Class 4), and up to \$7,500 for lighter ZEVs. This credit helps reduce the initial purchase cost of BEVs and FCEVs, making them more competitive with traditional combustion

⁹² Smith, M., and Gonzales, J. 2014. *Costs Associated With Compressed Natural Gas Vehicle Fueling Infrastructure*. U.S. Department of Energy. <https://www.nrel.gov/docs/fy14osti/62421.pdf>.

⁹³ Seger, J., Otto, K., Phillips, S., Roeth, M., and Mihelic, R. 2024. *Confidence Report: Natural Gas’ Role in Decarbonizing Trucking*. North American Council for Freight Efficiency. <https://nacfe.org/wp-content/uploads/2024/03/Nat-Gas-2024-Confidence-Report.pdf>.

⁹⁴ Transport Project. n.d. *Better Than Zero*. Accessed March 21, 2025. <https://transportproject.org/wp-content/uploads/2024/10/Achieve-Better-Than-Zero-with-RNG-10-10-24.pdf>.

⁹⁵ Smith, M., and Gonzales, J. 2014. *Costs Associated with Compressed Natural Gas Vehicle Fueling Infrastructure*. U.S. Department of Energy. <https://www.nrel.gov/docs/fy14osti/62421.pdf>.



vehicles. However, it should be noted that the future of many federal clean vehicle incentives remains uncertain, as ongoing policy discussions may impact their renewal or modification.

Although the IRC 45W credit does not extend to CNG vehicles, these vehicles can benefit from other capital incentives, such as the Alternative Fuel Vehicle Refueling Property Credit, which covers up to \$100,000 per qualifying piece of refueling or charging infrastructure. This credit supports the initial capital investment in CNG/RNG, hydrogen, or charging stations, reducing the high up-front costs of infrastructure development. The credits are applied against the company's total tax liability and can be carried forward to future years if not fully used, making them valuable tools to offset the cost of alternative fuel deployments.

State-level programs offer a diverse array of incentives targeting vehicles, infrastructure, fuels, or all of these, with significant variations in their administration. These range from straightforward point-of-sale vouchers that provide an immediate discount on the purchase price to rebates that

require buyers to pay the full cost up-front and later receive a partial refund. Vouchers simplify the buying process by reducing costs directly at the point of sale, while rebates involve submitting claims and waiting for reimbursement. More complex are grants, which typically necessitate a competitive application process, detailed proposals, and potential matching funds, and which support larger-scale projects that demand careful planning and oversight. A number of states also have grants for new low-carbon liquid fuel infrastructure as well as road tax exemptions. Each state program varies on who in the fuel supply chain is eligible and what equipment is covered. It is important to verify the status of state funding, as some programs have deadlines and sunset dates.

Many state programs emphasize a clear prioritization of BEV and FCEV technologies. While infrastructure-specific funding remains somewhat limited, several states have initiated BEV-focused utility-led make-ready programs, which are described in Section 6.1. These initiatives enable utilities to absorb a greater share of the costs associated with deploying charging infrastructure, particularly for essential grid upgrades that can be prohibitively expensive

for fleet operators. By reducing infrastructure costs, these state-funded utility programs make vehicle-only incentives more feasible for various market applications.

Other states may be more supportive of agriculture-based biofuels, which support the local economy, and offer numerous incentives for higher levels of biofuel blending.

The Alternative Fuels Data Center maintains a searchable database of federal and state laws and incentives. Please see Learn More at the end of this section for more information on this tool.

4.3. UNCERTAINTY IN ESTIMATING ALTERNATIVE FUEL DEPLOYMENT COSTS

The estimation of costs associated with the deployment of alternative fuels in a fleet includes both hard and soft costs, with soft costs being more difficult to quantify. Depending on the powertrain deployed, varying hard costs include the price of vehicles, charging/refueling infrastructure, fuel, and maintenance. For most of these factors, estimates can be obtained by consulting manufacturers or projecting fuel costs, which can be hedged if needed. While maintenance and repair costs have become more established for more mature low-emission technologies such as CNG, they remain challenging to establish for more recent technologies like BEVs and FCEVs.

Battery electric and hydrogen fuel cell technologies are anticipated to have lower maintenance costs over time because they have fewer moving parts. However, during the early stages of adoption, these technologies often require higher maintenance, due to limited technician familiarity, diagnostic challenges, and longer wait times for specialized parts making regional access to skilled technicians and readily available parts essential. This variability across regions adds to uncertainty, which also influences insurance premiums, which are currently difficult to estimate. For smaller operators,

vehicle pricing poses additional challenges, as the secondary market for these emerging technologies has yet to develop. The absence of a robust resale market additionally contributes to financial institutions' reluctance to offer favorable loans, often resulting in zero residual value assumptions and higher monthly payments for ZEVs.

Soft costs include investments in staff training to adapt to new operational practices and more intensive software use for tracking vehicle and infrastructure performance. While these measures can increase costs initially, they enable efficiencies such as remote maintenance. From a driver's perspective, alternative fuel technologies often enhance comfort by reducing vibrations, odors, and noise—factors that can support driver retention but are difficult to quantify economically. Lastly, fleet decisions often consider the value of public perception, as adopting ZEVs aligns with sustainable practices and demonstrates a commitment to environmental responsibility.



4.4. ALTFLEET ECONOMIC INSIGHT TOOL

4.4.1 POWERTRAIN AND MARKET APPLICATIONS

The AltFleet Economic Insight Tool enables users to select their MHDV market segment and assess the economic implications of deploying alternative fuel technologies using a one-to-one replacement strategy. The goal of the tool is to allow fleet operators to evaluate the financial and emissions reduction impacts of small-scale pilot deployments of alternative fuel technologies while taking advantage of available financial incentives.

The tool includes 31 different MHDV applications for which default values are provided, categorized as presented below. The tool covers diesel, biodiesel (B20), RD (R99), and battery electric technologies for all applications. Gasoline, hybrid, CNG/RNG, and hydrogen fuel cell powertrains are only available for selected market applications, depending on data and market availability.

I – Passenger Transport

- **School Bus:** Specifically designed for transporting children to and from school and school-related activities (Type A, C, D)
- **Public Transit:** Includes vehicles used in municipal bus services (Class 8, 40 ft)
- **Passenger Van:** Smaller than buses, these are used for transporting smaller groups (Classes 3 and 4)
- **Shuttle Bus:** Used for short trips such as airport shuttles or hotel transport (Class 4)
- **Coach Bus:** Used for longer-distance travel, often equipped with storage and comfortable seating (Class 8)

II – Freight and Cargo Handling

- **Cargo Van:** Designed for transporting goods in urban settings (Classes 2b–4)

- **Chassis Cab:** Base vehicles that can be fitted with various cargo bodies or equipment (Classes 2b–7)
- **Box Truck:** Enclosed truck for transporting goods, often used by moving companies and couriers (Classes 4–8)
- **Step Van:** Typically used for delivery services where frequent entry and exit is necessary (Classes 2b–6)
- **Tractor:** The driving unit of a semitrailer truck (Class 8, regional and long haul)

III – Specialized Services

- **Refuse:** Garbage trucks designed for waste collection (Class 8)
- **Fire Truck:** Equipped with firefighting apparatus and often emergency medical equipment (Class 8)

4.4.2 HOW TO USE THE TOOL

Users should begin by navigating through the sections of the tool, starting with specifying their market of operations by selecting their state or territory, vehicle application, configuration, and weight class. Next, users can assess different powertrain technologies by selecting both existing and alternative fuels and inputting specific vehicle details such as fuel efficiency and number of vehicles. The tool then prompts users to define operational conditions, including average daily distance, number of operation days per year, and vehicle lifetime. Default values are provided for all parameters, but users can override these to better reflect their specific circumstances.

In the financial assumptions section, users can input discount rates, fuel costs, vehicle purchase prices, maintenance costs, insurance rates, depreciation rates, financing rates, and infrastructure costs. Additionally, they can input subsidies per vehicle and for charging/refueling infrastructure. Subsidies per vehicle should be estimated by evaluating any

state incentives available in the user's region based on the sidebar that provides links to all programs. The tool allows users to input costs for both refueling and charging infrastructure, accommodating the diverse needs of various powertrain technologies across multiple applications. Whether users are deploying biodiesel, hydrogen fuel cell, CNG/RNG, or battery electric vehicles, the tool provides flexibility in estimating the infrastructure costs associated with the chosen alternative fuel technology.

For refueling infrastructure, users can input the total costs directly, including expenses for refueling stations and necessary site upgrades. For charging infrastructure, users have two options for inputting costs. The first option allows users to directly input the total charging infrastructure cost, including the costs of stations, construction, and grid upgrades. This option is suitable for users who have hired an electrical engineering firm that has provided a quote for the charging infrastructure needed based on the number of vehicles and the drive cycles of their deployment. The second option provides a more detailed, bottom-up approach, where users can select specific charging models with different power levels (i.e., charging speeds) and input the number of chargers needed along with their individual costs. Additionally, users can input the costs for infrastructure construction and grid upgrades separately. This method is ideal for users who have developed an understanding of the battery size and required charging power level associated with the vehicles they intend to purchase (or have discussed charging power needs with their OEM). Both options also allow users to input the total amount in state subsidies available for charging infrastructure, ensuring an accurate and comprehensive assessment of the net costs.

Once all inputs are completed, the tool calculates and visualizes cumulative costs and net present value (NPV) costs over the vehicle's lifetime. The tool also estimates well-to-wheel GHG emissions and tailpipe NO_x and PM_{2.5} emissions, providing insights into potential emissions reductions. By analyzing these results, users can make informed decisions about transitioning to sustainable vehicle technologies. For scenarios in which the NPV of the alternative fuel technology deployment is higher than the original fuel, the tool outputs the cost in dollars per ton of GHG saved if the fleet decides to go ahead with the project.

Why One-to-One Replacement?

The deployment of alternative fuel technology at scale often does not result in a one-to-one replacement of vehicles for many MHDV applications, as existing technology capabilities cannot always cater to all duty cycle applications, particularly for BEVs. Users should not expect to transition their entire fleet based on this tool alone. This tool is primarily intended for smaller pilot vehicle deployments to start assessing different technologies while taking advantage of existing financial incentives. After identifying the lowest payload and shortest routes in a fleet that can be reliably served by alternative fuels, the tool can be used to compare costs and take advantage of financial incentives designed to promote small-scale deployments. The default daily and yearly distances traveled for each vehicle configuration are based on existing models. However, for higher values, users should check model availability with their OEM, as there may be trade-offs between range and payload. Additionally, larger-scale deployments require an assessment of routes to design infrastructure at a system level, often resulting in fewer chargers than vehicles for BEVs and more complex fueling configurations for FCEVs and CNG/RNG.



ESTIMATE COSTS

Learn More

TOOLS

- **[AltFleet Economic Insight Tool:](#)** The calculator tool from TEI that accompanies this guide enables fleets to assess the cost and emissions reduction potential for the deployment of low- and zero-emission technology options.
- **[Fleet Total Cost of Ownership Tool:](#)** A fleet total cost of ownership tool from Oregon-based Portland General Electric.
- **[Federal and State Laws and Incentives:](#)** The DOE's searchable database of federal and state laws and incentives for alternative fuels and vehicles, air quality, fuel efficiency, and other transportation-related topics.

ADDITIONAL RESOURCES

- **[The Easiest and Hardest Commercial Vehicles to Decarbonize:](#)** This TEI report examines the complexities of decarbonizing the MHDV sector, identifying the top and bottom five applications for decarbonization based on technology readiness and emissions impact, emphasizing the need for flexible policies and diverse solutions.
- **[Study Examines Cost Competitiveness of Zero-Emission Trucks:](#)** The NREL sets out projections on cost parity for various classes of ZEV and examines the factors impacting the economics.
- **[Road to Zero: Research and Industry Perspectives on Zero-Emission Commercial Vehicles:](#)** A comprehensive overview of MHDZEVs from research (NREL) and industry (Volvo Group North America) professionals.
- **[Alternative Fuel Tool Kit:](#)** Detailed overview of CNG fuel, along with its benefits, applications, infrastructure providers, and cost calculators, from North Carolina Clean Tech.
- **[Decarbonizing Heavy-Duty Vehicles in the U.S.:](#)** This report from NREL provides an economic analysis of decarbonizing the heavy-duty vehicle sector across the US.



SECTION 5.

Target Setting

Fleet targets may be designed to contribute to larger organizational targets, such as net zero by 2050, associated interim targets (typically 2030), and others. They may also be designed to meet stakeholder/customer demands for lower-emissions transportation, to get ahead of regulatory requirements, or to future-proof operations.

The organization should begin by assessing existing fleet emissions and setting a baseline against which target setting for reductions can be measured. TEI's [Carbon Avoidance Tracker](#) (CAT) program is

a tool that can be used to create a baseline and generate year-over-year reports to track percentage reductions and metric tons of CO₂e avoided. This level of information is increasingly in demand by companies doing business with fleet organizations and may be required in many instances. Early planning should include an open dialogue with customers and other supply chain stakeholders to determine the rate at which the fleet must react to emissions reduction demands.

The CAT program is based on liquid fuel consumption levels, includes biofuel and BEV impacts, and is modeled through Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model.

Keep in mind that targets need to be realistic, accounting for the availability of technology within the context of the fleet composition and operational requirements of the vehicles, and for capital and operational cost profiles. By setting realistic targets, the organization can prepare to meet carbon reduction shortfalls through alternative and acceptable methods such as carbon credit purchases if necessary.

5.1. TARGETS FOR ZEV ADOPTION

Setting fleet decarbonization targets is a tailored process, unique to each organization's specific business requirements and operational landscape. When considering adoption of ZEVs into the fleet, it's critical to acknowledge that existing ZEVs may not directly replace diesel engine trucks on a one-to-one basis due to factors such as vehicle efficiency, operational demands, and charging or refueling infrastructure availability. Moreover, the infrastructure required for charging does not need to match the number of vehicles on a one-to-one scale. This transition signifies a shift in service delivery methods, underlining the importance of change management in adapting to new operational models.

Piloting plays an indispensable role in understanding how ZEVs fit within specific business contexts and

ecosystems. Initial pilot programs are recommended for gauging vehicle performance, infrastructure needs, and operational adjustments required for ZEV integration. Post-piloting, the gradual introduction of new vehicles allows for the refinement of ZEV and alternative targets based on real-world insights, ensuring a tailored and efficient fleet composition. While there are currently more options available for medium-duty vehicles, the landscape for heavy-duty vehicles is rapidly evolving, with new alternatives emerging annually.

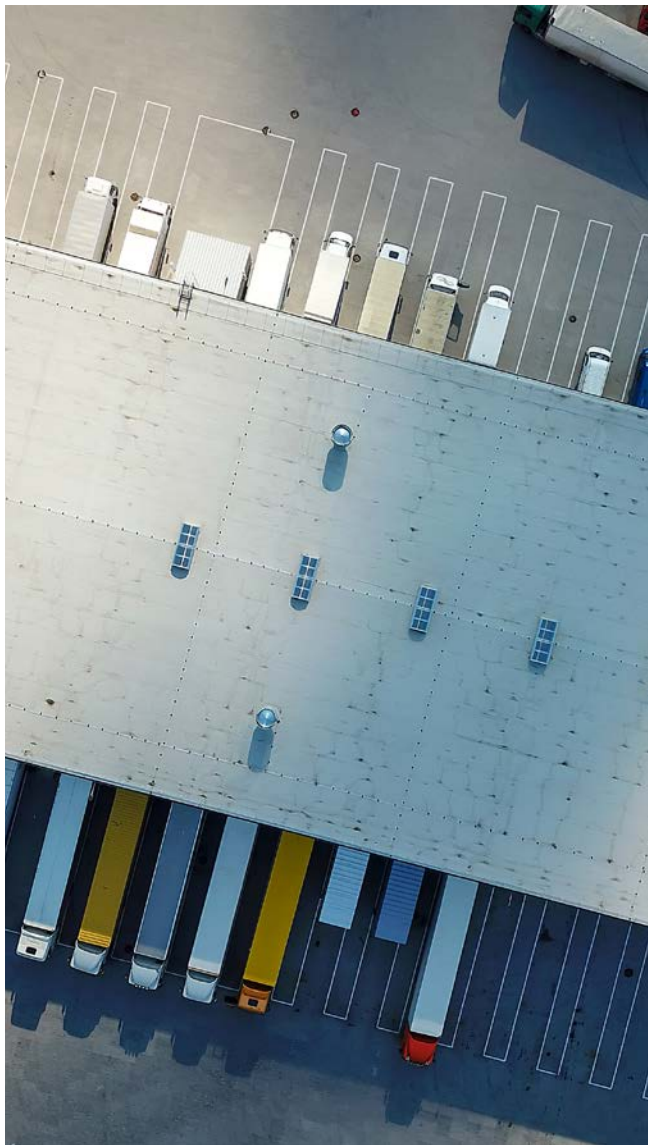
5.2. TARGETS FOR LOW-EMISSION OPTIONS

From an economic perspective, some MHDZEV applications still require significant advancements to compete with diesel, as evidenced by the limited number of models available, particularly in the heaviest long-range applications. However, this does not mean that heavier vehicle classes lack emissions reduction options. While full zero-emission solutions remain largely in the pilot stage as of 2024, intermediate options—such as adopting CNG/RNG, biofuels, or hybrid electric models—can enable fleet owners to reduce emissions in the short term. These transitional measures can help bridge the gap until more commercially viable zero-emission options become available in the coming years.



5.3. DEVELOP A FLEET DECARBONIZATION PLAN

A fleet decarbonization plan should be treated as a strategic roadmap, closely tied to organizational objectives, regulatory requirements, and customer demands. Initial goals should be clear, actionable, and aligned with long-term targets. This includes assigning roles, identifying success factors, and mitigating risks through pilot testing. Short-term plans should be built on a foundation of realistic assessments and serve as stepping stones toward broader decarbonization objectives.



5.4. DESIGN PILOT PROJECTS

Overview

Before you commit to one technology type, pilot testing can reveal the benefits and use cases in the context of your organization's fleet operations, allowing for data collection on vehicle performance, maintenance needs, and operational challenges.

Tell Me More

Designing a pilot program involves selecting specific metrics to monitor. These metrics are critical as they can vary significantly based on local conditions such as climate, road quality, and operational conditions. The primary goal of the pilot is to provide a deeper, more nuanced understanding of the technology's performance. This goes beyond the general averages and worst-case scenarios typically provided by the OEMs. By closely analyzing how the technology operates in real-world conditions, you can identify potential areas for optimization and cost savings. This comprehensive data collection will be instrumental in understanding the full spectrum of operational dynamics and will help in making informed decisions about scaling the technology. The insights gained from the pilot will enable you to plan the expansion of the technology in a way that is both economically viable and optimized for your specific operational context.

Partnerships and Collaboration: Collaboration among diverse stakeholders is critical for the success of pilot projects and subsequent full-scale deployment. Partnerships should be aligned with the chosen technology, and key stakeholders include:

- **Utilities and Infrastructure Providers:** For fleets deploying ZEVs, utilities play a central role in charging infrastructure build-out, rate design, and energy planning.⁹⁶ Similarly, natural gas and hydrogen suppliers are critical partners for CNG/RNG and FCEV pilots. These partners help fleets

⁹⁶ North American Council for Freight Efficiency. n.d. *A Trucking Fleet Primer for Commercial Truck Electrification*. Accessed April 14, 2024. <https://nacfe.org/wp-content/uploads/2020/07/Fleet-Primer-090522.pdf>.

navigate infrastructure requirements, understand associated costs, and plan for ongoing maintenance.

- **Managers and Fleet Operations Teams:** Close coordination is required between fleet managers and facility managers to integrate new fueling or charging technologies into existing operations. Facility managers often have existing relationships with utilities or fuel suppliers, which can help streamline the process.
- **Vehicle Manufacturers:** Vehicle manufacturers provide essential technical guidance on vehicle capabilities, implementation requirements, and maintenance best practices.
- **Consultants and Analysts:** External expertise can assist in designing pilot programs, defining success metrics, and analyzing pilot data to extract actionable insights.
- **Policy Stakeholders:** Engaging local and national policymakers or funding agencies can help identify and secure grants, incentives, and other financial supports for the pilot program.

Learning Objectives and Data Collection: Clearly identifying learning objectives early on allows organizations to understand what aspects of the pilot they need to focus on to be able to scale and replicate the chosen technology in their wider operations. These could include the impact of weather conditions on vehicle performance, driving behavior changes, maintenance schedule changes, and duty cycle changes. Establishing learning objectives in advance can inform data collection and analysis to help build a body of knowledge to support future implementation and adoption.

Costs and Available Supports for Piloting: The financial implications of piloting low-emission and zero-emission technologies are significant, particularly when compared to traditional ICE technology. Pilots provide a critical opportunity to assess the cost of ownership for various technologies, helping organizations make informed, financially responsible decisions.



ESTIMATE COSTS

Learn More

ADDITIONAL RESOURCES

- **[Road to Zero: Research and Industry Perspectives on Zero-Emission Commercial Vehicles:](#)** A comprehensive overview of MHDZEVs from research (NREL) and industry (Volvo Group North America) professionals.
- **[A Roadmap to Fleet Electrification:](#)** From planning to implementation, this guide from MHDZEV OEM Lion Electric covers the basics of electrifying your MHDV fleet.



SECTION 6.

Identify Energy Supply

The first step in implementing a fleet decarbonization plan is to identify and connect with energy suppliers.

6.1. FOR BEVS, CONNECT WITH UTILITIES

Overview

Before installing EV charging stations, it is crucial to communicate with your local electrical utility. While implementing a small-scale BEV pilot might be feasible under the existing power capacity at your depot, larger-scale electrification requires higher power loads. These are often not readily available at a depot and necessitate careful planning with your

electricity provider or the addition of alternative solutions like stationary battery storage or a microgrid.

Tell Me More

Utility infrastructure consists of multiple components, including generation, transmission, and distribution. Each geographic area has an existing capacity determined by its location and infrastructure. Introducing charging infrastructure at a depot requires utilities to verify available capacity at the distribution level to accommodate the necessary loads. Depending on the scale of the deployment, the required upgrades can vary widely in terms of magnitude, cost, and timeline. Examples

include transformer upgrades, which can take between six months and two years, and upgrading or replacing distribution substations for substantial loads, which can take up to six years.

Utilities typically perform demand projection studies and construct distribution capacity based on the anticipated electrical loads in each geographic region. These upgrade costs are then typically reflected in rate increases. As of 2024, grid upgrades for MHDV electrification are not typically included in utilities' demand projections in most states, as the demand can't be confirmed in advance, and utilities require approval to proactively build infrastructure. Consequently, the costs associated with grid upgrades often fall on the fleet. However, some jurisdictions provide funding programs to assist fleet operators with the cost implications of installing charging infrastructure. This funding is increasingly available from utilities and local governments and include make-ready programs offered by electrical utilities to cover the costs of necessary electrical grid upgrades to the distribution system and/or the charging depot. Make-ready programs are approved by state public utility commissions and funded by ratepayers. Over the long term, these programs are expected to drive down electric rates for all customers through increased electricity sales.

It is therefore imperative to approach your local utility at the earliest opportunity and share any electrification plans well in advance. This early communication allows them to potentially consider your future load needs in their planning and projections and advise you on available financial incentives for your deployment.

- **Initial Contact:** Reach out to your local utility early in the planning process. Discuss your plans to integrate EVs into your fleet and the potential increase in electricity demand.

- **Understanding Rates and Programs:** Inquire about special rates, programs, or incentives available for EV charging. Understand the different billing structures and how they may impact your operating costs.
- **Grid Capacity and Upgrade Requirements:** Determine if the existing electrical grid can support your charging needs or if upgrades are necessary. Discuss any potential costs and timelines for such upgrades. If the utility anticipates long delays, you may want to investigate alternatives such as distributed energy resources (DERs), which often combine solar and battery technology to improve power access and create power redundancies for the organization.
- **Technical Assistance:** Request technical assistance from your utility or consultant in planning the charging infrastructure. They can provide valuable insights into managing load and optimizing energy use.
- **Ongoing Communication:** Establish a point of contact and maintain open lines of communication with your utility. They can provide ongoing support and information about new programs or incentives.

6.2. FOR FCEVS, IDENTIFY FUEL PRODUCER/PROVIDER

Overview

The DOE is actively expanding hydrogen production and delivery infrastructure through initiatives like the Regional Clean Hydrogen Hubs (H2Hubs) program, which has allocated up to \$7 billion to establish regional clean hydrogen hubs across the nation.⁹⁷ Companies involved in the initiative include Amazon in California, Bloom Energy in the mid-Atlantic, Chevron in the Gulf Coast, and ExxonMobil in the Midwest.⁹⁸ The

⁹⁷ U.S. Department of Energy. n.d. Regional Clean Hydrogen Hubs. Accessed December 6, 2024. <https://www.energy.gov/oced/regional-clean-hydrogen-hubs-0>.

⁹⁸ Spector, J. 2023. "11 winners from the US' \$7B investment in 'clean hydrogen.'" Canary Media. <https://www.canarymedia.com/articles/hydrogen/11-winners-from-the-us-7b-investment-in-clean-hydrogen>.

Clean Air Task Force (CATF) has developed the CATF U.S. Hydrogen Hubs Map, depicting all the proposed hydrogen hubs across the US.⁹⁹

However, hydrogen production and delivery infrastructure in the U.S. is still relatively nascent, with only 74 total hydrogen fueling stations across the country, more than 70% of which are located in California.¹⁰⁰ Without dedicated infrastructure (i.e., hydrogen-specific pipelines), transporting hydrogen via trucks is the primary means of receiving hydrogen fuel. Therefore, to keep bulk delivery costs down, the required amount of hydrogen fuel should be satisfied either by a nearby hydrogen production hub, or, if possible, by on-site low-carbon or zero-emission hydrogen production.

Tell Me More

Connecting directly with a hydrogen producer or supplier will be crucial to securing a steady supply of sustainably produced hydrogen. Identifying and collaborating with hydrogen providers who are actively involved in expanding the hydrogen refueling network is essential. Such collaboration can ensure access to reliable and efficient hydrogen refueling solutions tailored to the needs of MHDV fleets. Furthermore, the price of hydrogen is expected to decrease as the hydrogen economy expands across different regions, making it more viable for MHDVs.

- Initial Contact:** Start by reaching out to potential hydrogen producers to discuss their production capabilities and the types of hydrogen they offer (green, blue, gray). This initial engagement will help gauge their ability to meet your specific needs and comply with environmental standards. For on-site production, initial contact should also involve consulting with companies that specialize in hydrogen production equipment to understand the technological and infrastructural requirements.
- Delivery and Logistics:** Evaluate the producer's logistics capabilities, including their delivery methods, frequency, and reliability, as well as the geographic reach of their service. It is important to ensure that they can consistently meet your fleet's demand without delays. Consider the proximity of the hydrogen production site to your operations, as this will significantly impact delivery logistics and potential costs.
- On-Site Production (for Electrolysis On-Site):** As explored in Section 3.5.2, there are many options for producing hydrogen, and the exact pathway will depend on a variety of factors including local expertise and the availability of renewable electricity and water or other possible feedstocks and pathways. Assessing the feasibility of installing an on-site hydrogen production unit to produce hydrogen directly at your facility should include a detailed analysis of space requirements, energy sources, initial capital investment, operational costs, safety, and risk management.
- Technical Assistance:** Whether you choose external delivery or on-site production, ensure that the hydrogen producer or equipment supplier offers comprehensive technical support. This support should cover installation, operation, and troubleshooting of the hydrogen infrastructure.
- Ongoing Communication:** Maintain open lines of communication with your hydrogen supplier to manage and adapt the supply agreement as your fleet's needs evolve. Regular updates regarding hydrogen production advancements, changes in regulations, and new sustainability practices are essential for a long-term partnership. For on-site production, this also means regular consultations with your equipment provider to ensure that your system remains up-to-date and compliant with the latest safety and environmental standards.

⁹⁹ Clean Air Task Force. n.d. CATF U.S. Hydrogen Hubs Map. Accessed March 21, 2025. <https://www.catf.us/us-hydrogen-hubs-map/>.

¹⁰⁰ Fastech. 2024. The State of Hydrogen Fueling Stations in the U.S. <https://www.fastechus.com/blog/hydrogen-fueling-stations-us>.

6.3. FOR BIODIESEL AND RD, IDENTIFY FUEL PRODUCER/PROVIDER

Overview

Before incorporating alternative fuels into your fleet's operations, an important first step is to establish connections with a fuel supplier or producer. Biodiesel can be sourced in bulk directly from producers or suppliers, who often handle the blending process. (If blending is done in-house, proper equipment and knowledge of biodiesel properties are necessary to ensure compliance with fuel standards.) Depending on the location, RD is typically available through major fuel suppliers and can be delivered in bulk. Since it is a drop-in fuel, existing diesel storage and dispensing systems at depots can usually be used without modifications. Establishing a purchasing agreement with a reliable supplier is crucial, considering the potentially higher costs associated with RD and competition for supply.

Both the availability and cost of biodiesel and RD are location specific. California currently stands out as the state offering the most favorable regulations and incentives for the adoption of these fuels, with Oregon, Washington, and New Mexico following closely behind. California adopted the LCFS, which has been driving the adoption of RD and biodiesel with significant incentives. The LCFS offers CI credits, rewarding producers and users of low-carbon fuels including RD and biodiesel. These credits reduce fuel costs, often making the price of RD equal to or lower than the price of traditional diesel, while incentivizing investment in production and infrastructure. Other states have followed California's LCFS model for their incentives, offering similar savings for fleet owners in these areas.



Tell Me More

Sourcing alternative fuels typically involves:

- **Initial Contact:** Reach out to potential alternative fuel suppliers or producers early in the planning process. Discuss your fleet's needs, potential volumes, and delivery schedule requirements.
- **Understanding Pricing and Contracts:** Inquire about bulk purchasing options, short-term contracts if the fuel is for piloting, long-term contracts if appropriate, and price stability measures.
- **Infrastructure and Delivery Logistics:** Determine if your existing storage facilities are suitable for alternative fuels or if upgrades are necessary. Discuss any potential costs and requirements for infrastructure changes such as additional storage tanks or upgraded fuel handling systems.
- **Technical Assistance:** Ask your suppliers to help you understand the specific handling, blending, and usage requirements of alternative fuels. They can provide valuable insights into maintaining fuel quality and optimizing performance.
- **Ongoing Communication:** Establish a point of contact with your fuel supplier and maintain open lines of communication. They can provide ongoing support, information about new developments in fuel technology, and adjustments to delivery schedules based on usage patterns or any seasonal differences in fuel usage that should be accounted for.

Although it is assumed that most refueling will occur at the depot, the DOE's Alternative Fueling Station Locator¹⁰¹ highlights the following trends in fuel availability in the U.S.:

- Biodiesel is widely available at public refueling stations in blends of B20 and above along the entire West Coast of the U.S., as well as the

Farm Belt of the Midwestern region. It should be noted that B5 or lower will not be labeled at public dispensers, and volumes between 5% and 20% will vaguely state "May contain up to 20% biodiesel." If the fleet operator requires specific biofuel content for the purpose of annual emissions reporting, then the operator should contact the fuel retailer for more information.

- Public refueling for RD is limited primarily to California.



6.4. FOR CNG/RNG, IDENTIFY FUEL PRODUCER/PROVIDER

Overview

When planning for CNG/RNG adoption, the feasibility of installing infrastructure at a fleet depot is significantly influenced by how close it is to the existing natural gas network. This network often caters to other uses, and leveraging its proximity can reduce costs and streamline fuel supply logistics. Additionally, the availability and pressure of natural gas at a specific location determine the type of refueling infrastructure that can be installed. Where pipeline access is unavailable, virtual pipeline solutions, which transport CNG gas by truck, can provide temporary or permanent CNG or RNG supply. These can support either mobile fueling directly at fleet depots or off-site delivery to satellite

101 Alternative Fuels Data Center. n.d. : Alternative Fueling Station Locator. Accessed March 21, 2025. <https://afdc.energy.gov/stations#/find/nearest?fuel=RD>.

fueling infrastructure. While these solutions can be valuable during early deployment or in remote areas, they are typically less cost-effective and scalable than pipeline-connected infrastructure and should be assessed based on delivery logistics, fuel volume needs, and long-term fleet strategy.

- High-pressure locations may allow for direct pipeline connections to fast-fill refueling stations, which are more suitable for fleets with high daily fuel demands.
- Low-pressure locations may require additional equipment, such as compression systems, to boost pressure levels for vehicle refueling. These added requirements can increase installation costs and should be factored into planning.
- Off-grid solutions using truck-delivered CNG or RNG may be more viable for depots located far from the existing network but may come with higher operating costs due to fuel transportation.
- Understanding the specific gas pressure and network dynamics at your depot is crucial to designing cost-effective and reliable refueling infrastructure.



Tell Me More

Several natural gas providers across the U.S. offer CNG and RNG. It is important to establish early relationships with these providers to understand their production capacity, supply logistics, ownership of environmental attributes, and pricing.

- **Initial Contact:** Begin by reaching out to potential CNG and RNG producers or suppliers. Discuss their production capabilities, the quality of the gas they provide, and their compliance with environmental standards. For RNG, it's also important to understand the feedstock sources, the production process, and the book-and-claim process that may allow the fleet operator to claim the environmental attributes. No two parties can claim the same emissions reductions in achieving the sustainability goals of one of the parties.
- **Delivery and Logistics:** Evaluate the supplier's logistics capabilities, including their delivery methods, frequency, and reliability, as well as their geographic reach. Ensure that they can consistently meet your fleet's demand without delays. Proximity of the production site to your operations can significantly impact delivery logistics and costs.
- **On-Site Production (for RNG):** This is relevant only to landfills and some farms; however, if you are considering on-site production of RNG, assess the feasibility of installing biogas production units at your facility. This includes analyzing space requirements, the availability of organic waste feedstock and energy sources, as well as initial capital investment, operational costs, and safety measures. Consult with companies specializing in biogas production equipment to understand the technological and infrastructural requirements.
- **Technical Assistance:** Ensure that the fuel producer or equipment supplier offers comprehensive technical support. This support should cover the installation, operation, and troubleshooting of the refueling infrastructure.

Ongoing technical assistance is crucial for maintaining the efficiency and reliability of the fuel supply.

- **Ongoing Communication:** Maintain regular communication with your fuel supplier to manage and adapt the supply agreement as your fleet's needs evolve. Stay current on advancements in CNG/RNG production, changes in regulations, and new sustainability practices. For on-site RNG production, regular consultations with your equipment provider are necessary to ensure the system remains up-to-date and compliant with the latest safety and environmental standards.

Although it is assumed that most refueling will occur at the depot, the DOE's Alternative Fueling Station Locator¹⁰² highlights the following trends in public fuel availability in the U.S.:

- CNG is fairly widely available across the U.S., with the exception of the Rocky Mountain region.
- Public refueling for RNG is limited primarily to California.



ESTIMATE COSTS Learn More

TOOLS

- **[Alternative Fueling Station Locator](#):** The DOE's detailed map showing public refueling stations and fuel corridors for all alternative fuels addressed in this guide.

ADDITIONAL RESOURCES

- **[Fuel Prices](#):** The DOE'S Alternative Fuels Data Center reports on regional alternative and conventional fuel prices for biodiesel, CNG, ethanol, hydrogen, propane, gasoline, and diesel. Note that this is a snapshot in time of retail fuel prices.
- **[Argus Media](#)** is a leading independent provider of energy and commodity price benchmarks. Provides analysis and market coverage for international biofuel pricing and news. (Paid service.)
- **[OPIS Biofuels Daily Report](#)** is a daily breakdown of biofuel and RD pricing, market analysis, and real-time news. (Paid service.)
- **[Preventing Electric Truck Gridlock](#):** This 2023 report from RMI highlights the challenges facing rapid electrification of the trucking industry and discusses solutions to ensure that grid power is available.

102 Alternative Fuels Data Center. n.d. : Alternative Fueling Station Locator. Accessed March 21, 2025. <https://afdc.energy.gov/stations#/find/nearest?fuel=RD>.



SECTION 7.

Plan For Charging/ Refueling Infrastructure

7.1. BEV CHARGING

7.1.1 CONDUCT A FACILITY ASSESSMENT

Overview

Charging requirements may necessitate changes to depots, yards, and facilities. Conducting a comprehensive facility assessment prior to the installation of charging infrastructure will reveal the specific needs of your fleet and facility. Evaluating the vehicles, layout, and available power capacity at your site will allow you to develop a tailored EV deployment plan. Furthermore, you must understand any local permitting or code

requirements associated with the installation of new infrastructure. This may involve researching building and electrical codes, permit requirements, and utility interconnections.

Tell Me More

A facility assessment is required to evaluate the electrical layout of your location and quantify the existing power capacity at your depot. The charging infrastructure also requires physical space, and a site assessment helps determine the number of charging stations that can be accommodated within your depot, along with ease of access, parking configurations, and safety considerations.

The assessment should cover installation considerations, including the potential need for trenching or upgrading electrical panels. Factors such as distance from the power source, obstacles between charging stations and the electrical panel, and the condition of existing electrical infrastructure should be evaluated. This information is critical for developing a charging infrastructure plan that aligns with what can realistically be accommodated at the depot under its existing conditions and footprint.

Steps include:

- **Site Evaluation:** Assess the physical layout of your facility to identify potential locations for charging stations. Consider factors like proximity to the electrical supply, space for vehicles, and accessibility for drivers.
- **Electrical Capacity Assessment:** Evaluate the existing electrical capacity of your facility. Determine if additional transformers, panels, or meters are required to support the charging infrastructure.
- **Necessary Upgrade Assessment:** Identify any necessary upgrades to the electrical system and associated costs. These may include new circuits, conduits, wiring, or other electrical components.
- **Safety and Compliance Analysis:** Confirm that all infrastructure plans comply with local building codes, electrical codes, and safety standards. Consider the placement of charging stations to ensure driver safety and avoid obstructing traffic flow.

7.1.2 CHARGING INFRASTRUCTURE PLANNING STUDY

After engaging with your utility and completing a facility assessment, use the gathered data and an operational analysis of your fleet characteristics to determine the scope of your deployment. This will form the basis for developing a tailored charging infrastructure plan.

Consider whether you want to own, operate, and maintain charging infrastructure and plan accordingly or partner with others to do so.

Design your charging infrastructure based on route and vehicle selection analysis, site assessment, and discussions with your local utility. Ensure that the plan accommodates current requirements and allows for future expansion. Consider the types of chargers (Level 2, DCFC), their placement, and the integration of smart charging solutions.

A careful analysis based on the duty cycle of each vehicle should be conducted to select the most appropriate chargers. Understanding specific usage patterns, such as the frequency and duration of trips and subsequent downtime, is essential. Considering chargers with multiple ports or cords can further enhance operational efficiency. These multi-port chargers allow several vehicles to be charged simultaneously or consecutively from a single station, optimizing the use of space and electrical connections. This setup is especially beneficial when a detailed drive cycle analysis of the fleet reveals that multiple vehicles are available to charge at overlapping or complementary times, reducing the need for extensive installation work and minimizing the physical footprint of charging stations.

Incorporate charging schedule planning into your strategy. Unlike fuel costs for ICE vehicles, electricity prices can vary significantly (though predictably) throughout the day. Many regions employ time-of-use (TOU) pricing, leading to higher costs during peak demand periods and lower costs during off-peak times. Leveraging TOU pricing by scheduling charging during off-peak hours can lead to substantial savings and reduce grid strain. You must also account for demand charges, which are based on the peak power usage within a billing cycle. Staggering the charging of multiple vehicles or adding stationary battery storage to facilitate peak shaving can mitigate high demand charges and lower operational costs.

Construction and operating permitting requirements must also be factored in during the planning stage. These permits, which vary by jurisdiction, ensure that the installation complies with local building codes, electrical standards, and zoning regulations. Obtaining these permits can take time and may involve coordination with multiple agencies, so early engagement is critical to avoid delays.

Beyond permitting, high demand for equipment has led to long lead times for acquiring necessary components, potentially extending installation timelines. Additionally, if significant utility upgrades or new service connections are required, fleets may encounter further delays because of utility resource constraints and scheduling backlogs. Engaging with utilities and equipment providers early can help mitigate these risks.

Consider consulting with a firm specializing in electric fleet infrastructure to navigate complexities like TOU pricing and demand charges effectively. Such firms can provide valuable insights and leverage proprietary tools to keep grid upgrades to a minimum.

Finally, establish a realistic timeline for the installation process, factoring in planning, permitting, equipment delivery, and commissioning of charging stations. Anticipate potential delays to ensure the timeline is practical and achievable. Proactive planning will streamline the process and help avoid unforeseen challenges.

Steps include:

- **Charging Needs Analysis:** Based on your fleet composition and usage patterns, determine the types and quantities of charging stations required. Consider the mix of Level 2 and DCFC stations based on vehicle needs and dwell times.
- **Scalability Assessment:** Design your infrastructure to be scalable, allowing for easy expansion as your fleet grows or as technology advances.

- **Budgeting and Cost Estimation:** Estimate the total costs, including equipment, installation, maintenance, and electricity. Include permitting costs and explore financing options or incentives.
- **Safety and Compliance Evaluation:** Ensure that the facility can accommodate the rigorous safety protocols required for operating a BEV depot. This includes adhering to electrical safety standards for high-voltage equipment, installing fire suppression systems near charging areas, and implementing robust thermal management protocols to mitigate risks associated with battery overheating.

7.2. FCEV REFUELING

7.2.1 CONDUCT A FACILITY ASSESSMENT

Overview

Fueling hydrogen-powered FCEVs requires a detailed facility assessment to evaluate site readiness, storage requirements, and the logistics of hydrogen delivery or on-site production. Unlike infrastructure needs for traditional fuels, hydrogen fueling infrastructure depends on specialized equipment such as storage tanks, compressors, and dispensers, as well as safety systems to manage high-pressure gas. Since hydrogen pipelines are generally unavailable for MHDV operations, fleets must rely on delivered hydrogen or on-site production. Understanding local permitting requirements and your operational needs is essential for developing a viable fueling infrastructure plan.

Tell Me More

A comprehensive facility assessment examines the depot's layout and existing infrastructure to determine the feasibility of installing hydrogen storage and dispensing systems. Proximity to existing hydrogen production facilities or distribution hubs influences the choice between having hydrogen delivered and generating it on-site. Delivered hydrogen is transported in high-pressure

cylinders or liquid form, while on-site production may involve electrolyzers (for green hydrogen) or reformers (for hydrogen derived from natural gas).

The depot's location and available space also determine the scale and configuration of fueling equipment. High-pressure systems, such as 350 bar or 700 bar dispensers, require careful planning to ensure safe and efficient operation. Safety features, including leak detection systems, ventilation, and emergency shut-off mechanisms, are critical components of the assessment. Additional considerations include ensuring compliance with local codes and permitting requirements, as well as planning for vehicle access and efficient traffic flow.

Delivered Hydrogen

Steps include:

- **Site Evaluation:** Analyze the depot's layout to identify suitable locations for hydrogen storage, compression, and dispensing. Consider factors such as vehicle parking, turning radius, and traffic flow.
- **Hydrogen Supply Assessment:** Determine whether hydrogen will be delivered to the site or produced on-site. Assess the feasibility of integrating equipment such as electrolyzers or reformers for on-site generation.
- **Pressure Requirements Review:** Evaluate the pressure required to fuel vehicles (e.g., 350 bar for medium-duty or 700 bar for heavy-duty vehicles) to determine the type of compressors and storage systems needed.
- **Safety and Compliance Analysis:** Ensure that plans meet rigorous safety standards, including the installation of leak detection systems, proper ventilation, and fire suppression equipment. Emergency shut-off mechanisms must be prominently placed and easily accessible.

On-Site Hydrogen Production

Steps include:

- **Site Evaluation:** Understand that several options exist, including electrolysis, on-site steam reformation, and pyrolysis. Identify potential locations for hydrogen production. Consider factors such as access to water and electricity supply (for electrolysis), integration with on-site renewable energy, and space for the necessary equipment.
- **Safety and Compliance Analysis:** On-site production must adhere to additional safety compliance and training requirements. Safety-related codes and standards are available through the DOE. Please refer to Learn More at the end of this section for additional information.



7.2.2 HYDROGEN REFUELING INFRASTRUCTURE PLANNING STUDY

After completing the facility assessment and collaborating with hydrogen suppliers, develop a detailed fueling infrastructure plan tailored to your fleet's operational needs. The plan should address current fueling requirements while accounting for future scalability and sustainability goals. Where pipeline access is unavailable, virtual pipeline solutions, which transport CNG gas by truck, can provide temporary or permanent CNG or RNG supply. These can support either mobile fueling directly at fleet depots or off-site delivery to satellite fueling infrastructure. While these solutions can be valuable during early deployment or in remote areas, they are typically less cost-effective and scalable than pipeline-connected infrastructure and should be assessed based on delivery logistics, fuel volume needs, and long-term fleet strategy.

There are two standard pressures for hydrogen refueling: 350 bar and 700 bar. These pressures cater to different vehicle needs, with 350 bar typically used for buses and lift trucks like forklifts, and 700 bar for passenger vehicles and other lighter-duty applications. However, several of the new heavy-duty FCEV trucks under development will also fill at 700 bar to allow for longer ranges without increasing tank capacity.

Steps include:

- **Refueling Needs Analysis:** Based on the operational analysis of your fleet, including vehicle types and usage patterns, determine the necessary capacity and type of refueling required.
- **Permitting Review:** Assess permitting and code requirements impacting design, construction, and operation.
- **Design:** Design the refueling infrastructure to be scalable, allowing for adjustments and expansions as your fleet grows or as hydrogen technology evolves. This could involve modular

refueling components that can be upgraded or expanded without significant disruptions.

- **Budgeting and Cost Estimation:** Estimate the total costs involved in establishing your hydrogen refueling infrastructure, including equipment, installation, and ongoing operational costs. Factor in potential costs for safety systems and compliance with regulatory standards. Explore financing options, government incentives, or grants available for hydrogen infrastructure projects to effectively manage up-front costs and long-term investments.

7.3. BIODIESEL AND RD REFUELING

As there is significant overlap in fueling infrastructure requirements between these alternative fuels and petroleum diesel, there is less need for new refueling infrastructure. The following applies primarily to biodiesel, as RD typically does not require specialized storage solutions beyond those used for petroleum diesel.

Steps include:

- **Storage Assessment:** Evaluate the compatibility of existing storage tanks and fueling infrastructure with biodiesel, which can degrade certain materials in higher blends. Biodiesel is sensitive to temperature and contamination, potentially necessitating heated and insulated tanks to prevent gelling in cold temperatures. Upgrading to biodiesel-compatible materials like stainless steel or coated steel is recommended. Filtration can remove any organic sediments in fuel that has been stored for several months. Good practice is to not store biodiesel blends for more than six months.
- **Site Evaluation:** Assess the layout for potential modifications in storage areas to accommodate fuel storage tanks. Consider proximity to existing diesel infrastructure and space needed for blending units if on-site blending is planned.

7.4. CNG/RNG REFUELING

7.4.1 CONDUCT A FACILITY ASSESSMENT

Overview

Designing CNG/RNG fueling infrastructure at your facility begins with a comprehensive assessment to determine site readiness and operational needs. This evaluation considers available space, the proximity of natural gas pipelines or delivery points, equipment specifications, and compliance with safety and environmental regulations. Understanding current fueling demand, peak usage, and scalability for future growth ensures that the infrastructure supports both immediate and long-term operational efficiency.

Tell Me More

A facility assessment for CNG/RNG refueling involves analyzing the depot layout and operational requirements in detail. Identifying areas suitable for storage tanks, compressors, and dispensers is critical, as these components must be strategically placed to ensure efficient operations and adherence to safety standards. Proximity to delivery access points or natural gas pipelines influences the feasibility and cost of infrastructure installation, while gas pressure at the site determines the type of compressors and storage equipment required.



Safety is a paramount consideration, requiring the installation of leak detection systems, proper ventilation, and emergency shut-off mechanisms. Additionally, all plans must comply with local safety and environmental regulations to mitigate risks associated with storing and handling compressed or renewable natural gas.

Steps include:

- **Site Evaluation:** Assess your facility to identify suitable areas for CNG or RNG refueling equipment, including high-pressure storage vessels. Key considerations include proximity to tube trailer delivery access or pipeline connections if on-site compression is planned, as well as secure, ventilated locations for safe gas handling.
- **Gas Supply Assessment:** Determine the proximity to the natural gas network and analyze the pressure at your location to inform the type of fueling infrastructure required. If your CNG/RNG is delivered via truck as opposed to pipeline, discuss these same requirements with your energy provider.
- **Infrastructure Requirements Survey:** Where pipeline access is unavailable, virtual pipeline solutions, which transport CNG gas by truck, can provide temporary or permanent CNG or RNG supply. These can support either mobile fueling directly at fleet depots or off-site delivery to satellite fueling infrastructure. While these solutions can be valuable during early deployment or in remote areas, they are typically less cost-effective and scalable than pipeline-connected infrastructure and should be assessed based on delivery logistics, fuel volume needs, and long-term fleet strategy.
- **Safety and Compliance Analysis:** Ensure that your facility can accommodate the rigorous safety protocols for handling and storing CNG and RNG, including leak detection systems, proper ventilation, and emergency shut-off mechanisms.

7.4.2 CNG/RNG REFUELING INFRASTRUCTURE PLANNING STUDY

Developing a CNG/RNG refueling infrastructure plan is a critical step following a thorough assessment of your current facilities. This strategic plan should detail the measures needed to secure sufficient access to CNG/RNG refueling options for your fleet.

The choice between time-fill and fast-fill systems should reflect the fleet's fueling needs. Time-fill systems, which refuel vehicles overnight, are typically more cost-effective for fleets with predictable schedules and downtime. Fast-fill systems, on the other hand, offer quicker refueling and are better suited for operations requiring rapid turnarounds.

Steps include:

- **Refueling Needs Analysis:** Based on the operational analysis of your fleet, including vehicle types and usage patterns, determine the necessary capacity and type of refueling required. This includes deciding between time-fill and fast-fill stations.
- **Scalability Assessment:** Design the refueling infrastructure to be scalable, allowing for adjustments and expansions as your fleet grows or as technology evolves. This could involve modular refueling components that can be upgraded or expanded without significant disruptions.
- **Budgeting and Cost Estimation:** Estimate the total costs involved in establishing the CNG or RNG refueling system, including equipment, installation, and ongoing operational expenses. Be sure to include safety systems, permitting, and compliance with regulatory standards. Where on-site compression or utility access is unavailable, virtual pipeline providers can offer turnkey solutions, delivering compressed gas and associated dispensing equipment as a bundled service. To manage up-front costs and long-term investments, explore financing options, government incentives, and grants available for natural gas infrastructure projects.



ESTIMATE COSTS **Learn More**

ADDITIONAL RESOURCES

- **Hydrogen Safety, Codes and Standards:** Resources from the DOE on practices and procedures that will enable safe operation, handling, and use of hydrogen and hydrogen systems.
- **Charging Forward with Electric Trucks:** This 2023 report from the NACFE comprehensively covers the considerations for deploying charging infrastructure at a depot. It includes understanding electricity basics and utility operations to estimate charging costs, facilitate charger installation, and maximize fuel savings from EV usage.
- **Natural Gas Fuel Safety:** From the DOE's Alternative Fuels Data Center, this link provides an overview of relevant NGV codes from the National Fire Protection Association, including NFPA 52 and 30A, which outline the safety requirements for fueling infrastructure and maintenance, respectively.
- **Federal Laws and Incentives:** The DOE's Alternative Fuels Data Center provides an overview of federal- and state-level laws and regulations, incentives, and programs related to alternative fuels and vehicles. Users can filter results based on fuel type.



SECTION 8.

Vehicle And Charging/Refueling Infrastructure Procurement

8.1 VEHICLE AND CHARGING/ REFUELING INFRASTRUCTURE PROCUREMENT

8.1.1 VEHICLES

When transitioning to alternative fuel technologies, fleet operators must work closely with OEMs to specify vehicle options that align with their operational needs and fueling infrastructure. This involves understanding vehicle capabilities, maintenance requirements, and what support is available from OEMs and suppliers.

For BEVs and FCEVs, understanding payload capacities, range capabilities, and the availability of maintenance support is critical. OEMs can provide information about battery warranties, expected degradation rates, and specific charging or hydrogen refueling requirements. For FCEVs, it is also important to confirm hydrogen tank capacities, refueling times, and performance in extreme weather conditions. Ensure that the chosen OEM has a reliable service network and maintenance support in the regions where the vehicles will operate.

For biodiesel and RD, confirm engine compatibility with specific fuel blends, such as B20 or B100, and verify that blending rates are covered under warranties. OEMs should also provide guidance on any required modifications or maintenance adjustments. Adhering to ASTM International standards ensures compliance with U.S. fuel quality requirements and optimal vehicle performance.

For CNG and RNG vehicles, OEMs should provide details on vehicle performance under varying duty cycles and payload demands. Fleet operators should confirm that the vehicles' fuel storage systems and engine configurations align with operational requirements, including compatibility with time-fill or fast-fill fueling systems. OEMs should also outline maintenance schedules for high-pressure fuel systems and provide warranty coverage for key components.



8.1.2 INFRASTRUCTURE

The successful deployment of alternative fuel vehicles depends on procuring and installing the right fueling or charging infrastructure. While OEMs provide essential guidance on the brands, configurations, and specifications most compatible with their vehicles, fleet operators must collaborate with infrastructure providers to secure the best pricing, installation services, and long-term support.

For BEVs, OEMs can advise on compatible charging solutions, such as Level 2 or DCFCs, and the necessary software integration for optimal performance. However, it is the responsibility of the fleet operator to engage charging infrastructure providers to plan and install systems that align with their fleet's operational demands. Providers can offer tailored solutions based on fleet size, vehicle duty cycles, and site-specific requirements, ensuring the infrastructure is cost-effective and scalable for future growth.

For FCEVs, OEMs may recommend configurations and pressure levels for hydrogen fueling systems, but the actual procurement and installation require collaboration with hydrogen suppliers and infrastructure specialists. These providers can help fleets determine whether delivered hydrogen or on-site production is the most economical and operationally efficient option, as well as ensure compliance with safety and regulatory standards.

Similarly, for CNG and RNG vehicles, OEMs offer guidance on system compatibility, such as whether time-fill or fast-fill configurations are most suitable. However, engaging directly with natural gas infrastructure providers allows fleets to assess the feasibility of on-site fueling versus accessing existing public refueling stations. Providers can also advise on site-specific requirements, such as storage capacity, compression needs, and safety protocols, while offering competitive pricing for installation and long-term maintenance.

When selecting an infrastructure provider, fleet operators should consider the total costs, including equipment, installation, and ongoing maintenance, to ensure that the solution aligns with their budget. Scalability is also critical, as the infrastructure must support both immediate fleet needs and future growth, ensuring long-term viability. Additionally, providers familiar with local and federal incentives can help fleets leverage available funding opportunities to reduce up-front costs.

8.2. TURNKEY SOLUTIONS FOR FLEET OPERATIONS

For fleet operators seeking a streamlined approach to adopting low- or zero-emission technologies, turnkey solutions provide a practical and efficient option. These solutions involve partnering with a single provider that manages various aspects of vehicle and infrastructure procurement, installation, and ongoing operations. Turnkey providers can take responsibility for sourcing any combination of vehicles and fueling or charging infrastructure, offering flexibility to suit fleet needs. The infrastructure may be installed on-site at the fleet's facility or at a public location strategically chosen to support operations. This approach reduces the complexity of integrating alternative fuel technologies, particularly for emerging options like BEVs, FCEVs, and CNG/RNG vehicles, for fleet operators.

Turnkey providers handle the entire process, from sourcing vehicles and configuring them to meet fleet requirements to designing and building the associated fueling or charging infrastructure. This comprehensive service often includes ongoing management and maintenance, ensuring that vehicles and infrastructure remain operational and optimized. Billing is typically based on a subscription model, enabling fleet operators to benefit from predictable costs while avoiding significant up-front capital expenditures.

By opting for a turnkey solution, fleet operators can leverage the expertise of specialists to streamline their transition to alternative fuels, ensuring that both the technological and operational transitions are smooth and cost-effective.





SECTION 9.

Training

9.1. TRAINING DRIVERS

Overview

As fleets transition to alternative fuel technologies, it is important to recognize that many drivers may have little to no experience operating vehicles powered by these new systems. While the fundamental principles of driving remain the same, each alternative fuel technology introduces unique operational characteristics that drivers must understand. Proper training ensures that drivers can operate vehicles safely and efficiently while maximizing the benefits of these technologies.

Drivers should receive foundational education about the different vehicle types and their specific

operational nuances compared to traditional diesel-powered vehicles. This includes understanding the unique characteristics of electric drive systems, hybrid powertrains, hydrogen fuel cell refueling processes, biodiesel and RD performance variations, and CNG/RNG systems. Training should also address operational best practices, such as energy-efficient driving techniques, fuel handling protocols, and seasonal considerations for fuel performance.

Tell Me More

BEVs

Light-duty EV sales in the U.S. represented only about 7.8% of total LDV purchases in 2024. Therefore, it is not unreasonable to suggest that

many drivers in the transportation sector have no experience driving a ZEV. Although the basic principles remain the same, there are a few nuanced specifics that make operating a BEV different from driving a traditional petroleum diesel vehicle. Drivers should be trained in energy-efficient driving techniques, including maximizing regenerative braking, accounting for range implications, and efficient acceleration and deceleration practices.

Drivers should be familiar with charge time implications and understand the time requirements for charging the vehicle they are operating. This information is available from the OEM and should be made available in accessible locations, including within the vehicle itself.

MHDZEV dealers and manufacturers provide some driver training, but this is not standardized across the industry. Training and testing should be addressed as soon as the vehicles and chargers are delivered and installed to ensure safe deployment of vehicles.

FCEVs

FCEVs involve refueling using high-pressure gas systems: either 350 or 700 bar. Safety protocols are paramount in training FCEV drivers on high-pressure storage system refueling.

HEVs

Like the adjustment to EV driving, HEV drivers should understand energy-efficient driving techniques, including maximizing regenerative braking, accounting for range implications, and efficient acceleration and deceleration practices. Let drivers know that HEVs are charged simply through regenerative braking.

Biodiesel and RD

Biodiesel may provide a slightly different torque response due to its higher cetane number, which can affect acceleration characteristics. Training

should cover operational changes related to fuel characteristics, especially in terms of how biodiesel and RD behave in different weather conditions. Biodiesel has a tendency to gel in cold temperatures, which could impact fuel flow and vehicle operation. Drivers should be trained to recognize the signs of fuel gelling and understand the importance of using winterized biodiesel blends or additives to enhance cold flow properties. Finally, it's important for drivers to be informed about the availability of these fuels, especially if operating routes where refueling opportunities for biodiesel or RD might be few and far between.

CNG and RNG

To successfully handle NGVs, drivers must be made aware of the operational differences between NGVs and petroleum diesel vehicles and the specific maintenance needs of NGVs. One of the largest training needs is to get drivers comfortable with a fuel gauge that shows pressure vs volume and does not move linearly. Important to educate drivers to avoid range anxiety. Next is to ensure drivers and depot crews are familiar with the risks of working with/maintaining high pressure equipment and the necessity to "respect" pressure. Older NGVs provide slightly less horsepower and torque when compared to standard diesel vehicles, differences that can be mitigated through proper gearing and vehicle operation. Additionally, all NGVs should be equipped with a fuel filter that is readily accessible to the driver. This filter must be drained as part of daily pre- or post-trip maintenance practices. Drivers must have sufficient training to understand these practices before operating these vehicles.¹⁰³ The Alternative Fuel Vehicle Institute (AVFI) provides targeted education on standards, regulations, and safety measures for CNG and RNG vehicles and fueling stations. See the Tools at the end of this section for a link to this resource.

103 Waste Advantage Magazine. 2014. "Alternative Fuels: Switching from Diesel to CNG or LNG Fueled Engines." <https://wasteadvantagemag.com/switching-from-diesel-to-cng-or-lng-fueled-engines/>.

9.2. TRAINING FACILITY MANAGEMENT TEAMS

Shifting toward ZEV technologies in MHDVs requires competent facility management operators. As thoughtful infrastructure updates and deployment play an important role in the success of zero-emission and low-carbon fleet deployment, it is essential that facility operators possess the skills to maintain and manage new infrastructure such as charging stations and CNG/hydrogen refueling equipment.

For charging equipment, facility managers should be aware of technical and permitting requirements for their charging infrastructure (Level 2, DCFCs, etc.) and ensure they are kept in optimal working condition. This includes a regular inspection schedule, checking for wear on critical components, and maintaining clean components. Facility managers should follow OEM specifications, including following any available operation manuals, specialized training resources, and outlined diagnostic strategies for troubleshooting.

Facility managers should understand CNG and hydrogen refueling systems and provide adequate training for safe handling and understanding of leak detection procedures. An inspection and maintenance schedule should be put in place for any new piece of infrastructure equipment to maintain its integrity and operability.



9.3. TRAINING MECHANICS

Overview

Preparing mechanics for the transition to alternative fuel technologies is essential to ensuring fleet reliability and safety. They will need specialized training on maintaining and repairing all varieties of zero-emission and low-carbon vehicles. Further, they will need new skills to accommodate new fleet operations, including infrastructure maintenance and energy procurement. Staff should have adequate training to handle new energy systems, such as high-wattage charging systems and CNG/hydrogen fueling equipment. Organizations may need to assess gaps in skills and hire or train personnel accordingly.

Tell Me More

BEV Maintenance

Although EV maintenance is generally lower than the required engine servicing for diesel-powered engine trucks, there are some nuances, including:

- **Tire Wear:** On average, EV trucks are heavier than the existing diesel-powered trucks they are replacing, which could have the knock-on effect of wearing the tread on the vehicles' tires faster.
- **Battery Capacity Decline and Cold Weather Performance:** Technicians should be aware that battery capacity, as with any lithium-ion battery, will degrade over time and may experience reduced performance (range).
- **Software Updates and Vehicle Prepping:** EVs require regular software updates for the vehicles' operating systems and diagnostic checks for electric drive units and battery management systems. These are typically done over the air (OTA) automatically on a regular basis. Having Wi-Fi available where vehicles are parked for charging or overnight storage can make updates quicker and easier. Otherwise, updates can be done while the truck is still charging and before

it's deployed to ensure the vehicle is optimized for the day's duty cycle.

- **Inspection of Charging Equipment:** Technicians should inspect charging cables and connectors for any signs of damage or wear due to regular use or vandalism to prevent faulty charging.
- **Battery Coolant:** Although EVs produce considerably less heat than ICE vehicles, many models of EVs recommend coolant to ensure that battery capacity lasts longer. Check with the OEM specifications of the vehicle as some recommend specific low-conductivity coolant be used.
- **High-Voltage Electrical Safety Training:** Some OEMs and other organizations provide specific high-voltage electrical safety courses for technicians. These courses ensure that technicians adhere to best practices, standards, and frameworks for handling electrical hazards and working safely. Uncertified personnel should never be expected to handle high voltage.

FCEV Maintenance

There are limited dedicated training programs for MHDFCEV maintenance. More should become available as hydrogen becomes an important component of the American energy ecosystem.

There are a few varieties of hydrogen-powered vehicles, so technicians need to understand which vehicle type they are dealing with. After the creation of electricity from hydrogen, FCEVs behave similarly to other EVs and do not have any moving engine components like those found in ICE trucks.

With that understanding, a few issues specific to FCEVs should be considered.

- **Cathode Air Filter Checks:** Clean air is essential for the fuel cell's operation. The cathode air filter must be inspected regularly and replaced at OEM-recommended intervals to prevent clogging and ensure an adequate supply of clean air to the PEM.
- **Electrolyte Fluid Check:** Ensure the proper level of electrolyte fluid is available for the vehicle to function normally.
- **High-Pressure Storage Inspection:** FCEVs store hydrogen at high pressures (up to 700 bar), necessitating regular inspections of the storage tanks and related high-pressure components for any signs of stress, damage, or leaks. Inspections of storage components should follow manufacturer guidelines to ensure the integrity of the storage system and minimize the risk of leakage.
- **High-Pressure Safety Training and Equipment:** Technicians should be trained in handling hydrogen safely, understanding the risks associated with high-pressure systems, and knowing how to respond to hydrogen-related emergencies.





Biodiesel Maintenance

While most OEMs state that blends up to B20 can be maintained without any extra attention or details, there are some nuances and factors to be aware of when using biodiesel blends higher than B20. If fleet managers have any questions about engine compatibility or warranty provisions related to fuel choice, they should seek clarity by consulting with their OEM.

- **Degradation of Rubber Components:** Biodiesel blends higher than B20 have been reported to degrade rubber, so any seals or hoses in the fuel system that are made of rubber will be susceptible to damage. Technicians should take extra care when inspecting rubber components to make sure they are in working order.
- **Filter Clogging:** Fuel filter clogging leads to difficult cold weather starts, an issue that can be mitigated by scheduling more frequent maintenance intervals to clean or replace filters. It is also recommended not to let vehicles sit with biodiesel in their tanks for long periods (more than a month). Biodiesel can degrade, which can contribute to fuel filter clogging and potential damage to the fuel injection system.

Renewable Diesel Maintenance

RD is a drop-in replacement for petroleum diesel and is chemically almost identical. Maintenance of vehicles using RD should follow a regular maintenance schedule consistent with that of a petroleum diesel engine truck.

HEV Maintenance

HEVs have both electrical motor and ICE components, requiring attention to both systems. HEVs require technicians who are specially trained for working with high-voltage systems and hybrid control software. Fleets must ensure that maintenance staff are certified to handle hybrid-specific components safely.

- **ICE Components:** Regular dry and wet service schedules can be followed on the ICE side.
- **Battery Specific:** Hybrid batteries and power electronics generate additional heat, requiring dedicated cooling systems that must be inspected and maintained to prevent overheating and ensure performance longevity.

CNG and RNG Maintenance

Maintenance technicians must receive specialized training to address the unique requirements of NGVs. Technicians should be trained to conduct regular inspections of natural gas storage tanks for damage caused by road debris or chemical exposure. Tanks on MHDVs should be inspected in a qualified service facility once every 12 months.¹⁰⁴

Training should also include proper handling and maintenance of the pressurized systems and of the ignition system, which differs from that in the traditional diesel engine. Natural gas engines rely on spark plugs and related components that are more sensitive to spark quality and voltage; these components require regular inspection and maintenance to ensure optimal performance and longevity. Inspection and replacement intervals are provided by the vehicle manufacturer in the associated maintenance manual.

The AFVI offers training that is certified by the ASE (Automotive Service Excellence) Education Foundation. Courses offered cover all aspects of safety, operations, and maintenance for both the vehicles and fueling infrastructure. See the Learn More section below to access the AFVI's course catalog.

Other Training Options

As zero-emission transportation gains momentum, new programs are being developed to support the maintenance and operation of these technologies. Many training modules are currently geared toward LDVs, reflecting the initial wave of EV adoption. However, as demand for MHDZEVs grows, it is anticipated that more resources tailored to these larger vehicles will become available. In the interim, consulting with the vehicle's OEM is advisable, as they can provide training and resources with the most up-to-date and vehicle-specific requirements.



ESTIMATE COSTS
Learn More

TOOLS

- **National Alternative Fuels Training Consortium (NAFTC)**: The NAFTC offers a variety of courses for fleet owners, operators, and maintenance staff. Courses cover a broad range of fuel types, including battery electric, CNG, and biodiesel.
- **AFVI Course Catalog**: The AFVI offers live in-person, live online, and on-demand e-learning courses for fleet owners, operators, and maintenance staff.

¹⁰⁴ Alternative Fuels Data Center. n.d. Natural Gas Vehicle Maintenance and Safety. Accessed December 9, 2024. <https://afdc.energy.gov/vehicles/natural-gas-maintenance-safety>.

SECTION 10.

Monitor And Report On Performance and Cost

Regular monitoring of essential metrics enables fleet operators to stay adaptable and modify their strategies when necessary to ensure they meet their objectives.

10.1. ESTABLISHING A BASELINE AND DEVELOPING INDICATORS

Effective performance tracking and management begins with establishing baselines and developing key performance indicators (KPIs). This foundation enables fleet operators to measure progress, identify areas for improvement, and make data-driven

decisions. Regular reporting and in-depth analysis of collected data are essential for understanding fleet performance, making informed decisions, and communicating progress to stakeholders.

Fleet operators should begin by establishing baseline metrics of current fleet performance, including fuel consumption, maintenance costs, vehicle uptime, and emissions. Once those are defined, develop specific, measurable indicators tailored to your fleet's operational goals and the unique aspects of your alternative fuel vehicles. These indicators might include energy consumption, cost per mile, uptime percentages, and GHG emissions reduction. Set realistic and measurable targets for each KPI,

considering industry benchmarks and your fleet's historical performance. Regularly reviewing these indicators will help you gauge your fleet's progress toward its goals and identify areas for improvement.

Develop a structured reporting framework that includes data collection, analysis, and dissemination of findings at regular intervals. Reports should be clear, concise, and tailored to the needs of different stakeholders, including management, operational staff, and external partners.

Incorporate data visualization tools and dashboards to present information in an easily understandable format. Analyze the data to identify patterns, compare performance against targets, and draw insights. Use these insights to refine operational strategies, enhance efficiency, and scale your alternative fuel deployment effectively.



10.2. MONITORING TELEMATICS, OPERATIONAL, AND COST DATA

Continuous monitoring of telematics, operational, and cost data is vital to understand the real-time performance of your fleet and the efficiency of your alternative fuel deployment. This data can be used to scale your deployment cost-effectively.

Leverage telematics systems to collect data on vehicle location, energy usage (or fuel consumption for nonelectric vehicles), driving patterns, and refueling or charging events. Combine this with operational data, such as vehicle availability, load capacity, and route completion rates, alongside cost data, including fuel or electricity costs, maintenance expenses, and total cost of ownership.

Use this comprehensive dataset to monitor your fleet's performance against established KPIs. Analyzing this data will help identify trends, pinpoint inefficiencies, and uncover opportunities for cost savings and operational improvements across different fuel technologies. In-depth monitoring can enable the establishment of preventive maintenance approaches and optimization of fuel or energy consumption.

For BEVs, specifically, close monitoring of the real-time performance during small-scale pilot deployments is crucial. It allows you to understand the capabilities of the technology under your specific local conditions. This understanding can guide you to plan your larger deployment in the most cost-effective manner by avoiding overdesign, such as purchasing vehicles with larger batteries than necessary or building out more charging infrastructure than you need. This principle can extend to other technologies by allowing you to tailor infrastructure and vehicle specifications to your fleet's actual needs, such as the appropriate capacity for hydrogen or CNG fuel tanks or the optimal blend of biodiesel or RD, thereby ensuring that the deployment is both efficient and cost-effective.

In the context of alternative fuel technologies, whether battery electric, hydrogen fuel cell, biodiesel or RD, or CNG/RNG, it is critical to pilot different vehicles and infrastructure types. Closely monitor their performance under your specific local conditions before scaling. This approach allows for informed decisions that consider the unique requirements and benefits of each alternative fuel technology, ensuring that your deployment is tailored to your operational needs and environmental goals.

10.3. REPORTING AND ANALYZING DATA

After you've collected performance and operational data, the next step is to transform this data into actionable insights. The captured data from pilot phases and ongoing operations can be used to discover areas that can be improved and inform future strategies for wider and more effective ZEV adoption.

Consider developing a “lessons learned and best practices” document. The information you've gathered throughout the study and pilot processes is the basis for scaling ZEV adoption and for guiding future projects internally to avoid any major pitfalls. If the document is made publicly available, it can support adoption efforts more broadly within the transportation industry.

By effectively reporting and analyzing data, organizations can make informed decisions and ensure that their move toward zero-emission fleet operations is not only strategic but also aligned with broader objectives. This continuous loop of performance tracking, reporting, and analysis is essential for the adoption of MHDZEVs and alternative fuels.



ESTIMATE COSTS Learn More

ADDITIONAL RESOURCES

- **[Electric Trucks Have Arrived:](#)** Documenting A Real-World Trucking Demonstration: The NACFE's Run on Less – Electric demonstration showcased commercial BEVs under a number of applications. Data such as daily range, charging events, regenerative braking, and weather conditions were collected.
- **[Building a Business Case for Adopting EVs and Sustainable Fleet Strategies:](#)** A guide from Geotab to help fleet owners outline their plan to reduce operating costs and carbon emissions through electrification.

About the Transportation Energy Institute

The Transportation Energy Institute, founded by NACS in 2013, is a 501(c)(4) nonprofit research-oriented think tank dedicated to evaluating the market issues related to vehicles and the fuels that power them. By bringing together diverse stakeholders of the transportation and fuels markets, the Institute helps to identify opportunities and challenges associated with new technologies and to facilitate industry coordination to help ensure that consumers derive the greatest benefit.

The Transportation Energy Institute commissions and publishes comprehensive, fact-based research projects that address the interests of the affected stakeholders. Such publications will help to inform both business owners considering long-term investment decisions and policymakers considering legislation and regulations affecting the market. Research is independent and unbiased, designed to answer questions, not advocate a specific outcome. Participants in the Transportation Energy Institute are dedicated to promoting facts and providing decision makers with the most credible information possible so that the market can deliver the best in vehicle and fueling options to the consumer.

For more about the Transportation Energy Institute visit transportationenergy.org

TRANSPORTATION ENERGY INSTITUTE STAFF

John Eichberger

Executive Director
jeichberger@transportationenergy.org

Jeff Hove

Vice President
jhove@transportationenergy.org

Marjorie Frankel

Director, Marketing and Communications
mfrankel@transportationenergy.org

Liz Menz

Director, Research & Engagement
lmenz@transportationenergy.org

Karl Doenges

Executive Director,
Charging Analytics Program
kdoenges@convenience.org

Meagan Ray

Administrative and Project Manager
mray@transportationenergy.org

Amy Kalafa

Multimedia Designer
amy@a-ray.tv

For a list of current Transportation Energy Institute Board members and financial supporters, please visit transportationenergy.org.

©2025 Transportation Energy Institute

Disclaimer: The opinions and views expressed herein do not necessarily state or reflect those of the individuals on the Transportation Energy Institute Board of Directors and the Transportation Energy Institute Board of Advisors or any contributing organization to the Transportation Energy Institute. Transportation Energy Institute makes no warranty, express or implied, nor does it assume any legal liability or responsibility for the use of the report or any product or process described in these materials.



TRANSPORTATION
ENERGY INSTITUTE

(703) 518-7970
TRANSPORTATIONENERGY.ORG
@TEI_INSTITUTE

1600 DUKE STREET
SUITE 700
ALEXANDRIA, VA 22314