U.S. Department of Transportation, Climate Change Center
Climate Strategies that Work

HEAVY-DUTY DIESEL ENGINE RETROFIT AND REPLACEMENT

Retrofitting or replacing heavy-duty diesel engines cuts fuel use and associated emissions, contributing to cleaner air for local communities.

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OVERVIEW

Best Suited for:
Long Term & Short Term
Urban, Suburban, Rural, & Tribal

Heavy-duty vehicles and engines are significant contributors to greenhouse gas emissions and local air quality issues. Typical diesel engines in heavy-duty trucks, locomotives, port equipment, and marine vessels can last up to 30 years. The Environmental Protection Agency (EPA) estimates that over 10 million older diesel engines are in use today. Older engines are less efficient and less likely to have exhaust treatment devices like catalytic converters and diesel particulate filters. **Newer and more efficient engines have lower fuel consumption and help reduce costs in the long term.** Newer engines and vehicles have built-in fuel savings and emission controls, such as selective catalytic reduction, exhaust gas recirculation, and aerodynamic features.

Select components of diesel engines can be replaced as a more cost-effective alternative to whole vehicle or engine replacement. Engines can also be modified to use lower carbon intensity fuels, such as biodiesel, or more than one fuel (e.g., dual-fuel diesel or flexible-fuel engines). Heavy-duty engine and vehicle upgrades have the potential to improve air quality and reduce health impacts from diesel particulate matter and NOx emissions, particularly along major freight corridors, in downtown cores, and in and around ports.

Decarbonization strategies for heavy-duty equipment may include:

- Whole engine replacement
- Replacing specific engine components
- Exhaust and engine retrofit
- Aerodynamic designs and devices
- Idle reduction technologies

Replacing and retrofitting non-road engines can lower the carbon footprint of ports, railyards, and intermodal facilities and improve air quality for nearby communities. Non-road equipment includes locomotives, barges and other marine vessels, and cargo-handling equipment such as loaders, cranes, and drayage trucks.

Transitioning to lower emissions vehicles can be a challenge for the many small trucking companies and owner-operators. Over 95% of U.S. trucking companies have fewer than 10 trucks (American Trucking Association, 2024) and may not have the resources to plan ahead for lifecycle retrofits or turnover. **Larger fleets may be better suited to lead this transition.**

Source: EPA Diesel Emissions Reduction Act

Spotlight on the Ports of Los Angeles and Long Beach (San Pedro Ports)

These ports have been leading the way with zero-emissions equipment and a path to a net zero-emissions future. Recent efforts have focused on deploying electric yard tractors, drayage trucks, and cargo handling equipment (CHE). **CHE accounts for nearly 15% of CO_2 emissions and 5% of NOx emissions at the ports.** The ports have set a near-term goal of transitioning to a 100% zero-emission drayage truck fleet by 2035.

GREENHOUSE GAS REDUCTION POTENTIAL

This section provides an overview of greenhouse gas (GHG) emission reductions associated with the strategy. It highlights key findings and relevant metrics from GHG modeling resources, peer-reviewed studies, and real-world applications.

REGULATIONS SUPPORT DECARBONIZATION OF THE HEAVY-DUTY SECTOR

EPA's 2021 Clean Trucks Plan describes EPA's efforts to reduce GHG emissions and air pollutants from heavy-duty trucks through a series of rulemakings. The Phase 3 Greenhouse Gas Rule, which builds on two previous rulemakings, will further reduce GHG emissions from heavy-duty vehicles and engines, including vocational vehicles (such as delivery trucks, refuse haulers, public utility trucks, transit, shuttle, school buses, etc.) and tractors (such as day cabs and sleeper cabs on tractor-trailer trucks). The Phase 3 rule applies to model years 2027 through 2032 and allows manufacturers to choose what set of emissions control technologies (battery electric, fuel cell etc.) is best suited for their vehicle fleet. The revised emissions standards will help avoid approximately 1.8 billion metric tons of GHGs, over 50,000 tons of NOx, and 113 tons of $PM_{2.5}$ from 2027 through 2055 (EPA, 2024).

In 2023, the European Commission proposed a revision of the Regulation on CO_2 emission standards for heavy-duty vehicles. If adopted, the proposal will introduce more stringent standards in 2030 and beyond and extend the current regulation, which covers large trucks, to cover smaller trucks, city buses, long-distance buses, and trailers. The new standards are expected to decrease CO_2 emissions per km from new heavy duty vehicles by 90% by 2040, as compared to the reference period (1 July 2019 – 30 June 2020), with intermediate targets for 2030 (45%) and 2035 (65%). The regulation will also include an incentive mechanism for zero-emission and low-emission vehicles (European Commission, 2023).

TECHNOLOGIES THAT REDUCE FUEL CONSUMPTION AND EMISSIONS

Engine, vehicle, and transmission technologies that reduce truck fuel consumption will also reduce CO_2 emissions. A study by the Northeast States Center for a Clean Air Future (NESCCAF) and the International Council on Clean Transportation (ICCT) found that a combination of technologies can provide fuel savings of over 40% when applied to large tractor-trailers (NESCCAF et al., 2009).

Both battery electric and plug-in hybrid delivery trucks can achieve energy savings and reduce liquid fuel use. With appropriate en route charging, e-trucks can reduce overall energy costs by 29 to 44% (Gao et al., 2017).

Fuel cell electric vehicles emit only water vapor, producing no harmful tailpipe emissions. An International Council on Clean Transportation study compared the lifecycle greenhouse gas emissions from diesel and hydrogen trucks and buses in Europe and found that vehicles running on hydrogen produced from fossil fuels reduce GHG emissions by 15% to 33% compared to their diesel counterparts. If hydrogen is produced solely with renewable electricity, emissions can be reduced by up to 89% (O'Connell et al., 2023).

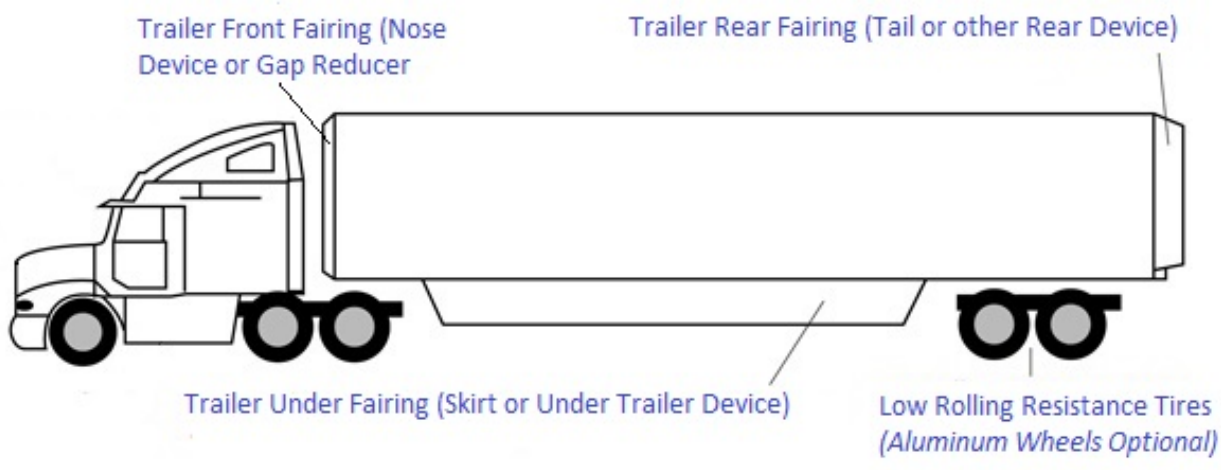
As hydrogen costs come down and fueling infrastructure expands, fuel cell electric vehicles will become a viable technology for heavy-duty applications. Learn more at the Department of Energy (DOE)'s Hydrogen and Fuel Cell Technologies Office (HFTO) website.

Upgrading a model year 2012 combination long-haul truck (Class 8) to an electric vehicle with aerodynamic components can save more than 15,000 gallons of fuel and nearly 200 tons of CO_2 emissions annually (EPA, n.d.).

Electric school buses produce less than half the GHG emissions of diesel and propane-powered school buses, including accounting of emissions from electricity generation (WRI, 2023).

Over three quarters of fuel consumption by medium and heavy-duty vehicles is due to the largest Class 8 vehicles (33,001 lb. and over). The most common Class 8 truck is the tractor-trailer combination, which is primarily employed in long-distance freight operations. Programs that target Class 8 energy efficiency may see the most significant CO_2 emissions reductions (NESCCAF et al., 2009).

EPA-designated SmartWay Tractors and Trailers are long-haul freight vehicles that significantly lower fuel consumption and emissions of air pollutants. These tractors and trailers have been tested and validated by EPA to meet specifications for fuel savings (EPA, 2024).



SmartWay Designated Trailer with Aerodynamic and Tire Components

SmartWay Trailer Specifications

	SmartWay Trailer	**SmartWay *Elite* Trailer**
Tires	Verified Low Rolling Resistance Tires (1% fuel savings)	
Aerodynamic Devices	One or more devices (at least 5% fuel savings)	Combination of two or more devices (at least 9% fuel savings)
Total Fuel Savings	6% or more	10% or more

CO-BENEFITS

This section outlines the multiple co-benefits associated with the strategy, including safety benefits, local air quality improvements, and improved accessibility. Each co-benefit presents examples that demonstrate how the strategy enhances regional or community well-being while addressing emissions.

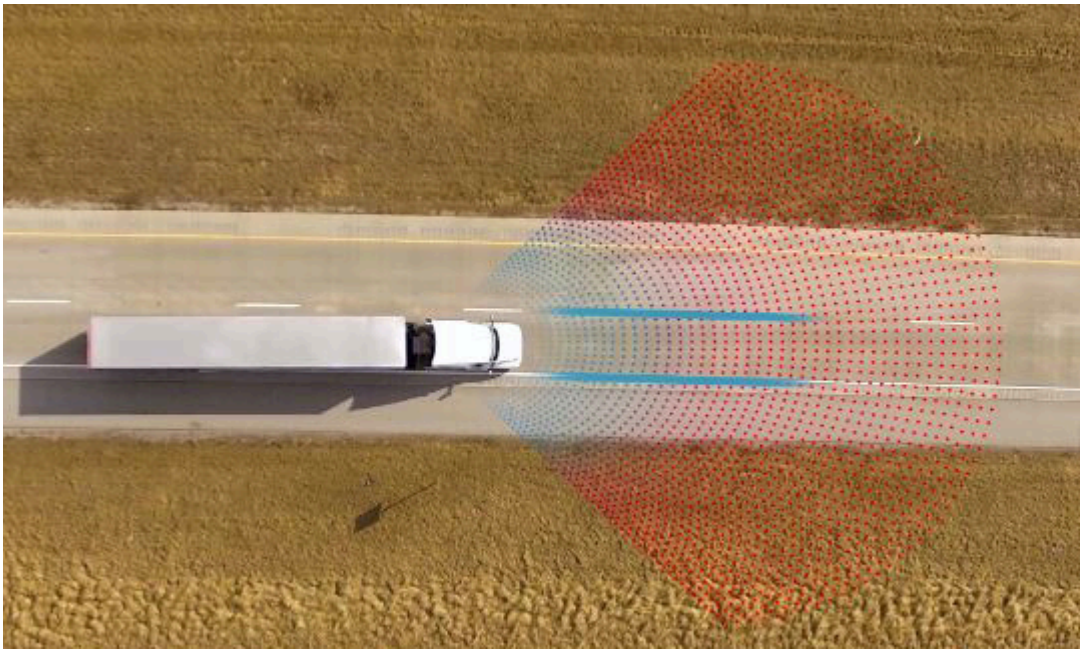
SAFETY

Many newer heavy-duty vehicles include safety features, such as collision warning and blind spot warning, which can help make streets safer for other vehicles and vulnerable road users (FMCSA, 2021).

An analysis of real-world data from 117 truck fleets found that trucks equipped with lane departure warning technology had a 21% lower crash rate compared to trucks without the technology (Routhier, 2024).

COST SAVINGS

Converting diesel truck fleets to newer model years or low and zero-emission vehicles can reduce overall maintenance and fuel costs for freight carriers. One research study found that per-mile maintenance costs for medium- and heavy-duty diesel engines increase by about 4-fold between the 0 to 50,000 and 50,000 to 100,000 mileage intervals (Boyce, 2022).



Lane Keep and Lane Centering Technology
(Source: Federal Motor Carrier Safety Administration)

AIR QUALITY AND HEALTH

Pollution from tailpipe and non-tailpipe emissions contribute to health inequities for communities, especially communities of color, which are disproportionately located near major roadways and ports (EPA, 2014).

The National Renewable Energy Laboratory analyzed baseline air pollutant concentrations in the Los Angeles area and changes to pollutant concentrations associated with electrification of heavy-duty trucks (Ravi et al., 2023):

- Although they account for only 5% of registered vehicles in the area, heavy-duty trucks contribute 51% of on-road nitrogen oxide emissions.
- Prioritizing electrification of trucks close to highways provides significant benefits to air quality-impacted disadvantaged communities.
- If 25% of trucks in Los Angeles are electrified, the number of annual avoided premature deaths due to $PM_{2.5}$ exposure will fall by over 50.

RURAL COMMUNITIES

Large volumes of freight either originate in rural areas or are transported through rural areas by road, rail, and waterways. **Two-thirds of rail freight originates in rural areas, and nearly half of all truck vehicle miles traveled (VMT) occur on rural roads** (USDOT, 2023). Upgrading heavy duty fleets to cleaner, more efficient versions can reduce noise and air quality impacts on rural communities.

Rural school districts often operate large fleets of school buses due to considerable distances between children's homes and schools. As part of the Clean School Bus Program, EPA prioritizes funding to rural and low-income areas. Upgrading rural fleets to low- or zero-emissions vehicles reduces emissions and exposure to toxic pollutants.

Read more about the program here.

Source: U.S. EPA Clean Bus Program

ACCESSIBILITY AND EQUITY

Near-port communities are often low-income communities of color that suffer disproportionate impacts, including noise and air pollution, from port operations.

- The population within 2 miles of the Port of Houston is comprised of 76% people of color (EPA Environmental Justice Primer for Ports).
- Fifty-eight percent of Los Angeles disadvantaged communities have high traffic impacts or diesel particulate matter exposure, and 32% of disadvantaged communities have both (Ravi et al., 2023).

Students from low-income families are exposed to higher levels of diesel exhaust pollution from school buses: 60% of these students ride the bus to school, compared to 45% of students from higher income families. Black and brown students and children with disabilities also rely on school buses more than their peers. Electrifying school bus fleets can help address these health concerns and inequalities (WRI, 2023).

Several federal and state programs that support heavy-duty vehicle upgrades prioritize projects in disadvantaged communities.

The California Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project HVIP includes a disadvantaged community incentive of 15% for vehicles that are purchased or leased by a public or private small fleet with 20 or fewer trucks or buses and less than $15 million in annual revenue for private fleets. Vouchers are also available for any purchase or lease by a California Native American tribal government (CARB, n.d.).

COST CONSIDERATIONS

Here are a few ballpark numbers from recent electric and alternative fuel truck projects:

- The Port of Oakland recently acquired 10 Peterbilt 579EVs at a cost of $5.1 million, or about $510,000 per semi-truck.
- Through the Reduction of Truck Emissions at Port Facilities Grant Program:
  - Puerto Rico Terminals received about $2.8 million to replace 7 diesel trucks with all-electric versions at the Port of San Juan and install 7 fast-charging stations.
  - Louisiana received $7.1 million to purchase 14 all-electric heavy-duty terminal trucks and five light-duty pickup trucks and support electrical infrastructure upgrades.
  - New Jersey received $2.2 million to replace 20 diesel trucks with new, low emissions propane versions – about $110,000 per truck.
  - The Northwest Seaport Alliance received $16 million to provide financial incentives to independent owner-operators and small trucking companies in the Seattle-Tacoma region to buy zero-emission, short-haul trucks. This funding will support between 36 and 58 truck purchases along with corresponding charging/fueling infrastructure.

Considering equipment costs, fuel and electricity costs, and other costs such as maintenance and insurance, the total annual costs for a diesel vs. electric city delivery truck are relatively similar ($47,700 vs. $45,200) (DANA, n.d.). Federal and state rebates may help further reduce costs of electric equipment.

Heavy-duty engine technologies that reduce fuel consumption and emissions range in cost from a **few hundred dollars for simple retrofits** to **$2,000-$3,000 for a turbocompound package** to **$20,000+ for more advanced technology packages** (NESCCAF et al., 2009). The cost of a **new semi-truck ranges from approximately $70,000 to $180,000**.

FUNDING OPPORTUNITIES

EPA's **Diesel Emissions Reduction Act (DERA) Program** funds grants and rebates that protect human health and improve air quality by reducing harmful emissions from diesel engines. DERA funds can be used to fund retrofit and replacement of diesel equipment, including school buses and transit buses.

EPA's **Clean Heavy-Duty Vehicle Program** offers grants and rebates to replace existing heavy-duty vehicles with clean, zero-emission vehicles.

EPA's **Clean Ports Program** provides for investment in clean, zero-emission port equipment and technology; to conduct relevant planning or permitting in connection with the purchase or installation of such equipment or technology; and to help ports develop climate action plans to reduce air pollutants at U.S. ports.

FHWA's **Congestion Management and Air Quality Improvement (CMAQ) Program** supports surface transportation projects and other related efforts that contribute air quality improvements and provide congestion relief. The BIL continues the CMAQ Program to provide a flexible funding source to State and local governments for transportation projects and programs to help meet the requirements of the Clean Air Act, including supporting heavy-duty engine and vehicle replacement and retrofit projects.

California Truck Replacement Programs, including the **San Joaquin Valley Air Pollution Control District program**, replace on-road diesel trucks with alternative technology units. Projects that will accelerate emission reductions in low income and disadvantaged communities experiencing greater air quality impacts may receive priority through the project review and selection process.

COMPLEMENTARY STRATEGIES

Heavy-duty vehicles spend considerable time idling with their engine on – school buses idle at bus stops, transit buses idle at curbs and park-and-ride lots, and trucks idle during deliveries and for longer periods of time at roadside rest stops. Idle reduction technologies can contribute to improved fuel efficiency and lower emissions.

Heavy-duty vehicles typically have relatively low fuel efficiency. Upgrading to newer engines and vehicles and retrofitting engines with emissions control technologies can improve the overall efficiency of heavy-duty fleets.

View All Strategies

CASE STUDIES

ELECTRIC REFUSE TRUCKS AT REPUBLIC SERVICES

Republic Services, in partnership with Oshkosh Corporation, released the first electric garbage truck fleet in fall 2023 in Phoenix, AZ and plans to roll out electric fleets in other U.S. cities, including Carlsbad, CA and Portland, OR in 2024. Republic expects electric vehicles to represent half of their new truck purchases by 2028.

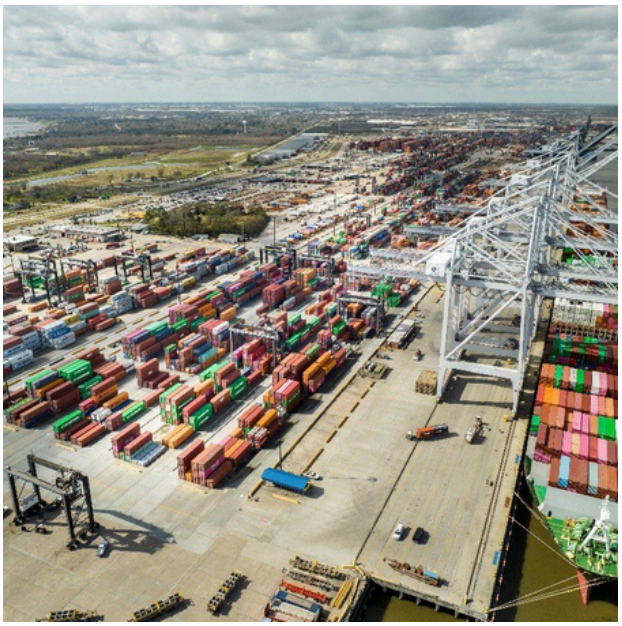
Source: Republic Services

MESILLA VALLEY TRANSPORTATION (MVT) SMARTWAY PARTNERSHIP

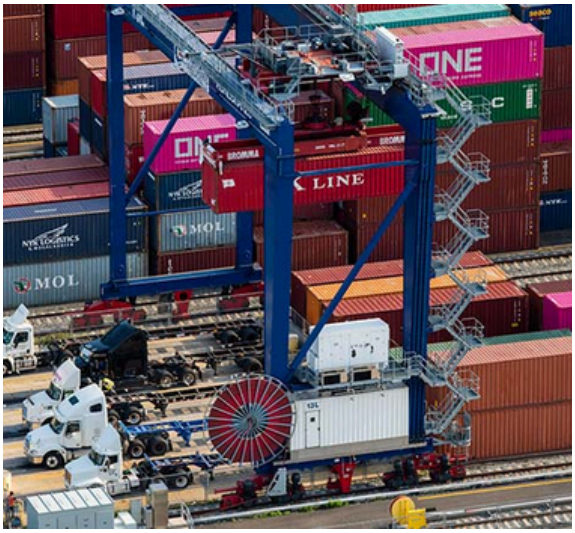
MVT is one of the largest truck load carriers in the U.S., operating routes between major manufacturing areas in the U.S., Canada, and Mexico. The company joined EPA's SmartWay program in 2004 and immediately began a fuel economy benchmarking exercise. Due to the size and age of its fleet, routes, and other factors, their fleetwide average was only 6.8 mpg. To improve fuel efficiency, MVT switched to trucks and trailers with single wide-based tires, equipped all trucks with direct-drive transmissions and idle reduction devices, and installed various aerodynamic features, including run skirts and trailer tails. MVT also provides training on smoother driving practices and offers financial incentives to drivers who achieve 8.6 mpg and above. MVT's fleet is now running close to 9 mpg and saves approximately 20,000 gallons of fuel monthly compared to 2004 levels.

PORT DRAYAGE TRUCK REPLACEMENT PROGRAM - PORT OF NY/NJ

The Port Drayage Truck Replacement Program (TRP) at the Port of New York and New Jersey is a voluntary subsidy program which encourages replacement of old heavy-duty diesel trucks with newer models. If all eligible trucks (ca. 5,600) are replaced, the port would see annual emissions reductions of 98.5 tons of NOx (13%) as well as sharp reductions in $PM_{2.5}$ and CO_2 emissions. The lower NOx emissions are expected to reduce local NOx concentrations by up to 63%, bringing levels below what is considered hazardous to human health and significantly improving air quality for vulnerable populations living near the port.



Source: Port Houston



Source: National Renewable Energy Laboratory

REDUCING EMISSIONS AND NOISE AT TRUCK BOTTLENECKS - HOUSTON, TX

The Barbours Cut Container Terminal is located on Galveston Bay near the inlet to the Houston Ship Channel. Poor air quality is a concern locally and regionally and the terminal is bordered by residential neighborhoods. As part of a case study in the Reducing Emissions and Noise at Truck Bottlenecks report, FHWA tested seven strategies for emissions impacts and found that clean trucks, drayage optimization strategies, and rail drayage could have significant emissions benefits for the region. For example, retiring and replacing 17% of the study area's trucks (all pre-2007 models) would reduce emissions of most criteria pollutants by 20-60% and reduce GHG emissions by 4%.

IMPLEMENTING HEAVY-DUTY DIESEL ENGINE RETROFIT AND REPLACEMENT: **WHAT TO READ NEXT**

Industry, often through partnerships with the public sector, is leading the way with reducing emissions from heavy-duty fleets. EPA develops new vehicle and engine standards with feedback from industry and trade groups. Vehicle and equipment manufacturers in turn develop new technologies to meet the standards. Consumers are also increasingly focused on buying sustainable products and services, which puts pressure on companies to offer cleaner, more efficient alternatives.

Source: EPA Smartway

EPA's SmartWay Program provides resources to fleet managers, carriers, and other stakeholders involved in freight transport to help advance supply chain sustainability. The program helps companies identify and select more efficient freight carriers, transport modes, equipment, and operational strategies to improve supply chain sustainability and lower costs from goods movement.

See lists of SmartWay-verified Technologies and Tractors & Trailers.

JUMP TO: Overview | GHG Reduction Potential | Co-Benefits | Cost Considerations | Funding Opportunities | Complementary Strategies | Case Studies | What to Read Next | Resources

EPA's Ports Initiative works in collaboration with the port industry, communities, and state and local governments to advance clean technologies and practices at ports. The Ports Initiative and Clean Ports Program website provides many technical resources for ports, guidance on community-port collaboration, and funding opportunities.

State and local incentive programs for low-emission and zero-emission heavy-duty vehicles can help encourage the transition of truck fleets to cleaner options. For example, California's HVIP provides base vehicle price breaks from $20,000 to $240,000, depending on the vehicle purchased (CARB, n.d.).

RESOURCES

GENERAL RESOURCES

FHWA's Study on Assessing Truck Emissions and Noise at Truck Freight Bottlenecks: This report discusses strategies to address truck emissions and noise at truck freight bottlenecks, including significant highway bottlenecks and truck access to intermodal connectors. The report includes case studies to demonstrate the potential benefits of various mitigation strategies at specific locations.

EPA SmartWay Program: This program promotes freight transportation efficiency and fuel-saving technologies. The SmartWay Transport Partnership is a collaboration between EPA and the freight industry – it is voluntary and uses strong market-based incentives.

EPA Regulations for Emissions from Vehicles and Engines: The EPA regularly revises regulations including standards for heavy-duty vehicles. The latest information on air pollutant and GHG emission standards for on road and nonroad vehicles and engines can be found at the EPA site.

North American Council for Freight Efficiency (NACFE) Medium-Duty Electric Trucks – Cost of Ownership (2018): NACFE published a guidance report which discusses the total costs of ownership of medium-duty electric trucks and addresses the market, battery technology, regulatory barriers, and the power grid.

TOOLKITS AND MODELLING APPROACHES

EPA Diesel Emissions Quantifier (DEQ): This tool evaluates clean diesel projects and upgrade options for medium-heavy and heavy-heavy duty diesel engines. It helps to estimate emissions benefits and cost-effectiveness for air pollutants and CO_2.

CMAQ Emissions Calculator Toolkit: This tool provides estimated emissions reductions projected from implementing various types of transportation projects eligible under the Congestion Mitigation and Air Quality Program (CMAQ). The toolkit includes modules that model the retrofit and repower/replacement of onroad and nonroad vehicles and equipment.

EPA SmartWay Electrification Resources: This resource includes the Total Cost of Ownership Calculators for Diesel vs. Electric Vehicles.

North American Council for Freight Efficiency (NACFE) Medium-Duty Electric Trucks – Cost of Ownership (2018): NACFE provides an Excel-based

total cost of ownership calculator comparing investment in diesel or gasoline trucks against battery electric alternatives.

California Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project Total Cost of Ownership Estimator: This is a tool that provides estimated cost comparisons between zero- and near-zero emission, medium- and heavy-duty buses and trucks of the same sizes with baseline fuels, including gasoline, diesel, and compressed natural gas. Inputs on the availability of grants and incentives can be made to provide an estimate of potential cost reductions for zero and near-zero emission trucks, including electric trucks.

Dana Total Cost of Ownership Calculator (2020): Dana, a drivetrain and electrified propulsion system supplier, provides total cost of ownership calculators for diesel and electric vehicles.

Vehicle Energy Consumption Calculation Tool (VECTO): In the EU, lorry manufacturers are required to monitor and report CO_2 emission and fuel consumption data to the European Commission. The tool can be used to model trucks, buses, and coaches with gross vehicle weights above 3,500 kg (7,716 lb.).

Mobility Energy Productivity Tool (MEP): This tool evaluates the ability of a transportation system to connect individuals to goods, services, employment opportunities, and others while accounting for time, cost, and energy.

WORKING WITH COMMUNITIES

U.S. Department of Energy's Clean Cities Coalition Network: This network supports communities in achieving cleaner air and reducing dependence on fossil fuels by promoting alternative transportation options.

FHWA's Zero Deaths and Safe System Program: This program provides resources and guidance to help communities eliminate traffic fatalities and serious injuries. Active transportation is a key component of the Safe System approach, promoting safer streets for pedestrians, cyclists, and motorists.

EPA's Smart Growth: This website provides resources and technical assistance to help communities integrate active transportation into their development plans, promoting compact, walkable neighborhoods.

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For more information visit the DOT Climate Change Center, https://www.transportation.gov/priorities/climate-and-sustainability/dot-climate-change-center