Appendix A:
Air Quality Improvement Program Benefit-Cost Scores

Fiscal Year 2025-26 & 2026-27

Table of Contents

Overview

The California Air Resources Board (CARB) proposes the allocation of $34.94 million of Fiscal Year (FY) 2025-26 and $33.19 million of FY 2026-27 appropriations from the Air Quality Improvement Program (AQIP) to the Clean Off-Road Equipment Voucher Incentive Project (CORE). This allocation to CORE and some of its projected outcomes are summarized in Table A-1. This Appendix A provides benefit-cost scores and other metrics for the heavy-duty projects CORE, Clean Truck and Bus Voucher Incentive Project (HVIP), and Sustainable Heavy-Duty Initiatives for Future Technology (SHIFT). The methods and assumptions used for the quantification of project metrics are described herein. It is important to note that projections for emission reductions are illustrative examples of what might be achieved with the allocated funding. Refined emission reduction estimates are quantified as projects are implemented and data become available.

Projections of project metrics use the outputs of several CARB models: CARB's California-specific version of Argonne National Laboratory's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model[1] (known as the CA-GREET4.0 model); CARB's EMission FACtors (EMFAC2025) model;[2] separate models for each sector in CARB's off-road mobile source inventory;[3] and CARB's Job Co-benefit Assessment Methodology and Modeling Tool.[4] California's Low Carbon Fuel Standard regulations[5] (LCFS), publicly available technical reports, incentive-project data, and estimations are also used when projecting project metrics. The types of emissions considered in this Appendix A are greenhouse gases (GHG) calculated in terms of their carbon-dioxide equivalency (CO_2e), oxides of nitrogen (NO_X), particulate matter less than 2.5 microns in size (PM2.5), and reactive organic gases (ROG). California considers NO_X, PM2.5, and ROG as criteria pollutants.

Table A-1: CORE Funding Allocation with Projected Outcomes of Emission Reductions of Metric Tons of GHG, Tons of NOX, PM2.5, and ROG, and Number of Equipment Pieces Funded

Program	Funding	GHG	NO_X	PM2.5	ROG	*N*
CORE	$68,130,000	40,585	122.0	1.2	12.8	562

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[1] *https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation*
[2] *https://arb.ca.gov/emfac/*
[3] *https://ww2.arb.ca.gov/our-work/programs/msei/road-categories/road-diesel-models-and-documentation*
[4] *https://ww2.arb.ca.gov/resources/documents/cci-methodologies*
[5] *https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard/lcfs-regulation*

The CORE benefit-cost score projections are summarized in Table A-2 along with the other analyzed heavy-duty CARB incentive programs for comparison.

Table A-2: Projected Benefit-Cost Scores [grams/$]

Project	GHG	NO_X	PM2.5	ROG	NO_X+PM2.5+ROG
CORE	596	1.612	0.015	0.171	1.798
HVIP	663	0.233	0.012	0.015	0.260
SHIFT	131	1.021	0.033	0.056	1.110

Emission Factors

Emission factors ($\mathcal{F}$) are quantities of emissions per distance traveled or emissions per time for various pieces of on-road or off-road equipment, respectively, in categories provided by various CARB models. Energy type, equipment classification, model year (MY), and engine power were used to further specify emission factors in these categories. These CARB modeled emission factors are used to quantify all project emission metrics in this Appendix A.

Emission factors for NO_X, PM2.5, and ROG are calculated based solely on equipment emissions because of their localized impact. Emissions of PM2.5 include those from on-road brake and tire wear, in addition to tailpipe exhaust.

GHG emission factors are determined on a well-to-wheel (WTW) basis because GHG emissions are global pollutants, meaning their effects are not proximate to when and where they are created. This WTW basis means that GHG emissions generated by providing utilized energy are included in the total GHG emissions projected. This WTW basis is accomplished with the use of carbon-equivalent intensities (i) from LCFS. Carbon-equivalent intensities are the WTW amount of GHG emissions per amount of energy used.

Carbon-equivalent intensities are multiplied by the energy densities (p) of their respective energy types to produce the carbon-equivalent densities for the various types of energy considered. The energy densities used in this Appendix A come from LCFS. The GHG emission factors ($\mathcal{F}_{GHG}$) are the ratios of the carbon-equivalent densities ($p \cdot i$) to the use rates (ω) of the pieces of equipment that utilize the energy. The use rates are pulled from the various CARB models as the ratio of miles traveled to amount of fuel or energy consumed for on-road equipment and fuel usage rates for off-road equipment. The overall calculation used for the GHG emission factors is shown in Equation A-1 in terms of quantities defined here.

Equation A-1: GHG Emission Factors

$$\mathcal{F}_{GHG} = \frac{p \cdot i}{\omega}$$

Battery-electric (BE) off-road equipment is not modeled by CARB, so their GHG emission factors are derived from their internal-combustion engine (ICE) equivalents. The same usage as their ICE equivalents is assumed along with an energy-efficiency ratio (h). For off-road equipment, the ICE GHG emission factors ($\mathcal{F}_{ICE}$) are converted into BE GHG emission factors ($\mathcal{F}_{BE}$) by multiplying them by the assumed energy-efficiency ratio and the ratio of BE to ICE carbon-equivalent intensities (i_{BE}/i_{ICE}). Equation A-2 shows this conversion in terms of quantities defined here.

Equation A-2: Off-Road Battery-Electric GHG Emission Factors

$$\mathcal{F}_{\mathrm{BE}} = \mathcal{F}_{\mathrm{ICE}} \cdot h \cdot \left(\frac{i_{BE}}{i_{ICE}}\right)$$

Hydrogen fuel-cell transit buses are not found in EMFAC2025. Their emission factors are derived from their BE equivalents, assuming they have the same usage rates as their BE equivalents and applying energy-efficiency ratios from LCFS. The hydrogen carbon-equivalent density used for transit buses is also from LCFS.

Benefit-Cost Scores

To facilitate the comparison of all incentive projects described in the Proposed Fiscal Year 2025-26 and Fiscal Year 2026-27 Funding Plan for the Air Quality Improvement Program (Proposed AQIP Funding Plan), the AQIP defined benefit-cost scores were estimated for each project.

The total number of pieces of equipment put into operation for a project (N) is estimated from previous and/or expected project performance. The ratio of total project funds (D) to average per-equipment project cost (c) yields the estimated number of pieces of equipment of project funded equipment. This calculation is shown in Equation A-3.

Equation A-3: Number of Equipment Pieces Provided Project Funding

$$N = D/c$$

Emission factors are used to estimate emission reductions created by each project specified in this Appendix A. The average annual usage (u) of project-funded equipment is combined, when necessary, with their relevant baseline and replacement emission factors to estimate the average annual emission reductions per number of pieces of equipment (r). This calculation is shown in Equation A-4 in terms of quantities defined here.

Equation A-4: Average Annual Emission Reductions per Number of Equipment Pieces

$$r = \left(\mathcal{F}_{\text{baseline}} - \mathcal{F}_{\text{replacement}}\right) \cdot u$$

Total project emission reductions (R) are tabulated by multiplying projected annual per-equipment reductions with the total amount of funded equipment and the number of equipment ownership years (Y) to meet project requirements. This tabulation is shown in Equation A-5 in terms of quantities defined here.

Equation A-5: Project Emission Reductions

$$R = r \cdot N \cdot Y$$

Benefit-cost scores ($\mathcal{B}$) are calculated as the ratio of total project emission reductions (the benefit) to total CARB funding allocated to that project (the cost). This calculation of benefit-cost score is consistent with the AB 8 definition for purposes of AQIP. This Appendix A has expanded its use beyond criteria pollutants to include GHGs in this Proposed AQIP Funding Plan. Equation A-6 shows the calculation of benefit-cost scores.

Equation A-6: Benefit-Cost Score

$$\mathcal{B} = R/D$$

Heavy-Duty Incentive Projects

As part of determining the allocation of AQIP funds, the benefit-cost scores of three heavy-duty incentive projects were considered: CORE, HVIP, and SHIFT. Some of the assumptions and estimates used to project these projects' benefit-cost scores are described here.

Clean Off-Road Equipment Voucher Incentive Project

CORE achieves emission reductions by accelerating the deployment of zero-emission off-road technologies by reducing the up-front costs of such equipment. Eligible equipment types include construction and agricultural equipment, airport ground support equipment, cargo handling equipment, commercial harbor craft, heavier lift forklifts, mobile power units, railcar movers and freight locomotives, and transport refrigeration units. Non-tailpipe emissions of PM2.5 are not accounted for with off-road equipment because they are not modeled and available in the CARB off-road inventories. Because CORE can fund a variety of equipment categories, it is important to note that the analysis in this Appendix A uses an illustrative example of the potential equipment.

It is projected that all CORE funding will go to six equipment categories, and a representative type of equipment has been chosen for each category for emission estimate purposes. These categories are agricultural tractors, heavier lift forklifts, excursion boat main engines, construction loaders, mobile power units, and transport refrigeration units. These six categories are used to project future CORE emission reductions and are further described in Table A-3.

Table A-3: CORE Projection Equipment Categories

Category	Fund Allocation	Horsepower	Voucher
Agricultural Tractors	10%	50 – 75	$53,000
Heavier Lift Forklifts	15%	100 – 175	$135,000
Excursion Boat Main Engines	15%	300 – 600	$251,000
Construction Loaders	25%	75 – 100	$150,000
Mobile Power Units	20%	75 – 100	$154,000
Transport Refrigeration Units	15%	25 – 50	$65,000

Emission reductions for each category are estimated as the exhaust emissions offset between a diesel engine and a battery-electric motor. The emission factors used for pieces of equipment in diesel-engine categories are shown in Table A-4, and those for pieces of equipment in zero-emission categories are shown in Table A-5.

Table A-4: CORE Diesel Emission Factors Per Equipment [grams/hour]

Category	GHG	NO_X	PM2.5	ROG
Agricultural Tractors	2,731	8.735	0.039	0.437
Heavier Lift Forklifts	9,106	1.718	0.138	2.263
Excursion Boat Main Engines	9,250	51.018	0.132	2.633
Construction Loaders	1,469	1.246	0.017	0.042
Mobile Power Units	3,396	0.253	0.158	0.596
Transport Refrigeration Units	2,111	6.331	0.038	0.529

Table A-5: CORE Electric Emission Factors Per Equipment [grams/hour]

Category	GHG	NO_X	PM2.5	ROG
Agricultural Tractors	775	0	0	0
Heavier Lift Forklifts	1,835	0	0	0
Excursion Boat Main Engines	2,725	0	0	0
Construction Loaders	417	0	0	0
Mobile Power Units	963	0	0	0
Transport Refrigeration Units	476	0	0	0

Based on recent CORE data, about 75% of vouchers go toward equipment domiciled in overburdened communities. Accounting for a 7% administrative cost, this projects to about 617 pieces of off-road equipment being incentivized by new CORE funding. CORE has a three-year ownership requirement; therefore, total potential emission reductions due to new CORE funding are quantified from three years of incentivized equipment use.

Clean Truck and Bus Voucher Incentive Project

California's HVIP plays a crucial role in the deployment of zero-emission technologies. HVIP accelerates commercialization by providing point-of-sale vouchers to make advanced vehicles more affordable. Launched by CARB in 2009, the project is the earliest project in the United States to demonstrate the function, flexibility, and effectiveness of first-come, first-served incentives that reduce the incremental cost of commercial vehicles. Based on historical HVIP data, over half of HVIP incentive funds go toward vehicles domiciled in overburdened communities.

Based on recent HVIP data, the emission-reduction projections in this Appendix A assume that 60% of future voucher funds would go to Class 8 vehicles, 5% to Class 7 vehicles, 20% to Class 6 vehicles, 10% to Class 4 vehicles, and 5% to Class 3 vehicles. The HVIP incentive amounts used for emission-reduction projections are $171,000 for Class 8, $122,000 for Class 7, $115,000 for Class 6, $99,000 for Class 4, and $70,000 for Class 3 vehicles. Projected emission reductions for HVIP are quantified for three years of vehicle operation. For this analysis, average vehicle miles traveled per year from EMFAC2025 are used. Note that EMFAC2025 estimates PM2.5 emissions from brake and tire wear. The projected average emission factors for HVIP are shown in Table A-6.

Table A-6: HVIP Average Diesel and Electric Emission Factors [grams/mile]

Fuel	GHG	NO_X	PM2.5	ROG
Diesel	1,845	0.4972	0.0431	0.0299
Electric	457	0	0.0208	0

Sustainable Heavy-Duty Initiatives for Future Technology

Sustainable Heavy-Duty Initiatives for Future Technology (SHIFT) funds demonstration and pilot projects that advance emission reducing technologies in the heavy-duty sector. SHIFT projects are for technologies at a pre-commercialization phase and are not funded based on their potential to directly reduce emissions.

Benefit-cost scores for SHIFT were estimated using Equation A-6 directly. Applicants for SHIFT funded projects provide estimated emission reductions that they predict their project will achieve. These SHIFT applicants used CARB approved methodologies to predict their project emission reductions. A selection of funded SHIFT projects from over the past 10 years was used to estimate its benefit cost score. The predicted emission reductions from one year of operations from these selected projects were summed to get the estimated emission-reduction benefits, R in Equation A-6. The SHIFT project funding from these selected projects were summed to get the total cost, D in Equation A-6. Only benefit-cost scores were projected for SHIFT as a whole from these selected projects.

Quantified Project Metrics

Based on the assumptions stated above, the projected project metrics are quantified and tabulated here. Because carbon dioxide is the primary chemical product of combustion, the GHG reduction projection shown in Table A-7 are far larger than the projected reductions of NO_X, PM2.5, and ROG. This effect carries over to the benefit-cost scores shown in Table A-8, where the benefit of reducing the mass of GHG emissions per funded dollar of project cost is relatively larger. The benefit-cost scores are not made for comparisons between different emission types, however. The benefit-cost scores are made to compare CARB projects for a given emission type, where a larger score is better.

Table A-7: Voucher Project Projections of Average Annual Metric Tons of GHG Emission Reductions Per Equipment and Average Annual Tons of Criteria Pollutant Emission Reductions Per Equipment[6]

Project	GHG	NO_x	PM2.5	ROG
CORE	24.08	0.07180	0.00068	0.00760
HVIP	31.45	0.01221	0.00062	0.00079

Table A-8: Project-Life Projections of Benefit-Cost Scores [grams/$]

Project	GHG	NO_x	PM2.5	ROG
CORE	596	1.612	0.015	0.171
HVIP	663	0.233	0.012	0.015
SHIFT	131	1.021	0.033	0.056

[6] SHIFT projects are not included in this table due to their broader scope that includes charging infrastructure, energy generation, and energy storage, among other things.

Maximizing the Goals of the Air Quality Improvement Program

CARB shall provide preference in awarding funding to projects with higher benefit-cost scores that maximize the purposes and goals of the Air Quality Improvement Program. CARB may give additional preference based on the following criteria, as applicable, in funding awards to projects:

- Proposed or potential reduction of criteria or toxic air pollutants,
- Contribution to regional air quality improvement,
- Ability to promote the use of clean alternative fuels and vehicle technologies, as determined by CARB,
- Ability to achieve climate change benefits in addition to criteria pollutant or air toxic emission reductions,
- Ability to support market transformation of California's vehicle or equipment fleet to utilize zero-emission technologies, and
- Ability to leverage private capital investments.

Benefit-cost scores were calculated for possible funding allocations to CORE, HVIP, and SHIFT. CORE has by far the best benefit-cost scores for NO_X and ROG, while remaining competitively efficient at reducing PM2.5 and GHG. Totaled across all three quantified criteria pollutants, CORE's benefit-cost score is over 60 percent larger than any other analyzed CARB project. CORE supports many burgeoning zero-emission marketplaces in various categories of off-road equipment that are often used in non-attainment regions and disadvantaged communities in California. All three analyzed CARB projects can achieve climate change benefits through their reductions of GHG emissions. CORE's benefit-cost score for GHG reductions is within about 10 percent of the highest scoring project, HVIP. Funding from all CARB incentive projects prompt California consumers and businesses to move toward environmentally cleaner operations and leverage their private capital investments. CORE has historically shown its leveraging capability, utilizing low incentive caps while retaining high incentive demand far beyond available funds. Based on the goals of AQIP and the results of the benefit-cost score analysis, CARB decided to propose that all AQIP funding from FY 2025-26 and FY 2026-27 be allocated to CORE.

Acronym and Symbol List

AB – Assembly Bill

AQIF – Air Quality Improvement Fund

AQIP – Air Quality Improvement Program

$\mathcal{B}$ - Benefit-cost scores

BE – Battery-Electric

BEV – Battery-Electric Vehicle

c – Average per-equipment project cost

CARB – California Air Resources Board

CO_2e – Carbon Dioxide Equivalency

CORE – Clean Off-Road Equipment Voucher Incentive Project

D – Ratio of total project funds

EMFAC2025 – EMission FACtors

GGRF – Greenhouse Gas Reduction Fund

GHG – Greenhouse Gas

GREET – Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation

$\mathcal{F}$ – Emission factors

FY – Fiscal Year

h - Energy-efficiency Ratio

HVIP - Clean Truck and Bus Voucher Incentive Project

i – Carbon-equivalent Intensities

ICE – Internal-combustion Engine

LCFS – Low Carbon Fuel Standard

MY – Model Year

N – Total Number of Equipment

NO_x – Oxides of Nitrogen

p – Energy Densities

PM2.5 – Particulate Matter Less than 2.5 Microns in Size

r – Average Annual Emission Reductions per Equipment

R – Total Project Emission Reductions

ROG – Reactive Organic Gases

SHIFT – Sustainable Heavy-Duty Initiatives for Future Technology

u – Average Annual Usage

ω – Use Rates

WTW – Well-to-wheel

Y – Number of Equipment Ownership Years