**California Air Resources Board**

# Quantification Methodology

## California Air Resources Board
## Funding Agricultural Replacement Measures for Emission Reductions Program

**California ClimateInvestments**

**FINAL**
**October 3, 2023**

**Disclaimer:**

- This tool is designed to calculate emission reductions, cost-effectiveness, and maximum grant amounts. While every effort has been exhausted and made to ensure that the calculations are accurate and consistent with applicable program guidelines, determining final project eligibility and verifying outputs generated by the tool is the responsibility of district staff.

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## List of Acronyms and Abbreviations

| Acronym | Term |
|---|---|
| bhp | brake horsepower |
| CARB | California Air Resources Board |
| CCI | California Climate Investments |
| DGE | diesel gallon equivalent |
| Diesel PM | diesel particulate matter |
| EER | energy efficiency ratio |
| FARMER | Funding Agricultural Replacement Measures for Emissions Reductions |
| g | gram |
| gal | gallon |
| GGRF | Greenhouse Gas Reduction Fund |
| GHG | greenhouse gas |
| HHD | heavy-heavy duty trucks |
| hp | horsepower |
| kWh | kilowatt-hour |
| lbs | pounds |
| MHD | medium-heavy duty trucks |
| mi | mile |
| MJ | megajoule |
| $MTCO_2e$ | metric tons of carbon dioxide equivalent |
| $NO_x$ | oxides of nitrogen |
| PM | particulate matter |
| $PM_{2.5}$ | particulate matter with a diameter less than 2.5 micrometers |
| $PM_{10}$ | particulate matter with a diameter less than 10 micrometers |
| ROG | reactive organic gas |
| scf | standard cubic foot |
| UTV | utility terrain vehicles |
| VMT | vehicle miles traveled |
| yr | year |

## List of Definitions

| Term | Definition |
|---|---|
| Activity | Annual operation of the equipment, measured in annual average hours of use. |
| Baseline Equipment | Engine technology applied under normal business practices, such as the existing engine in a vehicle or equipment for replacements, repowers, and retrofits. In other words, the equipment that is currently owned/in operation that will be repowered, retrofitted, or scrapped and replaced with a newer, cleaner piece of equipment. |
| Co-benefit | A social, economic, or environmental benefit as a result of the proposed project in addition to the GHG reduction benefit. |
| Cost-effectiveness | A measure of the dollars provided to a project for each ton of covered emission reduction. |
| Cost-effectiveness Limit | The maximum amount of funds the Moyer Program will pay per weighted ton of emission reductions. |
| Deterioration | The increased exhaust emissions over time taking into account wear and tear on engines and emissions control devices. |
| Deterioration Life | A factor calculated from the period of time the engine has deteriorated, plus half the project life, used to estimate deterioration over the entire project life. |
| Deterioration Product | The result of multiplying the deterioration rate, equipment activity, and the deterioration life for a technology. |
| Deterioration Rate | Rates that estimate increased air pollutant emissions from engine wear and tear and other variables that increase engine emissions over time. On-road deterioration rates are established by weight class and engine model year, based on values in CARB's on-road emission inventory model. Off-road deterioration rates are established by horsepower and either Tier or model year, based on values in CARB category-specific inventory models. |
| Energy and Fuel Cost Savings | Changes in energy and fuel costs to the farmer or agricultural operation as a result of the project. Savings may be achieved by changing the quantity of energy or fuel used, conversion to an alternative energy or fuel source/vehicle, or renewable energy or fuel generation to displace existing fuel purchases. |

| Term | Definition |
| --- | --- |
| Intended Service Class | The service weight class that the vehicle will be used for. This is often, but not always, the same as the Gross Vehicle Weight Rating. |
| Key Variable | Project characteristics that contribute to a project's GHG emission reductions and signal an additional benefit (e.g., fossil fuel use reductions). |
| Load Factor | Average operational level of an engine in a given application as a fraction or percentage of the engine manufacturer's maximum rated horsepower. |
| Project Type | For the purposes of the FARMER Quantification Methodology, eligible projects fall into six project types that meet the objectives program and for which there are methods to quantify GHG emission reductions. |
| Quantification Period | Number of years that the equipment will provide GHG emission reductions that can reasonably be achieved and assured. Sometimes referred to as "Project Life" or "Useful Life." |
| Replacement Equipment | The new, retrofitted, or reconditioned equipment(s) that replaces the use of the baseline equipment(s). |
| Repower | Replacement of the existing engine with an electric motor or a newer emission-certified engine instead of rebuilding the existing engine to its original specifications. |
| Retrofit | Modifications to the engine and fuel system so that the retrofitted engine does not have the same emissions specifications as the original engine, or the process of installing a CARB-verified emissions control system on an existing engine. |

# Section A. Introduction

California Climate Investments is a statewide initiative that puts billions of Cap-and-Trade dollars to work facilitating GHG emission reductions; strengthening the economy; improving public health and the environment; and providing benefits to residents of disadvantaged communities, low-income communities, and low- income households, collectively referred to as "priority populations." Where applicable and to the extent feasible, California Climate Investments must maximize economic, environmental, and public health co-benefits to the State.

CARB is responsible for providing guidance on estimating the GHG emission reductions and co-benefits from projects receiving monies from the GGRF. This guidance includes quantification methodologies, co-benefit assessment methodologies, and benefits calculator tools. CARB develops these methodologies and tools based on the project types eligible for funding by each administering agency, as reflected in the program expenditure records available on the CARB Expenditure Records webpage.

For CARB's FARMER Program, CARB developed this FARMER Quantification Methodology to provide guidance for estimating the GHG emission reductions and selected co-benefits of each proposed project type. This methodology uses calculations to estimate GHG emission reductions from replacing older, higher- emitting agricultural equipment, vehicles, or irrigation pump engines with newer, more efficient equipment, vehicles, or irrigation pump engines; GHG emissions reductions from replacing internal combustion UTVs with zero-emission UTVs; and GHG emissions associated with the implementation of FARMER projects.

The FARMER Benefits Calculator Tool automates methods described in this document, provides a link to a step-by-step user guide with project examples, and outlines documentation requirements. Projects will report the total project GHG emission reductions and co-benefits estimated using the FARMER Benefits Calculator Tool as well as the total project GHG emission reductions per dollar of GGRF funds awarded. The FARMER Benefits Calculator Tool is available for download on the California Climate Investments Resources webpage.

Using many of the same inputs required to estimate GHG emission reductions, the FARMER Benefits Calculator Tool estimates the following co-benefits and key variables from FARMER Program projects: $PM_{2.5}$ Reductions (lbs), $NO_x$ Reductions (lbs), ROG Reductions (lbs), Diesel PM Reductions (lbs), Fossil Fuel Use Reductions (gallons), Fossil Fuel Based Energy Use Reductions (kWh), and Fuel Savings (dollars). Key variables are project characteristics that contribute to a project's GHG emission reductions and signal an additional benefit (e.g., criteria pollutant emission reductions, fuel use reductions). Additional co-benefits for which CARB assessment methodologies were not incorporated into the FARMER Benefits Calculator Tool may also be applicable to the project. Applicants should consult the FARMER Guidelines, solicitation materials, and agreements to ensure they are meeting FARMER programmatic requirements. The FARMER Guidelines are available on the CARB FARMER webpage.

## Methodology Development

CARB developed this Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability. CARB developed this FARMER Quantification Methodology to be used to estimate the outcomes of proposed projects, inform project selection, and track results of funded projects. The implementing principles ensure that the methodology would:

- Apply at the project-level;
- Provide uniform methods to be applied statewide, and be accessible by all applicants;
- Use existing and proven methods;
- Use project-level data, where available and appropriate; and
- Result in GHG emission reduction estimates that are conservative and supported by empirical literature.

CARB assessed peer-reviewed literature and tools and consulted with experts, as needed, to determine methods appropriate for the FARMER project types. CARB also determined project-level inputs available. The methods were developed to provide estimates that are as accurate as possible with data readily available at the project level. CARB released the Draft FARMER Quantification Methodology and Draft FARMER Benefits Calculator Tool for public comment on September 19, 2023. This Final FARMER Quantification Methodology and accompanying FARMER Benefits Calculator Tool have been updated to address public comments, where appropriate, and for consistency with updates to the FARMER Program Guidelines.

In addition, the University of California, Berkeley, in collaboration with CARB, developed assessment methodologies for a variety of co-benefits such as providing cost savings, lessening the impacts and effects of climate change, and strengthening community engagement. As they become available, co-benefit assessment methodologies are posted on the California Climate Investments Co-benefits webpage.

## Tools

The FARMER Benefits Calculator Tool relies on CARB-developed emission factors. CARB has established a single repository for emission factors used in CARB benefits calculator tools, referred to as the California Climate Investments Quantification Methodology Emission Factor Database (Database), available on the California Climate Investments Resources webpage. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

The FARMER Benefits Calculator Tool must be used to estimate the GHG emission reductions and co-benefits of the proposed project. The FARMER Benefits Calculator Tool can be downloaded from the California Climate Investments Resources webpage.

## Updates

CARB staff periodically review each quantification methodology and benefits calculator tool to evaluate their effectiveness and update methodologies to make them more robust, user-friendly, and appropriate to the projects being quantified. CARB updated the FARMER Quantification Methodology from the previous version to enhance the analysis and provide additional clarity. The changes include:

- Updating cost-effectiveness limits for Carl Moyer projects contracted on November 17, 2022 or later.
- Updating the GHG carbon intensity values to 2022 weighted averages.
- Updating the on-road fuel consumption factors to use data from EMFAC2021.
- Updating the fuel efficiency factors for off-road equipment to a 0.005 annual improvement from 1980-1986 and 0.0055 from 1987-2021, based on a study by California Polytechnic State University, San Luis Obispo.
- Updating the fuel and energy costs to 2022 averages.
- Adding "electric" as a replacement fuel option for Moyer and FARMER on-road truck projects.
- Adding emission factors for LSI tractors less than 25 hp.
- Adding emission factors for baseline equipment with diesel engines less than 25 hp for the zero-emission agricultural equipment category.
- Adding "General Fund" as an available funding source.
- Extending reporting period date dropdown selection to Q4 2030.
- Extending engine model year dropdown selection to 2030 for replacements.
- Removed "FY 2020-2021" from the "FARMER allocation fiscal year" dropdown.
- Fixing cost-effectiveness calculations for two-step projects.
- Fixing calculation of awards and cost-effectiveness for irrigation pump projects with alterative fuel baseline engines.
- Revising the Air District Reporting Sheet to match FARMER's data compilation sheet.

## Section B. Methods

The following section provides details on the methods supporting emission reductions in the FARMER Benefits Calculator Tool.

### Project Type

CARB developed the following project types that meet the objectives of the FARMER Program and for which there are methods to quantify GHG emission reductions:

1. On-road heavy-duty truck replacement and repower projects
    a. **Moyer On-Road Heavy-Duty Trucks:** Carl Moyer Program-eligible project category
    b. **FARMER On-Road Heavy-Duty Trucks (new/used):** FARMER On-Road FARMER project category
2. Off-road equipment replacement and repower projects
    a. **Off-Road Agricultural Equipment:** One-for-one transaction where a single baseline equipment is scrapped and a single new replacement equipment is procured
    b. **ZE Agricultural Equipment**: One-for-one transaction where a single baseline equipment is scrapped and a single electric replacement equipment is procured
    c. **Used Agricultural Equipment**: One-for-one transaction where a single baseline equipment is scrapped and a single used replacement equipment is procured
    d. **Off-Road Agricultural Equipment: 2 (or-more)-for-1**: In some cases, the replacement equipment is no longer available at similar horsepower ratings to the baseline equipment so the procurement of the higher horsepower equipment is allowed (additionally, multiple pieces of equipment may be scrapped to make the project more cost-effective,– also referred to as "2 (or more)-for-1")
3. Replacement and repower for irrigation pump engines
    a. **Irrigation Pump Engines:** One-for-one transaction where a single baseline pump is scrapped and a single replacement pump is procured
    b. **Irrigation Pump Engines: 2 (or-more)-for-1:** In some cases, the replacement pump is no longer available at similar horsepower ratings to the baseline equipment so the procurement of the higher horsepower pump is allowed (additionally, multiple pieces of equipment may be scrapped to make the project more cost-effective,– also referred to as "2 (or more)-for-1")

4. Zero-emission utility terrain vehicles
    a. **ZEV_Ag_UTV:** Rebates for the purchase of zero-emission utility terrain vehicles (UTV)
5. Agricultural Trade-Up (Ag Trade-Up) Pilot
    a. **Ag Trade-Up #1**: Transaction #1 - replacing off-road equipment with new off-road equipment
    b. **Ag Trade-Up #2:** Transaction #2 - replacing off-road equipment with the old off-road equipment that was replaced in Transaction #1
6. Infrastructure
    a. **Infrastructure (tied to project directly above):** Infrastructure that is meant to support a project from #1-4. Refer to the Carl Moyer Guidelines for guidance on eligible infrastructure.

## General Approach

Methods used in the FARMER Benefits Calculator Tool for estimating the GHG emission reductions and air pollutant emission co-benefits by project type are provided in this section. The Emission Factor Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated. These methods account for GHG emission reductions from replacing older farm equipment with newer, more efficient equipment. In general, the GHG emission reductions are estimated in the FARMER Benefits Calculator Tool using the approaches in Table 1. The FARMER Benefits Calculator Tool also estimates air pollutant emission co-benefits and key variables using many of the same inputs used to estimate GHG emission reductions.

### Table 1. General Approach to Quantification by Project Type

| Single Transaction Project Types (1a-b, 2a, 3a, 4) |
|---|
| Emission Reductions = Baseline Equipment/Vehicle Emissions – Replacement Equipment/Vehicle Emissions |
| 2 (or-more)-for-1 Transaction Project Types (2b, 3b) |
| Emission Reductions = $\sum_{i=1}^{N} Baseline\ Equipment/Vehicle\ Emissions - Replacement\ Equipment/Vehicle\ Emissions$<br><br>*N = # of baseline equipment/vehicles being scrapped* |
| Double Transaction Project Types (5a-b) |
| Emission Reductions = (First Baseline Equipment/Vehicle Emissions – First Replacement Equipment/Vehicle Emissions) + (Second Baseline Equipment/Vehicle Emissions – Second Replacement Equipment/Vehicle Emissions) |

More specifically, the FARMER Benefits Calculator Tool calculates estimates for GHG emissions reductions and air pollutant emission co-benefits using two methods for each of the project types:

1. Equations and methods from the Carl Moyer Program.
2. Equations and methods from previously existing CARB methodologies or Calculator Tools.

For all calculations, there are two pieces of equipment of interest:

1. The equipment/vehicle in use – i.e., the "baseline" vehicle/equipment.
2. The newer, replacement equipment/vehicle. Replacement, repower, and retrofitted (reconditioned) equipment/vehicles are collectively referred to as the "replacement" in the equations listed in this document. Note: the Carl Moyer Guidelines often refer to these equipment/vehicles as "reduced".

## A. Weighted Emissions Reductions and Maximum Grant Amount of FARMER Projects

### 1. Determine the weighted air pollutant emission reductions

Total weighted air pollutant emission reductions from FARMER projects are determined by taking the sum of the project's annual air pollutant emission reductions using Equation 1. While $NO_x$ and ROG emissions are given equal weight; emissions of combustion $PM_{10}$ (such as diesel exhaust $PM_{10}$ emissions) have been identified as a toxic air contaminant and thus carry a greater weight in the calculation, consistent with the Carl Moyer Guidelines (2017).

**Equation 1: Weighted Emission Reductions**

$$WER = ER_{NOx} + ER_{ROG} + 20 \times ER_{PM}$$

*Where,*

| | | | Units |
|---|---|---|---|
| *WER* | = | Annual weighted emissions reductions | US tons/yr |
| $ER_{NOx}$ | = | Annual NOx emission reductions | US tons/yr |
| $ER_{ROG}$ | = | Annual ROG emission reductions | US tons/yr |
| $ER_{PM}$ | = | Annual PM emission reductions | US tons/yr |

### 2. Determine the maximum grant amount

The maximum grant amount is determined to be the lowest result of the two following equations: Equation 2 and Equation 3. Moreover, additional funding caps are applicable to different project types. Please refer to the FARMER Program Guidelines and/or Carl Moyer Programs for more information regarding funding caps for Heavy Heavy-Duty, Medium Heavy-Duty, trucks with low $NO_x$ standards, among others. Please refer to the FARMER Program Guidelines and/or Carl Moyer Programs for more information regarding applicability.

**Equation 2: Potential Grant Amount at Applicable Cost-Effectiveness Limit**

$$PGA = CL \times WER \times \frac{1}{CRF}$$

| Where, | | | Units |
|---|---|---|---|
| *PGA* | = | Potential grant amount, based on cost-effectiveness limit | $ |
| *CL* | = | Cost-effectiveness limit | $/ton |
| *WER* | = | Weighted emissions reduction of replacing the baseline equipment | US tons/yr |
| *CRF* | = | Capital Recovery Factor | Unitless |

**Equation 3: Potential Grant Amount based on Maximum Percentage of Eligible Cost**

$$PGA = C_{replacement} \times PE$$

| Where, | | | Units |
|---|---|---|---|
| *PGA* | = | Potential grant amount, based on maximum percentage of eligible cost | $ |
| $C_{replacement}$ | = | Cost of replacement technology | $ |
| *PE* | = | Maximum percentage of eligible cost as specified in the FARMER Program Guidelines and/or Carl Moyer Program Guidelines | % |

## B. Emissions Reductions from On-Road Heavy-Duty Truck Replacement and Repower Projects

The FARMER Benefits Calculator tool calculates estimates of GHG emissions reductions and air pollutant emission co-benefits for each of the project types. The following subsections presents the equations and methods from the Carl Moyer Program and existing CARB methodologies or Calculator Tools used for On-Road Heavy-Duty Truck Replacement and Repower Projects (Trucks).

### 1. GHG Equations

Equation 4 shows the GHG emission reductions that occur over the project's entire quantification period. Using Equation 5, the GHG emission reductions from on-road heavy-duty truck replacement and repower projects are estimated as the difference between the baseline and replacement scenarios. Equation 6 is used to determine the estimated annual fuel consumption in the baseline and replacement scenarios based on annual vehicle miles traveled. For electric vehicle replacements, Equation 7 is used to determine the estimated annual energy consumption based on annual vehicle miles traveled.

Gross Vehicle Weight Rating, Model Year, and Calendar Year are used as lookup inputs to ascertain fuel economy from CARB's EMission FACtors (EMFAC) model.

**Equation 4: GHG Emission Reductions from On-Road Heavy-Duty Truck Projects (Quantification Period)**

$$QPER_{GHG} = QP \times ER_{GHG}$$

| Where, | | | Units |
|---|---|---|---|
| $QPER_{GHG}$ | = | GHG emission reductions over quantification period | $MTCO_2e$ |
| $QP$ | = | Quantification period | years |
| $ER_{GHG}$ | = | Annual GHG emission reductions of replacing the baseline truck with the replacement truck | $MTCO_2e$/yr |

**Equation 5: Annual GHG Emission Reductions from On-Road Heavy-Duty Truck Projects**

$$ER_{GHG} = ((FC_{baseline} \times CC_{baseline\ fuel}) - (FC_{replacement} \times CC_{replacement\ fuel})) \times \frac{1\ MTCO_2e}{1{,}000{,}000\ gCO_2e}$$

| Where, | | | Units |
|---|---|---|---|
| $ER_{GHG}$ | = | Annual GHG emission reductions of replacing the baseline truck with the replacement truck | $MTCO_2e$/yr |
| $FC_{baseline}$ | = | Fuel consumption of the baseline truck | gal/yr |
| $CC_{baseline\ fuel}$ | = | Carbon content of baseline fuel type | $gCO_2e$/DGE |
| $FC_{replacement}$ | = | Fuel consumption of the replacement truck | gal/yr |
| $CC_{replacement\ fuel}$ | = | Carbon content of replacement fuel type | $gCO_2e$/DGE |

If the baseline or replacement fuel type is CNG or RNG, its carbon content is converted to diesel gallon equivalent (DGE) for the GHG emissions calculations step.

**Equation 6: Fuel Consumption for the Baseline and Replacement Truck**

$$FC_i = \frac{AA}{MPG_i}$$

| Where, | | | Units |
|---|---|---|---|
| *FC* | = | Fuel consumption | gallons/yr |
| *AA* | = | Annual activity | miles/yr |
| *MPG* | = | Fuel economy | miles/gallon |
| *i* | = | Baseline or Replacement | |

**Equation 7: Fuel Consumption for Replacement Electric Trucks**

$$FC_{replacement,elec} = \frac{AA}{MPkWh_{replacement,elec}} \times \frac{ED_{elec}}{ED_{diesel}} \times \frac{1}{EER}$$

Where,

| | | | Units |
|---|---|---|---|
| $FC_{replacement,\ elec}$ | = | Fuel consumption of electric vehicle | DGE/yr |
| $AA$ | = | Annual activity | miles/yr |
| $MPkWh$ | = | Energy economy | miles/kWh |
| $ED_{elec}$ | = | Energy density of electricity | MJ/kWh |
| $ED_{Diesel}$ | = | Energy density of diesel | MJ/DGE |
| $EER$ | = | Energy economy ratio of electricity relative to diesel. | |

## 2. Criteria and Toxic Air Pollutant Equations

Estimates of individual air pollutant emission reductions from on-road heavy-duty truck replacement and repower projects are calculated. Equation 8 shows the air pollutant emission reductions that occur over the project's entire quantification period. Based upon Carl Moyer Program methods, individual air pollutant emission reductions are estimated as the difference between the baseline and replacement scenarios using Equation 9.

Intended Service Class, Model Year, and $NO_x$ standards are used as lookup inputs to ascertain emission factors and deterioration rates from the Carl Moyer Program Guidelines. The following calculations are repeated for each type of pollutant – i.e., $NO_x$, ROG, and $PM_{10}$.

**Equation 8: Emission Reductions from On-Road Heavy-Duty Truck Projects (Quantification Period)**

$$QPER_{pollutant} = QP \times ER_{pollutant} \times 2{,}000\ \frac{lbs}{US\ ton}$$

| Where, | | | Units |
|---|---|---|---|
| $QPER_{pollutant}$ | = | Emission reductions over quantification period | lbs |
| $QP$ | = | Quantification period | years |
| $ER_{pollutant}$ | = | Annual emission reductions of replacing the baseline truck with the replacement truck | US tons/yr |

**Equation 9: Annual Emission Reductions from On-Road Heavy-Duty Truck Projects**

$$ER_{pollutant} = \text{AEP}_{baseline} - \text{AEP}_{replacement}$$

| Where, | | | Units |
|---|---|---|---|
| $ER_{pollutant}$ | = | Annual emission reductions of replacing the baseline truck with the replacement truck | US tons/yr |
| $AEP_{baseline}$ | = | Annual emissions for the baseline truck | US tons/yr |
| $AEP_{replacement}$ | = | Annual emissions for the replacement truck | US tons/yr |

Equation 10 is used to determine the estimated annual air pollutant emissions in the baseline and replacement scenarios, using respective values for emission factors and mile-based deterioration product.

**Equation 10: Annual Emissions for Baseline and Replacement Truck**

$$AEP_i = (EF_i + DP_i) \times AA \times \frac{1\ US\ ton}{907{,}200\ g}$$

| Where, | | | Units |
|---|---|---|---|
| $AEP_i$ | = | Annual air pollutant emissions for the truck | US tons/yr |
| $EF_i$ | = | Zero-mile emission factor for the truck | gram/mile |
| $DP_i$ | = | Mile-based deterioration product for the truck | gram/mile |
| $AA$ | = | Annual activity | miles/yr |
| $I$ | = | Baseline or Replacement | |

Equation 11 is used to determine the mile-based deterioration product in the baseline and replacement scenarios, using respective values for deterioration rate and total equipment activity.

**Equation 11: Mile-Based Deterioration Product for Baseline and Replacement Truck**

$$DP_i = \frac{DR_i \times TEA_i}{10{,}000}$$

| Where, | | | Units |
|---|---|---|---|
| $DP_i$ | = | Mile-based deterioration product for the truck | gram/mile |
| $DR_i$ | = | Deterioration rate for the truck | g/mi-10,000 mi |
| $TEA_i$ | = | Total equipment activity of the truck | miles |
| $i$ | = | Baseline or Replacement | |

Equation 12 is used to determine the total equipment activity in the baseline and replacement scenarios, using respective values for deterioration life.

**Equation 12: Total Equipment Activity for the Baseline and Replacement Truck**

$$TEA_i = AA_i \times DL_i$$

| Where, | | | Units |
|---|---|---|---|
| $TEA$ | = | Total equipment activity of the truck | miles |
| $AA_i$ | = | Annual activity | miles/yr |
| $DL_i$ | = | Deterioration life of the truck | years |
| $i$ | = | Baseline or Replacement | |

Equation 13 is a modified equation for Total Equipment Activity and is used in the case where the truck is used and not brand new. This formula is used when the current odometer reading is >10,000 miles – the criteria used for defining a used truck.

**Equation 13: Total Equipment Activity for Used Truck**

$$TEA_i = AA_i \times DL_i + COR$$

| Where, | | | Units |
|---|---|---|---|
| $TEA_i$ | = | Total equipment activity of the truck | miles |
| $AA_i$ | = | Annual activity | miles/yr |
| $DL_i$ | = | Deterioration life of the truck | years |
| $COR$ | = | Current Odometer Reading | miles |
| $i$ | = | Baseline or Replacement | |

Equation 14 is used to determine the deterioration life in the baseline scenario.

**Equation 14: Deterioration Life for the Baseline Truck**

$$DL_{baseline} = YR_{replacement} - MY_{baseline} + \frac{QP}{2}$$

| *Where,* | | | Units |
|---|---|---|---|
| $DL_{baseline}$ | = | Deterioration life of the baseline truck | years |
| $YR_{replacement}$ | = | Expected first year of operation of the replacement truck | year |
| $MY_{baseline}$ | = | Baseline engine model year | year |
| $QP$ | = | Quantification Period (this is essentially project life or "project implementation time frame" as denoted in the Carl Moyer Guidelines) | years |

Equation 15 is used to determine the deterioration life in the replacement scenario. If the replacement truck is not brand new, but is instead used, then Equation 16 is applied to calculate deterioration life.

**Equation 15: Deterioration Life for the Replacement Truck**

$$DL_{replacement} = \frac{QP}{2}$$

| *Where,* | | | Units |
|---|---|---|---|
| $DL_{replacement}$ | = | Deterioration life of the replacement truck | years |
| $QP$ | = | Quantification Period (this is essentially project life or "project implementation time frame" as denoted in the Carl Moyer Guidelines) | years |

**Equation 16: Deterioration Life for the Truck if it is Used**

$$DL_i = YR_i - MY_i + \frac{QP}{2}$$

| *Where,* | | | Units |
|---|---|---|---|
| $DL_i$ | = | Deterioration life of the truck | years |
| $YR_i$ | = | Expected first year of operation of the truck | year |
| $MY_i$ | = | Engine model year | year |
| $QP$ | = | Quantification Period (this is essentially project life or "project implementation time frame" as denoted in the Carl Moyer Guidelines) | years |

### a. Two-Step Cost-Effectiveness Calculations

It should be noted that in some cases, a project may be eligible for a two-step cost-effectiveness calculation. This generally occurs when the replacement equipment/vehicle exceeds (i.e., is cleaner than) the requirements of regulations. To perform the two-step cost-effectiveness calculations, the same criteria and toxic air pollutant equations from the Carl Moyer Program Guidelines are used, but they are performed twice. Rather than performing the calculations to ascertain the emissions as the difference between the baseline equipment/vehicle and the replacement equipment/vehicle, the Calculator Tool will first perform the equations as the difference between the baseline equipment/vehicle and the theoretical equipment/vehicle that the applicant would have had to purchase to be in compliance with regulation. This is considered the first step. The second step then consists of performing the equations as the difference between the theoretical equipment/vehicle that the applicant would have had to purchase to be in compliance with regulation and the replacement equipment/vehicle which is cleaner that the requirement per regulation. Surplus emissions reductions calculated in the first step will be based on the regulation requirements and a $30,000 cost-effectiveness limit. Surplus emissions reductions (cleaner than required) calculated in the second step will be based on the maximum project life and a $100,000 cost-effectiveness limit.

For a project that is eligible for a two-step calculation, the potential grant amount based on cost-effectiveness limits is determined using Equation 17 by summing the potential grant amount calculated at a $30,000 cost-effectiveness limit (Step 1) with the potential grant amount calculated at a $100,000 cost-effectiveness limit (Step 2).

**Equation 17: Potential Grant Amount for Two-Step Cost-Effectiveness**

$$PGA_{Two-Step} = PGA_{Step\ 1} + PGA_{Step\ 2}$$

| Where, | | | Units |
|---|---|---|---|
| $PGA_{Two\text{-}Step}$ | = | Potential grant amount for a project eligible for a Carl Moyer Two-Step Cost-Effectiveness Calculation | $ |
| $PGA_{Step\ 1}$ | = | Potential grant amount based on Step 1 cost-effectiveness limit | $ |
| $PGA_{Step\ 2}$ | = | Potential grant amount based on Step 2 cost-effectiveness limit | $ |

Using Equation 18, total estimated cost-effectiveness can then be determined from the potential grant amount calculated in Equation 16 and from the annual emissions reductions weighted by two quantification periods as seen in Equation 19.

**Equation 18: Total Estimated Cost-Effectiveness**

$$ECE = PGA_{Two-Step} \times \frac{CRF_{Step\ 2}}{TWER}$$

| Where, | | | Units |
|---|---|---|---|
| $ECE$ | = | Estimated cost-effectiveness for a Carl Moyer Two-Step Cost-Effectiveness Calculation | $ |
| $CRF_{Step\ 2}$ | = | Capital Recovery Factor used in 2nd Step calculation | Unitless |
| $TWER$ | = | Total annual weighted emissions reductions | US tons/yr |

**Equation 19: Total Annual Weighted Emission Reductions**

$$TWER = WER_{Step\ 1}\left(\frac{QP_{Step\ 1}}{QP_{Step\ 2}}\right) + WER_{Step\ 2}\left(\frac{QP_{Step\ 2}}{QP_{Step\ 2}}\right)$$

| Where, | | | Units |
|---|---|---|---|
| $TWER$ | = | Total annual weighted emissions reductions | US tons/yr |
| $WER_{Step\ 1}$ | = | Weighted emissions reductions from Step 1 Calculations | US tons/yr |
| $QP_{Step\ 1}$ | = | Quantification period from Step 1 Calculations | years |
| $WER_{Step\ 2}$ | = | Weighted emissions reductions from Step 2 Calculations | US tons/yr |
| $QP_{Step\ 2}$ | = | Quantification period from Step 2 Calculations | years |

## C. Emissions Reductions from Off-Road Equipment Replacement and Repower Projects

The FARMER Benefits Calculator Tool calculates estimates for GHG emissions reductions and air pollutant emission co-benefits for each of the eligible project types. The following subsections present the equations and methods from the Carl Moyer Program and existing CARB methodologies or Calculator Tools used for Off-Road Equipment Replacement and Repower Projects.

### 1. GHG Equations

Equation 20 shows the GHG emission reductions that occur over the project's entire quantification period. Using Equation 21, the GHG emission reductions from off-road equipment replacement and repower projects are estimated as the difference between the emissions from the baseline and replacement equipment. To determine GHG emissions for off-road equipment, fuel consumption is calculated for the baseline and replacement equipment and multiplied by the fuel's carbon content using Equation 22.

**Equation 20: GHG Emission Reductions from Off-Road Equipment Replacement and Repower Projects (Quantification Period)**

$$QPER_{GHG} = QP \times ER_{GHG}$$

| *Where,* | | | Units |
|---|---|---|---|
| $QPER_{GHG}$ | = | GHG emission reductions over quantification period | $MTCO_2e$ |
| $QP$ | = | Quantification period | years |
| $ER_{GHG}$ | = | Annual GHG emission reductions of replacing the baseline equipment with the replacement equipment | $MTCO_2e/yr$ |

**Equation 21: Annual GHG Emission Reductions from Off-Road Equipment Replacement and Repower Projects**

$$ER_{GHG} = GHG_{baseline} - GHG_{replacement}$$

| Where, | | | Units |
|---|---|---|---|
| $ER_{GHG}$ | = | Annual GHG emission reductions of replacing the baseline equipment with the replacement equipment | $MTCO_2e/yr$ |
| $GHG_{baseline}$ | = | Annual GHG emissions for the baseline equipment | $MTCO_2e/yr$ |
| $GHG_{replacement}$ | = | Annual GHG emissions for the replacement equipment | $MTCO_2e/yr$ |

**Equation 22: GHG Emissions from Off-Road Equipment Replacement and Repower Projects**

$$GHG_i = FC_i \times CC_{fuel} \times \frac{1\ MTCO2e}{1{,}000{,}000\ g}$$

| Where, | | | Units |
|---|---|---|---|
| $GHG_i$ | = | Annual greenhouse gas emissions | MTCO2e/yr |
| $FC_i$ | = | Fuel consumption | gal/yr, scf/yr |
| $CC_{fuel}$ | = | Carbon content (depends on fuel type) | gCO2e/gal, gCO2e/scf |
| $i$ | = | Baseline or replacement | |

Equation 23 is used to determine the estimated annual fuel consumption in the baseline and replacement scenarios, using respective values for brake specific fuel consumption, maximum rated horsepower, load factor, and fuel efficiency factor. It should be noted that while the Carl Moyer methods use the equipment load factors listed in the Carl Moyer Program Guidelines, the GHG equations use a different load factor taken from CARB's *Analysis of California's Diesel Agricultural Equipment Inventory according to Fuel Use, Farm Size, and Equipment Horsepower*.

The BSFC values used are as follows: 1) compression-ignited engines <= 100 hp: 0.408 lb/hp-hr, 2) compression-ignited engines >100 hp: 0.367 lb/hp-hr, 3) spark-ignited engines using CNG: 0.507 lb/hp- hr, and 4) 4-stroke spark-ignited engines using gasoline: 0.605 lb/hp-hr.

**Equation 23: Fuel Consumption for the Baseline and Replacement Equipment**

$$FC_i = BSFC_i \times HP_{max,i} \times LF_i \times AA \times FEF_i$$

| Where, | | | Units |
|---|---|---|---|
| *FC* | = | Fuel consumption of the equipment | gallon/yr |
| *BSFC* | = | Brake specific fuel consumption | gal/bhp-hr |
| $HP_{max}$ | = | Maximum rated horsepower of the equipment | bhp |
| *LF* | = | Load factor of the equipment | Unitless |
| *AA* | = | Annual Activity | hours/year |
| *FEF* | = | Fuel efficiency factor | Unitless |
| *i* | = | Baseline or Replacement | |

Fuel efficiency factor is determined Using Equation 24 – Equation 25.

**Equation 24: Fuel Efficiency Factor of the Baseline Equipment**

$$FEF_{baseline} = 1$$

| Where, | | | Units |
|---|---|---|---|
| $FEF_{baseline}$ | = | Fuel efficiency factor of the baseline equipment | Unitless |

**Equation 25: Fuel Efficiency Factor of the Replacement Equipment**

$$FEF_{replacement} = 1 - (MY_{replacement} - MY_{baseline}) \times AFEF_{year}$$

| Where, | | | Units |
|---|---|---|---|
| $FEF_{replacement}$ | = | Fuel efficiency factor of the replacement equipment | Unitless |
| $MY_{replacement}$ | = | Model year of the replacement equipment | year |
| $MY_{baseline}$ | = | Model year of the baseline equipment | year |
| $AFEF_{year}$ | = | Annual fuel efficiency factor, dependent on year. | Unitless |

According to work by Grisso et al. (2014), tractor models tested in 2000 were 10-15% more efficient than tractors tested in 1980. Grisso et al. presented no data before 1980 and no data after 2007. McCullough et. al. (2022) expanded upon this work, measuring an average improvement in fuel efficiency of 0.55% per year across all tractor tiers from 1987 – 2021. Therefore, no efficiency losses are assumed for models before 1980 and no efficiency gains are gained after 2021. Thus, the annual fuel efficiency factor ($AFEF_{year}$) = 10% gains/20 years = 0.5%/year = 0.005 for 1980 – 1987 models, and 0.55% = 0.0055 for 1987 – 2021 models.

As seen in Equation 26 – Equation 27, the load factor of the replacement equipment is varied up to a certain percentage per data from CARB's diesel agricultural equipment inventory survey and discussed in *Analysis of California's Diesel Agricultural Equipment Inventory according to Fuel Use, Farm Size, and Equipment Horsepower*. Please refer to the document to see what standard deviation value applies to a given equipment type.

**Equation 26: Load Factor of the Replacement Equipment**

$$LF_{replacement} = \frac{HP_{max,baseline} \times LF_{baseline}}{HP_{max,replacement}}$$

| *Where,* | | | <u>Units</u> |
|---|---|---|---|
| $LF_{replacement}$ | = | Load factor of the replacement equipment | Unitless |
| $HP_{max,\ baseline}$ | = | Maximum rated horsepower of the baseline equipment | bhp |
| $LF_{baseline}$ | = | Load factor of the baseline equipment | Unitless |
| $HP_{max,\ replacement}$ | = | Maximum rated horsepower of the replacement equipment | bhp |

**Equation 27: Load Factor of the Replacement Equipment**

$$LF_{replacement} = LF_{baseline} \pm\leq LF_{stdev}$$

| *Where,* | | | <u>Units</u> |
|---|---|---|---|
| $LF_{replacement}$ | = | Load factor of the replacement equipment | Unitless |
| $LF_{baseline}$ | = | Load factor of the baseline equipment | Unitless |
| $LF_{stdev}$ | = | Load factor standard deviation used as adjustment bounds | Unitless |

In the case where the replacement equipment is electric, Equation 23 – Equation 27 and their respective parameters are not applicable. As such, the GHG emissions for these replacement equipment are based on electricity consumed using

Equation 28. Electricity consumed is calculated using Equation 29 and is based on the fuel consumption of the baseline equipment, but with an appropriate energy efficiency ratio (EER) applied.

**Equation 28: Annual GHG Emissions from Zero-Emission Replacement Equipment**

$$GHG_{ZEV\ replacement} = EU_{ZEV\ replacement} \times CC_{electricity} \times \frac{1\ MTCO_2e}{1{,}000{,}000\ gCO_2e}$$

| Where, | | | Units |
|---|---|---|---|
| $GHG_{ZEV\ replacement}$ | = | Greenhouse gas emissions of the zero-emission replacement equipment | $MTCO_2e$/yr |
| $EU_{ZEV\ replacement}$ | = | Electricity use of the zero-emission replacement equipment | kWh/yr |
| $CC_{electricity}$ | = | Carbon content of electricity | $gCO_2e$/kWh |

**Equation 29: Electricity Usage for Zero-Emission Replacement Equipment**

$$EU_{replacement} = \frac{FC_{baseline} \times ED_{baseline\ fuel}}{ED_{electricity} \times EER_{electricity}}$$

| Where, | | | Units |
|---|---|---|---|
| $EU_{replacement}$ | = | Electricity use of the zero-emission replacement | kWh/year |
| $FC_{baseline}$ | = | Fuel consumption of the baseline equipment | gallon/year, scf/year |
| $ED_{baseline\ fuel}$ | = | Energy density of the baseline equipment's fuel type | MJ/gal, MJ/scf |
| $ED_{electricity}$ | = | Energy density of electricity | MJ/kWh |
| $EER_{electricity}$ | = | Energy Efficiency Ratio relative to baseline equipment's fuel type | Unitless |

### 2. Criteria and Toxic Air Pollutant Equations

Equation 30 shows the individual air pollutant emission reductions that occur over the project's entire quantification period. The individual air pollutant emission reductions from off-road equipment replacement and repower projects are estimated, based upon methods outlined in the Carl Moyer Program Guidelines, as the difference between the baseline and replacement scenarios using Equation 31.

Horsepower, Engine Tier, and Model Year are used as lookup inputs to ascertain emission factors and deterioration rates from the Carl Moyer Program Guidelines. The following calculations are repeated for each type of pollutant – i.e., $NO_X$, ROG, and $PM_{10}$.

**Equation 30: Emission Reductions from Off-Road Equipment Replacement and Repower Projects (Quantification Period)**

$$QPER_{pollutant} = QP \times ER_{pollutant} \times 2{,}000 \frac{lbs}{US\ ton}$$

| Where, | | | Units |
|---|---|---|---|
| $QPER_{pollutant}$ | = | Emission reductions over quantification period | lbs |
| $QP$ | = | Quantification period | years |
| $ER_{pollutant}$ | = | Annual emission reductions | US tons/yr |

**Equation 31: Annual Emission Reductions from Off-Road Equipment Replacement and Repower Projects**

$$ER_{pollutant} = \mathrm{AEP}_{baseline} - \mathrm{AEP}_{replacement}$$

$$ER_{pollutant} = \mathrm{AEP}_{baseline} - \mathrm{AEP}_{replacement}$$

| Where, | | | Units |
|---|---|---|---|
| $ER_{pollutant}$ | = | Annual emission reductions | US tons/yr |
| $AEP_{baseline}$ | = | Annual emissions for the baseline equipment | US tons/yr |
| $AEP_{replacement}$ | = | Annual emissions for the replacement equipment | US tons/yr |

Equation 32 is used to determine the estimated annual air pollutant emissions in the baseline and replacement scenarios, using respective values for emission factors and deterioration product.

**Equation 32: Annual Emissions for Baseline and Replacement Equipment**

$$AEP_i = (EF_i + DP_i) \times LF_i \times HP_i \times \frac{AA}{907{,}200\ (g/US\ ton)}$$

| Where, | | | Units |
|---|---|---|---|
| $AEP_i$ | = | Annual emissions for the equipment | US tons/yr |
| $EF_i$ | = | Zero-mile emission factor for the equipment | g/bhp-hr |
| $DP_i$ | = | Hour-based deterioration product for the equipment | g/bhp-hr |
| $LF_i$ | = | Equipment Load Factor | Unitless |
| $HP_i$ | = | Maximum rated horsepower of the equipment | bhp |
| $AA$ | = | Annual Activity | hours/year |
| $i$ | = | Baseline or Replacement | |

Equation 33 is used to determine the hour-based deterioration product in the baseline and replacement scenarios, using respective values for deterioration rate and total equipment activity.

**Equation 33: Hour-Based Deterioration Product for Baseline and Replacement Equipment**

$$DP_i = DR_i \times TEA_i$$

| *Where,* | | | Units |
|---|---|---|---|
| $DP_i$ | = | Hour-based deterioration product for the equipment | g/bhp-hr |
| $DR_i$ | = | Deterioration rate for the equipment | g/bhp-hr-hr |
| $TEA_i$ | = | Total equipment activity of the equipment | hours |
| $i$ | = | Baseline or Replacement | |

Equation 34 is used to determine the total equipment activity in the baseline and replacement scenarios, using respective values for deterioration life.

**Equation 34: Total Equipment Activity for the Baseline and Replacement Equipment**

$$TEA_i = AA \times DL_i$$

| *Where,* | | | Units |
|---|---|---|---|
| $TEA_i$ | = | Total equipment activity of the equipment | hours |
| $AA$ | = | Annual activity | hours/year |
| $DL_i$ | = | Deterioration life of the equipment | years |
| $i$ | = | Baseline or Replacement | |

Equation 35 is used to determine the deterioration life in the baseline scenario.

**Equation 35: Deterioration Life for the Baseline Equipment**

$$DL_{baseline} = YR_{replacement} - MY_{baseline} + \frac{QP}{2}$$

| Where, | | | Units |
|---|---|---|---|
| $DL_{baseline}$ | = | Deterioration life of the baseline equipment | years |
| $YR_{replacement}$ | = | Expected first year of operation of the replacement equipment | year |
| $MY_{baseline}$ | = | Baseline engine model year | year |
| $QP$ | = | Quantification Period (this is essentially project life or "project implementation time frame" as denoted in the Carl Moyer Guidelines) | years |

Equation 36 is used to determine the deterioration life in the replacement scenario. If the replacement equipment is not brand new, but is instead used, then Equation 37 is applied to calculate deterioration life.

**Equation 36: Deterioration Life for the Replacement Equipment**

$$DL_{replacement} = \frac{QP}{2}$$

| Where, | | | Units |
|---|---|---|---|
| $DL_{replacement}$ | = | Deterioration life of the replacement equipment | years |
| $QP$ | = | Quantification Period (this is essentially project life or "project implementation time frame" as denoted in the Carl Moyer Guidelines) | years |

**Equation 37: Deterioration Life for the Replacement Equipment if it is Used**

$$DL_{replacement} = YR_{replacement} - MY_{replacement} + \frac{QP}{2}$$

| *Where,* | | | Units |
|---|---|---|---|
| $DL_{replacemnet}$ | = | Deterioration life of the replacement equipment | years |
| $YR_{replacemnet}$ | = | Expected first year of operation of the replacement equipment | year |
| $MY_{replacemnet}$ | = | Replacement equipment engine model year | year |
| $QP$ | = | Quantification Period (this is essentially project life or "project implementation time frame" as denoted in the Carl Moyer Guidelines) | years |

### a. Two-Step Cost-Effectiveness Calculations

Please refer to the description regarding two-step cost-effectiveness calculations in the "Criteria and Toxic Air Pollutant Equations" subsection of the "Emissions Reductions from On-Road Heavy-Duty Truck Replacement and Repower Projects" section. This calculation methodology is also applied to Off-Road Equipment Replacement and Repower projects when the Replacement is a zero-emission vehicle/equipment – e.g., electric forklifts used in agriculture, electric tractors, and so forth.

## D. Emissions Reductions from Irrigation Pump Engines Replacement and Repower Projects

The FARMER Benefits Calculator Tool estimates GHG emissions reductions and air pollutant emission co-benefits for each of the project types. The following subsections present the equations and methods from the Carl Moyer Program and existing CARB methodologies or Calculator Tools used for Irrigation Pump Engines Replacement and Repower Projects.

### 1. GHG Equations

Equation 38 shows the GHG emission reductions that occur over the project's entire quantification period. Using Equation 39, the difference in GHG emissions between the baseline pump and the replacement pump constitutes the overall reduction.

**Equation 38: GHG Emission Reductions from Irrigation Pump Engines (Quantification Period)**

$$QPER_{GHG} = QP \times ER_{GHG}$$

| Where, | | | Units |
|---|---|---|---|
| $QPER_{GHG}$ | = | GHG emission reductions over quantification period | $MTCO_2e$ |
| $QP$ | = | Quantification period | years |
| $ER_{GHG}$ | = | Annual GHG emission reductions | $MTCO_2e/yr$ |

**Equation 39: Annual GHG Emission Reductions from Irrigation Pump Engines**

$$ER_{GHG} = GHG_{baseline} - GHG_{replacement}$$

| Where, | | | Units |
|---|---|---|---|
| $ER_{pollutant}$ | = | Annual GHG emission reductions | $MTCO_2e/yr$ |
| $GHG_{baseline}$ | = | Annual GHG emissions for the baseline equipment | $MTCO_2e/yr$ |
| $GHG_{replacement}$ | = | Annual GHG emissions for the replacement equipment | $MTCO_2e/yr$ |

Using Equation 40, GHG emissions are a function of fuel consumption.

**Equation 40: GHG Emissions from Gasoline, Diesel, or Alternative Fuels Irrigation Pump Engines**

$$GHG_i = FC_i \times CC_{fuel} \times \frac{1\ MTCO_2e}{1{,}000{,}000\ gCO_2e}$$

| Where, | | | Units |
|---|---|---|---|
| $GHG_i$ | = | Annual greenhouse gas emissions | $MTCO_2e$/yr |
| $FC_i$ | = | Fuel consumption | gal/yr, scf/yr |
| $CC_{fuel}$ | = | Carbon content (depends on fuel type) | $gCO_2e$/gal, $gCO_2e$/scf |
| *i* | = | Baseline or Replacement | |

Equation 41 is used to determine the estimated annual fuel consumption in the baseline and replacement scenarios, using respective values for brake specific fuel consumption, maximum rated horsepower, and the load factor.

It should be noted that while the Carl Moyer methods use the equipment load factors listed in the Carl Moyer Program Guidelines, the GHG equations use a different load factor taken from CARB's *Analysis of California's Diesel Agricultural Equipment Inventory according to Fuel Use, Farm Size, and Equipment Horsepower*.

The BSFC values used are as follows: 1) compression-ignited engines <= 100 hp: 0.408 lb/hp-hr, 2) compression-ignited engines >100 hp: 0.367 lb/hp-hr, 3) spark-ignited engines using CNG: 0.507 lb/hp- hr, and 4) 4-stroke spark-ignited engines using gasoline: 0.605 lb/hp-hr.

**Equation 41: Fuel Consumption for the Baseline and Replacement Irrigation Pump Engines**

$$FC_i = BSFC_i \times HP_{max,i} \times LF_i \times AA$$

| Where, | | | Units |
|---|---|---|---|
| *FC* | = | Fuel consumption of the equipment | gal/yr |
| *BSFC* | = | Brake specific fuel consumption | gal/bhp-hr |
| $HP_{max}$ | = | Maximum rated horsepower of the equipment | bhp |
| *LF* | = | Load factor of the equipment | Unitless |
| *AA* | = | Annual Activity | hours/year |
| *i* | = | Baseline or Replacement | |

As seen in Equation 42 – Equation 43, the load factor of the replacement equipment varies up to a certain percentage per data from CARB's diesel agricultural equipment inventory survey and discussed in *Analysis of California's Diesel Agricultural Equipment Inventory according to Fuel Use, Farm Size, and Equipment Horsepower*. Please refer to the document to see what standard deviation value applies to a given equipment type.

**Equation 42: Load Factor of the Replacement Irrigation Pump Engine**

$$LF_{replacement} = \frac{HP_{max,baseline} \times LF_{baseline}}{HP_{max,replacement}}$$

| *Where,* | | | Units |
|---|---|---|---|
| $LF_{replacement}$ | = | Load factor of the replacement equipment | Unitless |
| $HP_{max,\ baseline}$ | = | Maximum rated horsepower of the baseline equipment | bhp |
| $LF_{baseline}$ | = | Load factor of the baseline equipment | Unitless |
| $HP_{max,\ replacement}$ | = | Maximum rated horsepower of the replacement equipment | bhp |

**Equation 43: Load Factor of the Replacement Irrigation Pump Engine**

$$LF_{replacement} = LF_{baseline} \ \pm\leq \ LF_{stdev}$$

| *Where,* | | | Units |
|---|---|---|---|
| $LF_{replacement}$ | = | Load factor of the replacement equipment | Unitless |
| $LF_{baseline}$ | = | Load factor of the baseline equipment | Unitless |
| $LF_{stdev}$ | = | Load factor standard deviation used as adjustment bounds | Unitless |

In the case where the replacement equipment is electric, Equation 41 – Equation 43 and their respective parameters are not applicable. As such, the GHG emissions for these replacement equipment are based on electricity consumed using Equation 44. Electricity consumed is calculated using Equation 45 and is based on the fuel consumption of the baseline equipment, but with an appropriate energy efficiency ratio (EER) applied.

**Equation 44: Annual GHG Emissions from Zero-Emission Irrigation Pump Engine**

$$GHG_{replacement} = EU_{replacement} \times CC_{electricity} \times \frac{1\ MTCO_2e}{1{,}000{,}000\ gCO_2e}$$

| Where, | | | Units |
|---|---|---|---|
| $GHG_{replacement}$ | = | Annual greenhouse gas emissions | $MTCO_2e$/yr |
| $EU_{replacement}$ | = | Electricity use of the zero-emission replacement engine | kWh/year |
| $CC_{electricity}$ | = | Carbon content of electricity | $gCO_2e$/kWh |

**Equation 45: Electricity Usage for Zero-Emission Irrigation Pump Engine**

$$EU_{replacement} = \frac{FC_{replacement} \times ED_{baseline\ fuel}}{ED_{electricity} \times EER_{electricity}}$$

| Where, | | | Units |
|---|---|---|---|
| $EU_{replacement}$ | = | Electricity use of the zero-emission replacement | kWh/yr |
| $FC_{baseline}$ | = | Fuel consumption of the baseline tractor | gal/yr, scf/yr |
| $ED_{baseline\ fuel}$ | = | Energy density of the baseline tractor's fuel type | MJ/gal, MJ/scf |
| $ED_{electricity}$ | = | Energy density of electricity | MJ/kWh |
| $EER_{electricity}$ | = | Energy Efficiency Ratio of electricity relative baseline tractor's fuel type | Unitless |

### 2. Criteria and Toxic Air Pollutant Equations

Please refer to the equations and methods described in the "Criteria and Toxic Air Pollutant Equations" subsection of the "Emissions Reductions from Off-Road Equipment Replacement and Repower Projects" section. The same equations and methods are utilized.

#### a. Two-Step Cost-Effectiveness Calculations

Please refer to the description regarding two-step cost-effectiveness calculations in the "Criteria and Toxic Air Pollutant Equations" subsection of the "Emissions Reductions from On-Road Heavy-Duty Truck Replacement and Repower Projects" section.

## E. Emissions Reductions from Zero-Emission Utility Terrain Vehicles Rebates

The FARMER Benefits Calculator tool calculates estimates for GHG emissions reductions and air pollutant emission co-benefits for each of the project types. The following subsections present the equations and methods from the Carl Moyer Program and existing CARB methodologies or Calculator Tools used for rebates for the purchase of Zero-Emission Utility Terrain Vehicles.

### 1. GHG Equations

Equation 46 shows the GHG emission reductions that occur over the project's entire quantification period. Using Equation 47 – Equation 51, GHG emissions are calculated based on fuel usage. Fuel usage for baseline vehicles and electricity usage for replacement vehicles are determined using Equation 49 and Equation 51, respectively.

**Equation 46: GHG Emission Reductions from Rebates for the Purchase of Zero-Emission Utility Terrain Vehicles (Quantification Period)**

$$QPER_{GHG} = QP \times ER_{GHG}$$

| Where, | | | Units |
|---|---|---|---|
| $QPER_{GHG}$ | = | GHG emission reductions over quantification period | $MTCO_2e$ |
| $QP$ | = | Quantification period | years |
| $ER_{GHG}$ | = | Annual GHG emission reductions | $MTCO_2e/yr$ |

**Equation 47: Annual GHG Emission Reductions from Rebates for the Purchase of Zero-Emission Utility Terrain Vehicles**

$$ER_{GHG} = GHG_{baseline} - GHG_{replacement\ UTV}$$

| Where, | | | Units |
|---|---|---|---|
| $ER_{GHG}$ | = | Annual emission reductions | $MTCO_2e/yr$ |
| $GHG_{baseline}$ | = | Annual GHG emissions for the baseline equipment (fuel type dependent) | $MTCO_2e/yr$ |
| $GHG_{replacement\ UTV}$ | = | Annual GHG emissions for the replacement equipment (fuel type dependent) | $MTCO_2e/yr$ |

**Equation 48: GHG Emissions for Baseline Vehicle/Equipment (diesel, gasoline, or alternative fuels)**

$$GHG_{baseline} = FC_{baseline} \times CC_{baseline\ fuel} \times \frac{1\ MTCO_2e}{1{,}000{,}000\ gCO_2e}$$

| *Where,* | | | Units |
|---|---|---|---|
| $GHG_{baseline}$ | = | Annual greenhouse gas emissions of the baseline UTV | $MTCO_2e$/yr |
| $FC_{baseline}$ | = | Fuel consumption of the baseline UTV | gal/yr, scf/yr |
| $CC_{baseline\ fuel}$ | = | Carbon content of the baseline fuel (depends on fuel type) | $gCO_2e$/gal, $gCO_2e$/scf |

**Equation 49: Fuel Usage for Baseline Vehicle/Equipment (diesel, gasoline, or alternative fuels)**

$$FC_{baseline} = BSFC \times HP \times LF \times AA \times GC$$

| *Where,* | | | Units |
|---|---|---|---|
| $FC_{baseline}$ | = | Fuel consumption of the baseline UTV | gal/yr, scf/yr |
| *BSFC* | = | Brake specific fuel consumption (fuel specific) | lb/bhp-hr |
| *HP* | = | Maximum rated horsepower of the equipment | bhp |
| *LF* | = | Load factor | Unitless |
| *AA* | = | Annual activity | hours/year |
| *GC* | = | Gallon conversion (fuel specific) | gal/lb, gal/scf |

On a case-by-case basis, applicants may have the option of scrapping a baseline tractor being operated and used as a UTV, in lieu of a baseline UTV, and replacing that equipment with the ZEV UTV. Each case will be at the discretion of CARB and the air districts.

**Equation 50: GHG Emissions from Zero-Emission Utility Terrain Vehicles**

$$GHG_{replacement\ UTV} = EU_{replacement\ UTV} \times CC_{electricity} \times \frac{1\ MTCO_2e}{1{,}000{,}000\ gCO_2e}$$

| Where, | | | Units |
|---|---|---|---|
| $GHG_{replacement\ UTV}$ | = | Annual greenhouse gas emissions of the replacement ZEV UTV | $MTCO_2e$/yr |
| $EU_{replacement\ UTV}$ | = | Electricity use of the replacement ZEV UTV | kWh/year |
| $CC_{electricity}$ | = | Carbon content of electricity | $gCO_2e$/kWh |

**Equation 51: Electricity Usage for Zero-Emission Utility Terrain Vehicles**

$$EU_{replacement\ UTV} = \frac{FC_{baseline\ UTV} \times ED_{baseline\ fuel}}{ED_{electricity} \times EER_{electricity}}$$

| Where, | | | Units |
|---|---|---|---|
| $EU_{replacement\ UTV}$ | = | Electricity use of the replacement ZEV UTV | kWh/yr |
| $FC_{baseline\ tractor}$ | = | Fuel consumption of the baseline tractor | gal/yr, scf/yr |
| $ED_{baseline\ fuel}$ | = | Energy density of the baseline tractor's fuel type | MJ/gal, MJ/scf |
| $ED_{electricity}$ | = | Energy density of electricity | MJ/kWh |
| $EER_{electricity}$ | = | Energy Efficiency Ratio relative baseline tractor's fuel type | Unitless |

### 2. Criteria and Toxic Air Pollutant Equations

Please refer to the equations and methods described in the “Criteria and Toxic Air Pollutant Equations” subsection of the “Emissions Reductions from Off-Road Equipment Replacement and Repower Projects” section. The same equations and methods are utilized.

## F. Emissions Reductions from Agricultural Trade-Up Pilot Projects

The Agricultural Trade-Up (Ag Trade-Up) Pilot project type is essentially two Off-Road equipment replacement and repower projects paired together. Projects under this category are limited to diesel as a fuel type. In the first transaction (known as Transaction #1), a farmer purchases new equipment (e.g., a Tier 4) to replace his older equipment (e.g., Tier 3). However, rather than scrapping the still functioning older baseline equipment, the first farmer can now transition his baseline vehicle to a different farmer enabling him/her to scrap their much older equipment (e.g., Tier 0 or Tier 1). In the Ag Trade-up, the baseline equipment from the first transaction effectively becomes the replacement vehicle in the second transaction.

### Transaction #1

The FARMER Benefits Calculator tool calculates estimates for GHG emissions reductions and air pollutant emission co-benefits for each of the project types. The following subsection refers to the equations and methods used to determine GHG and criteria and toxic air pollutant emissions for Transaction #1 in the Ag Trade-Up project type.

#### 1. GHG Equations for Transaction #1

Please refer to the equations and methods described in the "GHG Equations" subsection of the "Emissions Reductions from Off-Road Equipment Replacement and Repower Projects" section. The same equations and methods are utilized.

#### 2. Criteria and Toxic Air Pollutant Equations for Transaction #1

Please refer to the equations and methods described in the "Criteria and Toxic Air Pollutant Equations" subsection of the "Emissions Reductions from Off-Road Equipment Replacement and Repower Projects" section. The same equations and methods are utilized.

### Transaction #2

The FARMER Benefits Calculator tool calculates estimates for GHG emissions reductions and air pollutant emission co-benefits for each of the project types. The following subsection refers to the equations and methods used to determine GHG and criteria and toxic air pollutant emissions for Transaction #2 in the Ag Trade-Up project type.

#### 1. GHG Equations for Transaction #2

Please refer to the equations and methods described in the "GHG Equations" subsection of the "Emissions Reductions from Off-Road Equipment Replacement and Repower Projects" section. The same equations and methods are utilized.

### 2. Criteria and Toxic Air Pollutant Equations for Transaction #2

Please refer to the equations and methods described in the "Criteria and Toxic Air Pollutant Equations" subsection of the "Emissions Reductions from Off-Road Equipment Replacement and Repower Projects" section. The same equations and methods are utilized. There are two slight differences: 1) as noted in Equation 52, the Annual Activity that is used to determine the Total Equipment Activity is based on that equipment's original annual activity (i.e., Annual Activity from Transaction #1) with its first owner rather than the annual activity it will have under its second-hand owner, and 2) as noted in Equation 53, a modified version of the Deterioration Life calculation is performed. These changes were done to account for the fact that the methods and equations seen in the Carl Moyer Program Guidelines assume that the replacement vehicle/equipment is brand new.

For the baseline vehicle/equipment in transaction #1 that will serve as the replacement vehicle/equipment in transaction #2, the Annual Activity used to determine the Total Equipment Activity is based on that equipment's original annual activity with its first owner rather than the annual activity it will have under its second-hand owner. Since methods and equations seen in the Carl Moyer Program Guidelines assume that the replacement vehicle/equipment is brand new, this adjustment is done to account for the fact that the vehicle/equipment in question is used and not brand new.

**Equation 52: Total Equipment Activity for Baseline and Replacement Equipment**

$$TEA_i = AA \times DL_i$$

| *Where,* | | | Units |
|---|---|---|---|
| $TEA_i$ | = | Total equipment activity of the equipment | hours |
| $AA$ | = | Annual activity | hours/year |
| $DL_i$ | = | Deterioration life of the equipment | years |
| $i$ | = | Baseline or Replacement | |

**Equation 53: Deterioration Life for Replacement Equipment**

$$DL_{replacement} = YR_{replacement} - MY_{replacement} + \frac{QP}{2}$$

| Where, | | | Units |
| --- | --- | --- | --- |
| $DL_{replacement}$ | = | Deterioration life of the replacement equipment | years |
| $YR_{replacement}$ | = | Expected first year of operation of the replacement equipment | year |
| $MY_{replacement}$ | = | Replacement engine model year | year |
| $QP$ | = | Quantification Period (this is essentially project life or "project implementation time frame" as denoted in the Carl Moyer Guidelines) | year |

## G. Emissions Reductions from 2 (or-more)-for-1 Off-Road Equipment Replacement and Repower Projects

This project category is essentially the same as the Off-Road Equipment Replacement/Repower or the Irrigation Pump Engine Replacement/Repower. However, this category allows an applicant to procure a replacement at a different horsepower rating than their baseline if the given horsepower rating is no longer available. Additionally, this category allows for an applicant to scrap more than one baseline equipment to increase cost-effectiveness. The modified equations in this section, with the exception of the fuel efficiency factor, are also applicable to Agricultural Irrigation Pumps.

For the first year of the FARMER Program, staff developed a conservative GHG quantification methodology for 2 (or-more)-for-1 projects that mirrors the assumptions made in the Carl Moyer Program and does not account for vehicle or equipment efficiency improvements. Staff intends to fund this project category initially using AB 118 funds and will collect and analyze usage data from the implemented projects to inform and develop future quantification methodologies that incorporate efficiency improvements.

### 1. GHG Equations

Please refer to the equations and methods described in the "GHG Equations" subsection of the "Emissions Reductions from Off-Road Equipment Replacement and Repower Projects" section. The same equations and methods are utilized. However, a notable difference is that rather than scrapping one baseline equipment/vehicle, the applicant could opt to scrap multiple pieces of equipment/vehicles to improve the cost-effectiveness. This is reflected by modifying Equation 21 to be a summation - i.e., Equation 54. Note that for fuel consumption and carbon content, units vary depending of fuel type of baseline and/or replacement equipment, respectively.

**Equation 54: Annual GHG Emission Reductions from Off-Road Equipment Projects**

$$ER_{GHG} = \left(\sum_{j=1}^{N} GHG_{baseline,j} - GHG_{replacement}\right) \times \frac{1\ MTCO_2e}{1{,}000{,}000\ gCO_2e}$$

| Where, | | | Units |
|---|---|---|---|
| $ER_{GHG}$ | = | Annual GHG emission reductions of replacing the baseline equipment | $MTCO_2e$/yr |
| $GHG_{baseline,\ j}$ | = | Annual GHG emissions of the baseline equipment | $MTCO_2e$/yr |
| $GHG_{replacement}$ | = | Annual GHG emissions of the replacement equipment | $MTCO_2e$/yr |

*N = # of baseline equipment applicant is scrapping*

Moreover, the fuel efficiency factor applied to off-road equipment was also modified for the case where the applicant is scrapping more than one baseline equipment to increase the cost-effectiveness. The fuel efficiency is calculated by determining how much newer the replacement is relative to the baseline equipment as seen in Equation 25.

However, when multiple baselines are being scrapped, the average model year across all of the baselines is used as demonstrated in Equation 55.

**Equation 55: Fuel Efficiency Factor of the Replacement Equipment**

$$FEF_{replacement} = 1 - \left(MY_{replacement} - \frac{\sum_{j=1}^{N} MY_{baseline,j}}{N}\right) \times AFEF_{year}$$

| Where, | | | Units |
|---|---|---|---|
| $FEF_{replacement}$ | = | Fuel efficiency factor of the replacement equipment | Unitless |
| $MY_{replacement}$ | = | Model year of the replacement equipment | Year |
| $MY_{baseline,\ j}$ | = | Model year of the baseline equipment | Year |
| $AFEF_{year}$ | = | Annual fuel efficiency factor, dependent on year | Unitless |

*N = # of baseline equipment applicant is scrapping*

According to work by Grisso et al. (2014), tractor models tested in 2000 were 10-15% more efficient than tractors tested in 1980. Grisso et al. presented no data before 1980 and no data after 2007. McCullough et. al. (2022) expanded upon this work, measuring an average improvement in fuel efficiency of 0.55%

per year across all tractor tiers from 1987 – 2021. Therefore, no efficiency losses are assumed for models before 1980 and no efficiency gains are gained after 2021. Thus, the annual fuel efficiency factor ($AFEF_{year}$) = 10% gains/20 years = 0.5%/year = 0.005 for 1980 – 1987 models, and 0.55% = 0.0055 for 1987 – 2021 models.

Lastly, in determining the load factor for the replacement equipment, a weighted average based on usage (i.e., Annual Activity) of the horsepower values for the baseline equipment being scrapped is used.

Equation 56 is a modified version of Equation 26.

**Equation 56: Load Factor of the Replacement Equipment**

$$LF_{replacement} = \frac{\frac{\sum_{j=1}^{N}\left(HP_{max,baseline,j} \times AA_j\right)}{\sum_{j=1}^{N} AA_j} \times LF_{baseline}}{HP_{max,replacement}}$$

*Where,*

| | | | Units |
|---|---|---|---|
| $LF_{replacement}$ | = | Load factor of the replacement equipment | Unitless |
| $HP_{max,\ baseline\ j}$ | = | Maximum rated horsepower of the baseline equipment | bhp |
| $AA_j$ | = | Annual Activity | hours/year |
| $LF_{baseline}$ | = | Load factor of the baseline equipment | Unitless |
| $HP_{max,\ replacement}$ | = | Maximum rated horsepower of the replacement equipment | bhp |

*N = # of baseline equipment applicant is scrapping*

## 2. Criteria and Toxic Air Pollutant Equations

Please refer to the equations and methods described in the "Criteria and Toxic Air Pollutant Equations" subsection of the "Emissions Reductions from Off-Road Equipment Replacement and Repower Projects" section. The same equations and methods are utilized. However, one notable difference is that rather than scrapping one baseline equipment/vehicle, the applicant could opt to scrap multiple pieces of equipment/vehicles to improve the cost-effectiveness. This is reflected by modifying Equation 31 to be a summation – i.e., Equation 57.

**Equation 57: Annual Emission Reductions from Off-Road Equipment Replacement and Repower Projects**

$$ER_{pollutant} = \sum_{j=1}^{N} \text{AEP}_{baseline,j} - \text{AEP}_{replacement}$$

*Where,*

| | | | Units |
|---|---|---|---|
| $ER_{pollutant}$ | = | Annual emission reductions | US tons/yr |
| $AEP_{baseline,\,j}$ | = | Annual emissions for the baseline equipment | US tons/yr |
| $AEP_{replacement}$ | = | Annual emissions for the replacement equipment | US tons/yr |

*N = # of baseline equipment applicant is scrapping*

## Section C. References

The following references were used in the development of this Quantification Methodology and the FARMER Benefits Calculator Tool:

California Air Resources Board. (2018). Analysis of California's Diesel Agricultural Equipment Inventory according to Fuel Use, Farm Size, and Equipment Horsepower.

California Air Resources Board. (2018). CCI Quantification Methodology Emission Factor Database. Retrieved from: http://www.arb.ca.gov/cci-resources

California Air Resources Board. (2017). 2017 Off-road Diesel Emission Factors. https://ww2.arb.ca.gov/our-work/programs/msei/road-category/msei-documentation-road-diesel-equipment

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Grisso, R., Perumpral, J., Roberson, G., Pitman, R. (2014). Predicting Tractor Diesel Fuel Consumption. Retrieved from: http://pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/442/442-073/442-073_pdf.pdf

McCullough, M., Hamilton, L., Walters, C. (2022). Assessing the Cost and Fuel Consumption of Off-Road Agricultural Equipment. Retrieved from: https://digitalcommons.calpoly.edu/agb_fac/161/

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