California Air Resources Board

Quantification Methodology

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

California Climate Investments

FINAL
June 2, 2022

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.

Quantification Methodology for the CARB FARMER Program

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 at: www.arb.ca.gov/cci-expenditurerecords.

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 at: http://www.arb.ca.gov/cci-resources.

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 at: www.arb.ca.gov/farmer.

Methodology Development

CARB developed this Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability[1]. 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 May 19, 2022. 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 at: www.arb.ca.gov/cci-cobenefits.

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[1] California Air Resources Board. CCI Funding Guidelines for Administering Agencies. www.arb.ca.gov/cci-fundingguidelines

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 at: http://www.arb.ca.gov/cci-resources. 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: http://www.arb.ca.gov/cci-resources.

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 projects contracted after November 19, 2021, corresponding to updated Carl Moyer guidelines[2] approved at the November 19, 2021 CARB Board Meeting.
- Updating the GHG carbon intensity values to 2020 weighted averages.
- Adding a new project type for Zero-Emission (ZE) Agricultural Equipment.
- Adding a new project type for Used Agricultural Equipment.
- Adding Forklifts as a selectable off-road equipment type.
- Adding optional LSI engine certification standards as a selection, where applicable.
- Adding "APCF (FARMER)" as an available funding source.
- Adding inputs for "farm size" information.
- Fixing GHG calculations for mobile off-road electric replacements.
- Fixing emissions calculations involving on-road baseline trucks with model years older than the available emission factors.
- Fixing the "Baseline Tier" display on the Air District Reporting Summary sheet.
- Revising Project Implementation Costs outputs to be in terms of "$ per hour" rather than "$ per job".
- Revising the GHG and Co-benefits Summary sheets to display FARMER-prorated emissions.

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[2] CARB. Carl Moyer Program Guidelines. https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm

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[3]:

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")

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[3] CARB. FARMER Program Guidelines.
https://ww2.arb.ca.gov/resources/documents/farmer-program-guidelines

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[4] that is meant to support a project from #1-4

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[4] Refer to the Carl Moyer Guidelines for guidance on eligible infrastructure:
https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm

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)
$\text{Emission Reductions} = \sum_{i=1}^{N} Baseline\ Equipment/Vehicle\ Emissions\ -\ Replacement\ Equipment/Vehicle\ Emissions$ *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[5].
2. Equations and methods from previously existing CARB methodologies or Calculator Tools.

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[5] CARB. Carl Moyer Program Guidelines. https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm

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/year
ER_{NOx}	=	Annual NO_x emission reductions	US tons/year
ER_{ROG}	=	Annual ROG emission reductions	US tons/year
ER_{PM}	=	Annual PM emission reductions	US tons/year

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.

Equation 2: Potential Grant Amount at Applicable Cost-Effectiveness Limit[6]

$$PGA_{CE} = CL \times WER \times \frac{1}{CRF}$$

Where,			Units
PGA_{CE}	=	Potential grant amount, based on cost-effectiveness limit	$
CL	=	Cost-effectiveness limit	$/ton
WER	=	Weighted emissions reduction of replacing the baseline equipment	tons/year
CRF	=	Capital Recovery Factor	Unitless

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[6] Please refer to the FARMER Program Guidelines and/or Carl Moyer Programs for more information regarding applicability.

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

$$PGA_{EC} = C_{Replacement} \times PE$$

Where,			Units
PGA_{EC}	=	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.

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[7]

$$ER_{GHG} = ((FC_{baseline} \times CC_{baseline\ fuel})$$
$$- (FC_{replacement} \times CC_{replacement\ fuel})) \times \frac{1\ MTCO2e}{1,000,000\ gCO2e}$$

Where,			Units
ER_{GHG}	=	Annual GHG emission reductions of replacing the baseline truck with the replacement truck	MTCO2e/yr
$FC_{baseline}$	=	Fuel consumption of the baseline truck	gal/yr
$CC_{baseline\ fuel}$	=	Carbon content of baseline fuel type	gCO2e/DGE
$FC_{replacement}$	=	Fuel consumption of the replacement truck	gal/yr
$CC_{replacement\ fuel}$	=	Carbon content of replacement fuel type	gCO2e/DGE

Equation 6: Fuel Consumption for the Baseline and Replacement Truck

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

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

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 7 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 8.

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}.

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[7] If 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 7: 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   US tons/year
                              baseline truck with the replacement truck

Equation 8: Annual Emission Reductions from On-Road Heavy-Duty Truck Projects

$$ER_{pollutant} = AEP_{baseline} - AEP_{replacement}$$

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

Equation 9 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 9: 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 =   Annual emissions for the truck   US tons/year
EF =   Zero-mile emission factor for the truck   gram/mile
DP =   Mile-based deterioration product for the truck   gram/mile
AA =   Annual activity   miles/year
i =   Baseline or Replacement

Equation 10 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 10: Mile-Based Deterioration Product for Baseline and Replacement Truck

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

Where,   Units
DP   =   Mile-based deterioration product for the truck   gram/mile
DR   =   Deterioration rate for the truck   g/mi-10,000 mi
TEA   =   Total equipment activity of the truck   miles
i   =   Baseline or Replacement

Equation 11 is used to determine the total equipment activity in the baseline and replacement scenarios, using respective values for deterioration life.

Equation 11: 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   =   Annual activity   miles/year
DL   =   Deterioration life of the truck   years
i   =   Baseline or Replacement

Equation 12 is a modified equation for Total Equipment Activity and is used in the case where the truck is used and not brand new.

Equation 12: Total Equipment Activity for Used Truck[8]

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

                                                                                Units

Where,
TEA   =   Total equipment activity of the truck   miles
AA   =   Annual activity   miles/year
DL   =   Deterioration life of the truck   years
COR   =   Current Odometer Reading   miles
i   =   Baseline or Replacement

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[8] This formula is used when the current odometer reading is >10,000 miles – the criteria used for defining a used truck.

Equation 13 is used to determine the deterioration life in the baseline scenario.

Equation 13: Deterioration Life for the Baseline Truck

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

			Units
Where,			
$DL_{baseline}$	=	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 14 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 15 is applied to calculate deterioration life.

Equation 14: Deterioration Life for the Replacement Truck

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

			Units
Where,			
$DL_{replacement}$	=	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 15: Deterioration Life for the Truck if it is Used

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

			Units
Where,			
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
i	=	Baseline or Replacement	

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 16 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 16: Potential Grant Amount for Two-Step Cost-Effectiveness

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

Where,			Units
$PGA_{Two-Step}$	=	Potential grant amount for a project eligible for a Carl Moyer Two-Step Cost-Effectiveness Calculation	$
$PGA_{Step\ 1}$	=	Potential grant amount based on $30,000 cost-effectiveness limit	$
$PGA_{Step\ 2}$	=	Potential grant amount based on $100,000 cost-effectiveness limit	$

Using Equation 17, 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 18.

Equation 17: 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/year

Equation 18: 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/year
$WER_{Step\,1}$ =   Weighted emissions reductions from Step 1   US tons/year
                   Calculations
$QP_{Step\,1}$ =   Quantification period from Step 1 Calculations   Years
$WER_{Step\,2}$ =   Weighted emissions reductions from Step 2   US tons/year
                   Calculations
$QP_{Step\,2}$ =   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 19 shows the GHG emission reductions that occur over the project's entire quantification period. Using Equation 20, 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 21.

Equation 19: 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 20: 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 21: GHG Emissions from Off-Road Equipment Replacement and Repower Projects

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

Where,			Units
GHG	=	Greenhouse gas emissions	$MTCO_2e/yr$
FC	=	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 22 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*[9].

Equation 22: Fuel Consumption for the Baseline and Replacement Equipment[10]

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

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
FEF	=	Fuel efficiency factor	Unitless
i	=	Baseline or Replacement	

Fuel efficiency factor is determined using Equation 23 – Equation 24.

Equation 23: Fuel Efficiency Factor of the Baseline Equipment

$$FEF_{baseline} = 1$$

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

Equation 24: Fuel Efficiency Factor of the Replacement Equipment[11]

$$FEF_{replacement} = 1 - (MY_{replacement} - MY_{baseline}) \times 0.005$$

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

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[9] Analysis of California's Diesel Agricultural Equipment Inventory according to Fuel Use, Farm Size, and Equipment Horsepower. Link to main page: https://www.arb.ca.gov/msei/ordiesel.htm Link to document: https://www.arb.ca.gov/msei/ordiesel/agfuelstudy2018.pdf

[10] 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 (sources: Exhaust Emission Factors for Nonroad Engine Modeling – Spark-Ignition, U.S. EPA, 2010; Off-Road Diesel Emission Factors, California Air Resources Board, 2018).

[11] 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. Therefore, no efficiency losses are assumed for models before 1980 and no efficiency gains are gained after 2007. 10% gains/20 years = 0.5%/year = 0.005.

As seen in Equation 25 – Equation 26, 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.*

Equation 25: Load Factor of the Replacement Equipment

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

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 26: Load Factor of the Replacement Equipment[12]

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

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 22 – Equation 26 and their respective parameters are not applicable. As such, the GHG emissions for these replacement equipment are based on electricity consumed using Equation 27. Electricity consumed is calculated using Equation 28 and is based on the fuel consumption of the baseline equipment, but with an appropriate energy efficiency ratio (EER) applied.

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[12] Please refer to CARB's *Analysis of California's Diesel Agricultural Equipment Inventory according to Fuel Use, Farm Size, and Equipment Horsepower* to see what standard deviation value applies to a given equipment type.

Equation 27: Annual GHG Emissions from Zero-Emission Replacement Equipment

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

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/year
$CC_{electricity}$	=	Carbon content of electricity	gCO_2e/kWh

Equation 28: 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	gal/yr, scf/yr
$ED_{baseline\ fuel}$	=	Energy density of 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 29 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 30.

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 29: 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 30: Annual Emission Reductions from Off-Road Equipment Replacement and Repower Projects

$$ER_{pollutant} = AEP_{baseline} - AEP_{replacement}$$

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

Equation 31 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 31: 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 =   Annual emissions for the equipment   US tons/year
EF =   Zero-mile emission factor for the equipment   g/bhp-hr
DP =   Hour-based deterioration product for the   g/bhp-hr
               equipment
LF =   Equipment Load Factor   Unitless
HP =   Maximum rated horsepower of the equipment   bhp
AA =   Annual Activity   hours/year
i =   Baseline or Replacement

Equation 32 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 32: Hour-Based Deterioration Product for Baseline and Replacement Equipment

$$DP_i = DR_i \times TEA_i$$

Where,			*Units*
DP	=	Hour-based deterioration product for the equipment	g/bhp-hr
DR	=	Deterioration rate for the equipment	g/bhp-hr-hr
TEA	=	Total equipment activity of the equipment	hours
i	=	Baseline or Replacement	

Equation 33 is used to determine the total equipment activity in the baseline and replacement scenarios, using respective values for deterioration life.

Equation 33: Total Equipment Activity for the Baseline and Replacement Equipment

$$TEA_i = AA \times DL_i$$

Where,			*Units*
TEA	=	Total equipment activity of the equipment	hours
AA	=	Annual activity	hours/year
DL	=	Deterioration life of the equipment	years
i	=	Baseline or Replacement	

Equation 34 is used to determine the deterioration life in the baseline scenario.

Equation 34: 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 35 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 36 is applied to calculate deterioration life.

Equation 35: 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   years
"project implementation time frame" as denoted in
the Carl Moyer Guidelines)

Equation 36: Deterioration Life for the Replacement Equipment if it is Used

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

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

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

Equation 37: 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 38: Annual GHG Emission Reductions from Irrigation Pump Engines

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

Where,			Units
ER_{GHG}	=	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 39, GHG emissions are a function of fuel consumption.

Equation 39: GHG Emissions from Gasoline, Diesel, or Alternative Fuels Irrigation Pump Engines

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

Where,			Units
GHG	=	Greenhouse gas emissions	MTCO$_2$e/yr
FC	=	Fuel consumption	gal/yr, scf/yr
CC$_{fuel}$	=	Carbon content (depends on fuel type)	gCO$_2$e/gal
i	=	Baseline or Replacement	

Equation 40 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[13]*.

Equation 40: Fuel Consumption for the Baseline and Replacement Irrigation Pump Engines[14]

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

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	

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[13] Analysis of California's Diesel Agricultural Equipment Inventory according to Fuel Use, Farm Size, and Equipment Horsepower. Link to main page: https://www.arb.ca.gov/msei/ordiesel.htm Link to document: https://www.arb.ca.gov/msei/ordiesel/agfuelstudy2018.pdf

[14] 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 (sources: Exhaust Emission Factors for Nonroad Engine Modeling – Spark-Ignition, U.S. EPA, 2010; Off-Road Diesel Emission Factors, California Air Resources Board, 2018.

As seen in Equation 41 – Equation 42, 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.*

Equation 41: 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 42: Load Factor of the Replacement Irrigation Pump Engine[15]

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

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 40 – Equation 42 and their respective parameters are not applicable. As such, the GHG emissions for these replacement equipment are based on electricity consumed using Equation 43. Electricity consumed is calculated using Equation 44 and is based on the fuel consumption of the baseline equipment, but with an appropriate energy efficiency ratio (EER) applied.

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[15] Please refer to CARB's *Analysis of California's Diesel Agricultural Equipment Inventory according to Fuel Use, Farm Size, and Equipment Horsepower* to see what standard deviation value applies to a given equipment type.

Equation 43: Annual GHG Emissions from Zero-Emission Irrigation Pump Engine

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

Where,		Units
$GHG_{replacement}$	= 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 44: 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/year
$FC_{baseline}$	= 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 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 45 shows the GHG emission reductions that occur over the project's entire quantification period. Using Equation 46, Equation 47, and Equation 49, GHG emissions are calculated based on fuel usage. Fuel usage for baseline vehicles and electricity usage for replacement vehicles are determined using Equation 48 and Equation 50, respectively.

Equation 45: 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 46: 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 GHG 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 47: GHG Emissions for Baseline Vehicle/Equipment (diesel, gasoline, or alternative fuels)

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

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

Equation 48: Fuel Usage for Baseline Vehicle/Equipment (diesel, gasoline, or alternative fuels)[16]

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

Where,   Units
$FC_{baseline}$ =   Fuel consumption of the baseline UTV   gal/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   hr/yr
GC =   Gallon conversion (fuel specific)   gal/lb, gal/scf

Equation 49: GHG Emissions from Zero-Emission Utility Terrain Vehicles

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

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

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[16] 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: 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
$FC_{baseline\ UTV}$	= Fuel consumption of the baseline UTV	gal/yr
$ED_{baseline\ fuel}$	= Energy density of the baseline UTV's fuel type	MJ/gal, MJ/scf
$ED_{electricity}$	= Energy density of electricity	MJ/kWh
$EER_{electricity}$	= Energy Efficiency Ratio of electricity relative baseline UTV'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 51, 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 52, 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.

Equation 51: Total Equipment Activity for Baseline and Replacement Equipment

$$TEA_i = AA \times DL_i$$

Where,			Units
TEA	=	Total equipment activity of the equipment	hours
AA	=	Annual activity	hours/year
DL	=	Deterioration life of the equipment	years
i	=	Baseline or Replacement	

Equation 52: 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 20 to be a summation - i.e., Equation 53.

Equation 53: Annual GHG Emission Reductions from Off-Road Equipment Projects[17]

$$ER_{GHG} = \left(\sum_{i=1}^{N} GHG_{baseline} - GHG_{replacement} \right) \times \frac{1\ MTCO_2 e}{1,000,000\ g}$$

Where,   Units
ER_{GHG} =   GHG emission reductions of replacing the baseline $MTCO_2 e$/yr
                   equipment

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 24.

However, when multiple baselines are being scrapped, the average model year across all of the baselines is used as demonstrated in Equation 54.

Equation 54: Fuel Efficiency Factor of the Replacement Equipment[18]

$$FEF_{replacement} = 1 - (MY_{replacement} - \frac{\sum_{i=1}^{N} MY_{baseline}}{N}) \times 0.005$$

                                                         Units
Where,
$FEF_{replacement}$ =   Fuel efficiency factor of the replacement   Unitless
                                      equipment
$MY_{replacement}$ =   Model year of the replacement equipment   Year
$MY_{baseline}$ =   Model year of the baseline equipment   Year

N = # of baseline equipment applicant is scrapping

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 55 is a modified version of Equation 25.

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[17] For fuel consumption and carbon content, units vary depending of fuel type of baseline and/or replacement equipment, respectively.
[18] 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. Therefore, no efficiency losses are assumed for models before 1980 and no efficiency gains are gained after 2007. 10% gains/20 years = 0.5%/year = 0.005.

Equation 55: Load Factor of the Replacement Equipment

$$LF_{replacement} = \frac{\frac{\sum_{i=1}^{N} HP_{max,baseline} \times AA}{\sum_{i=1}^{N} AA} \times LF_{baseline}}{HP_{max,replacement}}$$

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

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 30 to be a summation – i.e., Equation 56.

Equation 56: Annual Emission Reductions from Off-Road Equipment Replacement and Repower Projects

$$ER_{pollutant} = \sum_{i=1}^{N} AEP_{baseline} - AEP_{replacement}$$

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

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. https://www.arb.ca.gov/msei/ordiesel/agfuelstudy2018.pdf

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://www.arb.ca.gov/msei/ordiesel.htm

California Air Resources Board. (2017). The Carl Moyer Program Guidelines. https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm

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

U.S. Environmental Protection Agency. (July 2010). Exhaust Emission Factors for Nonroad Engine Modeling – Spark Ignition. https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P10081YF.TXT