California Air Resources Board

Quantification Methodology

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

California Climate Investments

Note:
The California Air Resources Board (CARB) is accepting public comments on the Draft Funding Agricultural Replacement Measures for Emission Reductions (FARMER) Benefits Calculator Tool and the Draft FARMER Quantification Methodology until October 24, 2018 via GGRFProgram@arb.ca.gov. The Draft Benefits Calculator Tool and Draft Quantification Methodology are subject to change pending stakeholder comments and changes to FARMER Guidelines. The Final FARMER Benefits Calculator Tool and Final FARMER Quantification Methodology will be available on the California Climate Investments resources webpage at: http://www.arb.ca.gov/cci-resources.

DRAFT
October 10, 2018

Disclaimers:

- Please note that the FARMER Program released new project categories on September 26, 2018. These additional project categories are not included in this draft Quantification Methodology, and are not included in the Benefits Calculator Tool, but will be incorporated at a later date.

- 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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Section A. Introduction

California Climate Investments is a statewide initiative that puts billions of Cap-and-Trade dollars to work facilitating greenhouse gas (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.

The California Air Resources Board (CARB) is responsible for providing guidance on estimating the GHG emission reductions and co-benefits from projects receiving monies from the Greenhouse Gas Reduction Fund (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 Funding Agricultural Replacement Measures for Emissions Reductions (FARMER) Program, CARB staff 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 utility terrain vehicles (UTV) 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 a project example, 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), NOx Reductions (lbs), Reactive Organic Gas Reductions (lbs), Diesel PM Reductions (lbs), Fossil Fuel Use Reductions (gallons), Fossil Fuel Based Energy Use Reductions (kWh), and Fuel Savings ($). 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 program requirements. The FARMER Guidelines are available at: www.arb.ca.gov/farmer . All CARB co-benefit assessment methodologies are available at: www.arb.ca.gov/cci-cobenefits.

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.

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.

[1] California Air Resources Board. 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.

Applicants must use the FARMER Benefits Calculator Tool 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.

Section B. Methods

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

Project Type

CARB developed five project types that meet the objectives of the FARMER Program and for which there are methods to quantify GHG emission reductions[2]:

1. On-road heavy-duty truck replacement and repower projects;
2. Off-road equipment replacement and repower projects;
3. Repower for agricultural pump engines;
4. Rebates for the purchase of zero-emission UTVs; and
5. Off-Road Mobile Agricultural Equipment Trade-Up Pilot Project (Ag Trade-Up), consisting of (1) replacing off-road equipment with new off-road equipment, and (2) replacing off-road equipment with the off-road equipment that was replaced in (1).

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.

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

Table 1. General Approach to Quantification by Project Type

Single Transaction Project Types (#1-4)
Emission Reductions = Baseline Equipment/Vehicle Emissions – Replacement Equipment/Vehicle Emissions
Double Transaction Project Types (#5)
Emission Reductions = (Baseline Equipment Emissions – New Replacement Equipment Emissions) + (Baseline Equipment Emissions – Baseline Equipment 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[3].
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”.

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

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 pollutant reductions using Equation 1. While NOx and ROG emissions are given equal weight; emissions of combustion PM10 (such as diesel exhaust PM10 emissions) have been identified as a toxic air contaminant and thus carry a greater weight in the calculation.

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 NOx 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 NOx standards, among others.

Equation 2: Potential Grant Amount at applicable[4] Cost-Effectiveness Limit

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

Where,			Units
PGA	=	Potential grant amount	$
CL	=	Cost-effectiveness limit	$/ton
WER	=	Weighted emissions reduction of replacing the baseline equipment	ton/year
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	$
$C_{replacement}$	=	Cost of replacement technology	$
PE	=	Maximum percentage of eligible cost as specified in the FARMER Program Guidelines and/or Carl Moyer Program Guidelines	%

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

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

The FARMER Benefits Calculator tool calculates estimates for GHG emissions reductions and air pollutant emission co-benefits using 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 while accounting for annual vehicle miles traveled. Equation 6 is used to determine the estimated annual fuel consumption in the baseline and replacement scenarios.

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

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

Where,

			Units
$QPER_{pollutant}$	=	Emission reductions over quantification period	MTCO2e
QP	=	Quantification period	years
$ER_{pollutant}$	=	Annual emission reductions	MTCO2e/yr

Equation 5: Emission Reductions from On-Road Heavy-Duty Truck Replacement and Repower Projects

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

Where,			<u>Units</u>[5]
$ER_{pollutant}$	=	Emission reductions of replacing the baseline truck	MTCO2e/yr
$FC_{baseline}$	=	Fuel consumption of the baseline truck	gal/yr
$FC_{replacement}$	=	Fuel consumption of the replacement truck	gal/yr
$CC_{baseline\ fuel}$	=	Carbon content of baseline fuel type	gCO2e/DGE
$CC_{replacement\ fuel}$	=	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,			<u>Units</u>
FC	=	Fuel consumption	gallons/year
AA	=	Annual activity	miles/year
MPG	=	Fuel economy	miles/gallon
i	=	Baseline or Replacement	

[5] If carbon content for the baseline and replacement fuel types is CNG or RNG, it is converted to diesel gallon equivalent for the GHG emissions calculations step.

2. Criteria and Toxic Air Pollutant Equations

Individual air pollutant emission reductions from on-road heavy-duty truck replacement and repower projects are estimated. 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.

Gross Vehicle Weight Rating, Model Year, and NOx 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., NOx, ROG, and PM10.

Equation 7: Emission Reductions from On-Road Heavy-Duty Truck Replacement and Repower Projects (Quantification Period)

$$QPER_{pollutant} = QP \times ER_{pollutant} \times 2000 \frac{lbs}{US\ ton}$$

Where,			Units
$QPER_{pollutant}$	=	Emission reductions over quantification period	lbs
QP	=	Quantification period	years
$ER_{pollutant}$	=	Annual emissions reductions for the replacement truck	US tons/year

Equation 8: Emission Reductions from On-Road Heavy-duty Truck Replacement and Repower Projects

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

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 equipment	US tons/year

Equation 9 is used to determine the estimated annual air pollutant emissions in the project and baseline 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 project and baseline 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 used to determine the deterioration life in the baseline scenario.

Equation 12: Deterioration Life for the Baseline Truck

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

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
PL	=	Project life	years

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

Equation 13: Deterioration Life for the Replacement Truck

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

Where,			Units
$DL_{baseline}$	=	Deterioration life of the replacement truck	years
PL	=	Project life	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 taken from the Carl Moyer Program Guidelines are used, but they are performed twice. Rather than the 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.

In a project that is only a single step calculation, we use Equation 2 to determine the potential grant amount based on the 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 14 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 14: Potential Grant Amount at $30,000 and $100,000 Cost-Effectiveness Limit

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

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 15, total estimated cost-effectiveness can then be determined from the potential grant amount calculated in Equation 14 and from the annual emissions reductions weighted by 2 quantification periods as seen in Equation 16.

Equation 15: 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 16: 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 Calculations	US tons/year
$WER_{Step\ 2}$	=	Weighted emissions reductions from Step 2 Calculations	US tons/year
$QP_{Step\ 1}$	=	Quantification period from Step 1 Calculations	Years
$QP_{Step\ 2}$	=	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 using 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 Off-Road Equipment Replacement and Repower Projects.

1. GHG Equations

Equation 17 shows the GHG emission reductions that occur over the project's entire quantification period. To determine GHG emissions for Off-Road Ag equipment, fuel consumption is calculated for the baseline and replacement equipment and multiplied by the fuel's carbon content using Equation 18. 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*[6].

Equation 17: Emission Reductions from Off-Road Equipment Replacement and Repower Projects (Quantification Period)

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

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

[6] 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

Equation 18: Emission Reductions from Off-Road Equipment Replacement and Repower Projects

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

Where,

			Units[7]
$ER_{pollutant}$	=	Emission reductions of replacing the baseline equipment	MTCO2e/yr
$FC_{baseline}$	=	Fuel consumption of the baseline equipment	GGE/yr, DGE/yr, scf/yr
$FC_{replacement}$	=	Fuel consumption of the replacement equipment	GGE/yr, DGE/yr, scf/yr
$CC_{baseline\ fuel}$	=	Carbon content of baseline fuel type	gCO2e/GGE,gCO2e/DGE, scf/yr
$CC_{replacement\ fuel}$	=	Carbon content of replacement fuel type	gCO2e/GGE,gCO2e/DGE, scf/yr

[7] For fuel consumption and carbon content, units vary depending of fuel type of baseline and/or replacement equipment/vehicle, respectively.

Equation 19 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.

Equation 19: 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/year
BSFC	=	Brake specific fuel consumption[8]	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	

[8] Where necessary, brake specific fuel consumption (BSFC) values are converted from lb/bhp-hr to gal/bhp-hr using fuel type specific pounds to gallons conversions. For mobile equipment using gasoline as a fuel, BSFC = 18.5 bhp-hr/gal (ref: Table D-21 in the Carl Moyer Guidelines). For non-mobile equipment using gasoline as a fuel, BSFC = 17.5 bhp-hr/gal (ref: Table D-21 in the Carl Moyer Guidelines). For mobile equipment using diesel, engines with less than 100 HP use a BSFC of 0.408 lbs/bhp-hr while those with HP greater than 100 use 0.367 lbs/bhp-hr. This footnote applies to all instances involving a calculation where BSFC is a parameter.

Fuel efficiency factor is determined using Equation 20-Equation 21.

Equation 20: Fuel Efficiency Factor of the Baseline Equipment

$$FEF_{baseline} = 1$$

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

Equation 21: Fuel Efficiency Factor of the Replacement Equipment

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

Where,			Units
$FEF_{replacement}$	=	Fuel efficiency factor of the replacement equipment[9]	Unitless
$MY_{replacement}$	=	Model year of the replacement equipment	
$MY_{baseline}$	=	Model year of the baseline equipment	

[9] 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 22-Equation 23, 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 22: 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
$HP_{max,\ replacement}$	=	Maximum rated horsepower of the replacement equipment	bhp
$LF_{baseline}$	=	Load factor of the baseline equipment	Unitless

Equation 23: Load Factor of the Replacement Equipment

$$LF_{replacement} = LF_{baseline} \ \pm\leq \ LF_{stdev}$$ [10]

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	%

[10] Please refer to CARB's Ag Survey to see what standard deviation value applies to a given equipment type.

2. Criteria and Toxic Air Pollutant Equations

Equation 24 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 Carl Moyer Program methods, as the difference between the baseline and replacement scenarios using Equation 25.

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., NOx, ROG, and PM10.

Equation 24: Emission Reductions from Off-Road Equipment Replacement and Repower Projects (Quantification Period)

$$QPER_{pollutant} = QP \times ER_{pollutant} \times 2000 \frac{lbs}{US\ ton}$$

Where,

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

Equation 25: Emission Reductions from Off-Road Equipment Replacement and Repower Projects

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

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 equipment	US tons/year

Equation 26 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 26: 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 equipment	g/bhp-hr
AA	=	Annual activity	hours/year
LF	=	Equipment Load Factor	Unitless
HP	=	Maximum rated horsepower of the equipment	bhp
i	=	Baseline or Replacement	

Equation 27 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 27: 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 28 is used to determine the total equipment activity in the baseline and replacement scenarios, using respective values for deterioration life.

Equation 28: 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 29 is used to determine the deterioration life in the baseline scenario.

Equation 29: Deterioration Life for the Baseline Equipment

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

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
PL	=	Project life	years

Equation 30 is used to determine the deterioration life in the replacement scenario.

Equation 30: Deterioration Life for the Replacement Equipment

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

Where,			Units
$DL_{replacement}$	=	Deterioration life of the replacement equipment	years
PL	=	Project life	year

D. Emissions Reductions from Replacement and Repower for Agricultural Pump Engines

The FARMER Benefits Calculator Tool calculates estimates for GHG emissions reductions and air pollutant emission co-benefits using 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 the Repower of Agricultural Pump Engines.

GHG and criteria pollutant calculations will depend on the fuel consumption of the pump and the fuel type that is it using. For the baseline agricultural pump, the allowable fuel types are diesel, gasoline, and alternative fuels. If your equipment is using diesel or gasoline, please use Equation 34 during the fuel consumption calculation step. If your equipment is using an alternative fuel, please use Equation 35 during the fuel consumption calculation step. For the replacement equipment, there is the added option of using an electric pump. In such a case, please refer to and use Equation 36, and Equation 37.

1. GHG Equations

Equation 31 shows the GHG emission reductions that occur over the project's entire quantification period. Using Equation 32, the difference in GHG emissions between the baseline pump and the replacement pump constitutes the overall reduction.

Equation 31: Emission Reductions from Replacement and Repower for Agricultural Pump Engines (Quantification Period)

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

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

Equation 32: Emission Reductions from Agricultural Pump Engines

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

Where,			Units
$ER_{pollutant}$	=	Emission reductions of replacing the baseline equipment	MTCO2e/yr
$GHG_{baseline}$	=	Annual GHG emissions for the baseline equipment	MTCO2e/yr
$GHG_{replacement}$	=	Annual GHG emissions for the replacement equipment	MTCO2e/yr

GHG emissions, and subsequently, fuel usage for diesel-powered baseline and replacement equipment are determined using Equation 33-Equation 34, respectively.

Equation 33: Greenhouse Gas Emissions from Gasoline or Diesel Agricultural Pump Engines

$$GHG = F \times CC_{fuel} \times \frac{1\ MTCO2e}{1{,}000{,}000\ g}$$

Where,			Units
GHG	=	Greenhouse gas emissions	MTCO2e/yr
F	=	Annual fuel use	gal/yr
CC_{fuel}	=	Carbon content (depends on fuel type)	gCO2e/gal

Equation 34: Fuel Usage for Gasoline or Diesel Agricultural Pump Engines

$$F = BSFC \times HP \times LF \times AA$$

Where,			Units
F	=	Annual fuel use	gal/yr
BSCF	=	Brake specific fuel consumption	gal/bhp-hr
HP	=	Maximum rated horsepower of the equipment	bhp
LF	=	Load factor	Unitless
AA	=	Annual activity	hr/yr

GHG emissions, and subsequently, fuel usage for alternative fuel-powered baseline and replacement equipment are determined using Equation 35.

Equation 35: Fuel Usage for Alternative Fuels (CNG) Agricultural Pump Engines

$$F_{Alt\ Fuels} = F_{gasoline} \times \frac{ED_{gasoline}}{ED_{CNG}}$$

Where,

			Units
$F_{Alt\ Fuel}$	=	Annual fuel use (Alternative Fuel)	ft^3/yr
$F_{gasoline}$	=	Annual fuel use (Gasoline)	gal/yr
$ED_{gasoline}$	=	Energy Density gasoline	MJ/gal
ED_{CNG}	=	Energy Density CNG	MJ/ft^3

In the case where the replacement pump is electric, GHG emissions are calculated based on electricity use using Equation 36.

Equation 36: Greenhouse Gas Emissions from Electric Agricultural Pump Engines

$$GHG = EU_{replacement} \times CC_{GE} \times \frac{1\ MTCO2e}{1{,}000{,}000\ g}$$

Where,

			Units
GHG	=	Greenhouse gas emissions	MTCO2e/yr
$EU_{replacement}$	=	Electricity use of the replacement equipment	kWh/yr
CC_{GE}	=	Carbon Content of grid electricity	gCO2e/kWh

Electricity use is calculated based on the fuel usage of the existing baseline pump using Equation 37.

Equation 37: Electricity Usage for Electric Agricultural Pump Engines

$$EU_{replacement} = F_{baseline} \times \frac{LHV_{ULSD}}{ED_{electricity}}$$

Where,

			Units
$EU_{replacement}$	=	Electricity use of the replacement equipment	kWh/yr
$F_{baseline}$	=	Fuel usage of the baseline equipment	gal/yr
LHV_{ULSD}	=	Lower heating value for ultra low-sulfur diesel	MJ/gal
$ED_{electricity}$	=	Energy density of electricity	MJ/kWh

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 Rebates for the Purchase of Zero-Emission Utility Terrain Vehicles

The FARMER Benefits Calculator tool calculates estimates for GHG emissions reductions and air pollutant emission co-benefits using 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 rebates for the purchase of Zero-Emission Utility Terrain Vehicles.

1. GHG Equations

Equation 38 shows the GHG emission reductions that occur over the project's entire quantification period. Using Equation 39-Equation 40, GHG emissions are calculated based on fuel usage. Fuel usage for baseline vehicles and electricity usage for replacement vehicles are determined using Equation 41, Equation 42, and Equation 43, respectively.

Equation 38: Emission Reductions from Rebates for the Purchase of Zero-Emission Utility Terrain Vehicles (Quantification Period)

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

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

Equation 39: Emission Reductions from Rebates for the Purchase of Zero-Emission Utility Terrain Vehicles

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

Where,			Units
$ER_{pollutant}$	=	Annual emission reductions	MTCO2e/yr
$GHG_{baseline}$	=	Annual GHG emissions for the baseline equipment (fuel type dependent)	MTCO2e/yr
$GHG_{replacement}$	=	Annual GHG emissions for the replacement equipment (fuel type dependent)	MTCO2e/yr

Equation 40: Greenhouse Gas Emissions from Gasoline, Diesel, or Alternative Fuels Utility Terrain Vehicles

$$GHG = F \times CC_{fuel} \times \frac{1\ MTCO2e}{1{,}000{,}000\ g}$$

Where,			<u>Units</u>
GHG	=	Greenhouse gas emissions	MTCO2e/yr
F	=	Annual fuel use	gal/yr
CC_{fuel}	=	Carbon content (depends on fuel type)	gCO2e/gal

Equation 41: Fuel Usage for Baseline Utility Terrain Vehicles (diesel or gasoline)

$$F = BSFC \times HP\ \times LF\ \times AA \times\ GP$$

Where,			<u>Units</u>
F	=	Annual fuel use	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
GP	=	Gallon to pound conversion (fuel specific)	gal/lb

Equation 42: Fuel Usage for Baseline Utility Terrain Vehicles (alternative fuels)[11]

$$F = HP \times LF \times AA \times BSFC_{gasoline} \times GP \times \frac{ED_{gasoline}}{ED_{CNG}}$$

Where,			<u>Units</u>
F	=	Annual fuel use	gal/yr
HP	=	Maximum rated horsepower of the equipment	bhp
LF	=	Load factor	Unitless
AA	=	Annual activity	hr/yr
$BSFC$	=	Brake specific fuel consumption (gasoline)	lb/bhp-hr
GP	=	Gallon to pound conversion (fuel specific)	gal/lb
$ED_{gasoline}$	=	Energy density of gasoline	MJ/gal
ED_{CNG}	=	Energy density of CNG	MJ/ft^3

Equation 43: Electricity Usage for Zero-Emission Utility Terrain Vehicles

$$EU_{replacement} = F_{baseline} \times \frac{LHV_{CaRFG}}{ED_{electricity}} \times \frac{1}{EER}$$

Where,			<u>Units</u>
$EU_{replacement}$	=	Electricity use of the replacement vehicle	kWh/yr
$F_{baseline}$	=	Annual fuel use of the baseline vehicle	gal/yr
LHV_{CaRFG}	=	Lower heating value for California reformulated gasoline	MJ/gal
$ED_{elecricity}$	=	Energy density of electricity	MJ/kWh
EER	=	Energy Efficiency Ratio relative to gasoline	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.

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[11] CNG is the fuel used for alternative fuels.

F. Emissions Reductions from Agricultural Trade-Up Pilot Projects

The Agricultural (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 abandon use of 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 using 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

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

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 using 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

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

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 44, 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. Moreover, to account for the fact that the Replacement equipment in Transaction #2 is used rather than brand new, a modified version of the Deterioration Life calculation is performed as shown in Equation 45.

Equation 44: 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[12]	hours/year
DL	=	Deterioration life of the equipment	years
i	=	Baseline or Replacement	

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[12] 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.

Equation 45: Deterioration Life for the Replacement Equipment

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

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
PL	=	Project life	year

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://ww2.arb.ca.gov/resources/documents/cci-quantification-benefits-and-reporting-materials

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