California Air Resources Board

Quantification Methodology

California Air Resources Board
Community Air Protection Funds

California Climate Investments

FINAL
October 31, 2019
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<tr>
<th>Acronym</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEHY</td>
<td>alternative fuel hybrid</td>
</tr>
<tr>
<td>bhp-hr</td>
<td>brake horsepower hour</td>
</tr>
<tr>
<td>CAP</td>
<td>Community Air Protection</td>
</tr>
<tr>
<td>CARB</td>
<td>California Air Resources Board</td>
</tr>
<tr>
<td>CARL</td>
<td>Clean Air Reporting Log</td>
</tr>
<tr>
<td>CNG</td>
<td>compressed natural gas</td>
</tr>
<tr>
<td>DEHY</td>
<td>diesel hybrid</td>
</tr>
<tr>
<td>DESL</td>
<td>diesel</td>
</tr>
<tr>
<td>Diesel PM</td>
<td>diesel particulate matter</td>
</tr>
<tr>
<td>EER</td>
<td>energy economy ratio</td>
</tr>
<tr>
<td>ELEC</td>
<td>electric</td>
</tr>
<tr>
<td>gal</td>
<td>gallons</td>
</tr>
<tr>
<td>GAS</td>
<td>gasoline</td>
</tr>
<tr>
<td>GGRF</td>
<td>Greenhouse Gas Reduction Fund</td>
</tr>
<tr>
<td>GHG</td>
<td>greenhouse gas</td>
</tr>
<tr>
<td>HHD</td>
<td>heavy heavy-duty</td>
</tr>
<tr>
<td>hp</td>
<td>horsepower</td>
</tr>
<tr>
<td>kWh</td>
<td>kilowatt hours</td>
</tr>
<tr>
<td>lbs</td>
<td>pounds</td>
</tr>
<tr>
<td>LNG</td>
<td>liquefied natural gas</td>
</tr>
<tr>
<td>LPG</td>
<td>liquefied petroleum gas</td>
</tr>
<tr>
<td>MHD</td>
<td>medium heavy-duty</td>
</tr>
<tr>
<td>mi</td>
<td>miles</td>
</tr>
<tr>
<td>MJ</td>
<td>megajoule</td>
</tr>
<tr>
<td>MTCO$_2$e</td>
<td>metric tons of carbon dioxide equivalent</td>
</tr>
<tr>
<td>NO$_x$</td>
<td>oxides of nitrogen</td>
</tr>
<tr>
<td>PM</td>
<td>particulate matter</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>particulate matter with a diameter less than 2.5 micrometers</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>particulate matter with a diameter less than 10 micrometers</td>
</tr>
<tr>
<td>PROP</td>
<td>propane</td>
</tr>
<tr>
<td>ROG</td>
<td>reactive organic gas</td>
</tr>
<tr>
<td>scf</td>
<td>standard cubic feet</td>
</tr>
<tr>
<td>VAVR</td>
<td>voluntary accelerated vehicle retirement</td>
</tr>
<tr>
<td>VMT</td>
<td>vehicle miles traveled</td>
</tr>
<tr>
<td>yr</td>
<td>year</td>
</tr>
</tbody>
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### List of Definitions

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>The vehicle or equipment that is currently owned/in operation that will be replaced by a new purchase, or the vehicle or equipment that would have been purchased otherwise.</td>
</tr>
<tr>
<td>Co-benefit</td>
<td>A social, economic, or environmental benefit as a result of the proposed project in addition to the GHG reduction benefit.</td>
</tr>
<tr>
<td>Energy and Fuel Cost Savings</td>
<td>Changes in energy and fuel costs to the vehicle or equipment operator as a result of the project. Savings may be achieved by changing the quantity of energy or fuel used or conversion to an alternative fuel vehicle or equipment.</td>
</tr>
<tr>
<td>Key Variable</td>
<td>Project characteristics that contribute to a project’s GHG emission reductions and signal an additional benefit (e.g., passenger VMT reductions, renewable energy generated).</td>
</tr>
<tr>
<td>Quantification Period</td>
<td>Number of years that the project will provide GHG emission reductions that can reasonable be achieved and assured. Sometimes referred to as “Project Life” or “Useful Life”.</td>
</tr>
<tr>
<td>Replacement</td>
<td>The new vehicle or equipment that replaces a baseline vehicle or equipment.</td>
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</table>
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 the CARB CAP Funds, CARB staff developed this Final CAP Funds 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 changes in the quantity and type of fuel use resulting from incentives for cleaner-than-required vehicles and equipment eligible under the Carl Moyer Memorial Air Quality Standards Attainment Program (Moyer Program), the Goods Movement Emission Reduction Program (Prop 1B Program), and School Facility measures. Eligible and quantifiable vehicles and equipment include on-road trucks, school and transit buses, off-road equipment, marine vessels, locomotives, agricultural equipment, light duty vehicles, and lawn and garden equipment.

The Final CAP Funds Benefits Calculator Tool automates methods described in this document, provides a link to a step-by-step user guide, and outlines documentation requirements. Projects will report the total project GHG emission reductions and co-benefits estimated using the Final CAP Funds Benefits Calculator Tool as well as the total project GHG emission reductions per dollar of GGRF funds awarded. The Final CAP Funds Benefits Calculator Tool is available for download at: www.arb.ca.gov/cci-resources.

Using many of the same inputs required to estimate GHG emission reductions, the Final CAP Funds Benefits Calculator Tool estimates the following co-benefits and key variables from CAP Funds projects: energy and fuel cost savings (in dollars), fossil fuel use reductions (in gallons) and select criteria and toxic air pollutant emissions (in pounds) – including NOX, ROG, diesel PM, and PM2.5.
Key variables are project characteristics that contribute to a project’s GHG emission reductions and signal an additional benefit (e.g., fossil fuel use reductions). Additional co-benefits for which CARB assessment methodologies were not incorporated into the Final CAP Funds Benefits Calculator Tool may also be applicable to the project. Applicants should consult the CAP Funds guidelines to ensure they are meeting CAP Funds requirements. All CARB co-benefit assessment methodologies are available at: www.arb.ca.gov/cci-cobenefits.

Methodology Development

CARB developed this Final Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability.\(^1\) CARB developed this Final CAP Funds 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 tools and 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 CAP Funds 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 CAP Funds Quantification Methodology and Draft CAP Funds Benefits Calculator Tool for public comment in October 2019. This Final CAP Funds Quantification Methodology and accompanying CAP Funds Benefits Calculator Tool have been updated to address public comments, where appropriate, and for consistency with the CAP Funds 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. 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 Final CAP Funds Benefits Calculator Tool relies on project-specific outputs from the CARL database. Air districts will submit project information for projects implemented under the Moyer Program into CARL to calculate annual NOX, ROG, and PM10 which are then input into the Final CAP Funds Benefits Calculator Tool. Conversely, for Prop 1B projects, air districts will calculate annual NOX, ROG, and PM10 using the Final CAP Funds Benefits Calculator Tool and input the results into CARL. Air Districts can access CARL at: https://www.arb.ca.gov/app/cmp/. CARL is used statewide, subject to regular updates to incorporate new information, free of charge, and available to all air districts.

In addition to the tool above, the Final CAP Funds 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.

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 Final CAP Funds Quantification Methodology from the previous version\(^2\) to enhance the analysis and provide additional clarity. The updates include:

- The data source of on-road fuel consumption factors and VAVR VMT from EMFAC2014 to EMFAC2017\(^3\);
- GHG emission factors based upon 2018 LCFS Regulation and 2018 volume-weighted averages;
- The On-Road Vehicles GHG quantification approach to use mid-year emission factors instead of averaging of Year 1 and Year Final emission factors;
- The On-Road Vehicles GHG quantification approach to look up emission factors based on engine year instead of engine year+1 as a proxy for model year;
- For Prop 1B, updated air pollutant emission factors data source and air pollutant emission reductions calculation methodology from using EMFAC2014 to those provided in Carl Moyer Program Guidelines\(^4\);

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\(^3\) California Air Resources Board. Mobile Source Emission Inventory - EMFAC2017 Web Database. https://www.arb.ca.gov/emfac/2017/.

• Updated GHG calculations to apply an EER for technology conversions to electricity for Marine, Off-Road, and Lawn & Garden;
• Updated EER values for technology conversions to electricity for Agricultural Pumps;
• Updated the value for CNG fuel density; and
• Provide specific quantification methodology for agricultural pumps.
Section B. Methods

The following section provides details on the methods supporting emission reduction estimates in the Final CAP Funds Benefits Calculator Tool.

Project Types

There are eight project types that meet the objectives of the CAP Funds and for which there are methods to quantify GHG emission reductions. Other project features may be eligible for funding under the CAP Funds, but may instead be reported qualitatively. However, the following project types are quantified:

- On-Road Vehicles;
  - Prop 1B Medium Heavy-Duty and Heavy Heavy-Duty On-Road Vehicles;
  - On-Road Heavy-Duty Vehicles;
  - VAVR;
- Locomotives;
- Marine Vessels;
- Off-Road Equipment;
- Agricultural Pumps; and
- Lawn and Garden Equipment.

General Approach

Methods used in the Final CAP Funds Benefits Calculator Tool for estimating the GHG emission reductions and air pollutant emission co-benefits by project type are provided in this section. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

These methods account for reducing fuel use and/or switching to less-polluting fuels. In general, the GHG emission reductions are estimated in the Final CAP Funds Benefits Calculator Tool using the following approach:

\[
\text{GHG Emissions of Baseline Vehicle or Equipment} - \text{GHG Emissions of Replacement or Repowered Vehicle or Equipment} \\
\text{GHG Emission Reductions}
\]

The Final CAP Funds 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.

---

A. Emission Reductions from On-Road Vehicles

On-road vehicle projects include Prop 1B Medium Heavy-Duty and Heavy Heavy-Duty On-Road Vehicles, On-Road Heavy-Duty Vehicles, and VAVR. The following equations are used to calculate the emission reductions from on-road vehicle projects.

1. GHG Equations

Equation 1 is used to estimate the GHG emission reductions from on-road vehicle projects that occur over the project’s entire quantification period.

**Equation 1: GHG Emission Reductions from On-Road Vehicles**

\[
ER_{GHG} = \frac{AER_{GHG}}{1,000,000} \times Years
\]

Where, \( ER_{GHG} \) = GHG emission reductions over quantification period \( \text{Units} = \text{MTCO}_2\text{e} \)

\( AER_{GHG} \) = Annual GHG emission reductions from on-road vehicle projects \( \text{Units} = \text{MTCO}_2\text{e/yr} \)

\( 1,000,000 \) = Conversion from metric tons to grams \( \text{Units} = \text{g/MT} \)

\( Years \) = Project-specific project life used in Moyer or Prop 1B Program \( \text{Units} = \text{yr} \)

Equation 2 is used to estimate the annual GHG emission reductions, estimated as the difference between the baseline and replacement scenarios.

**Equation 2: Annual GHG Emission Reductions from On-Road Vehicles**

\[
AER_{GHG} = (EF_{baseline} - EF_{replacement}) \times VMT
\]

Where, \( AER_{GHG} \) = Annual GHG emission reductions from on-road vehicle projects \( \text{Units} = \text{MTCO}_2\text{e/yr} \)

\( EF_{baseline} \) = GHG emission factor of the baseline vehicle \( \text{Units} = \text{gCO}_2\text{e/mi} \)

\( EF_{replacement} \) = GHG emission factor of the replacement vehicle \( \text{Units} = \text{gCO}_2\text{e/mi} \)

\( VMT \) = Annual vehicle miles traveled \( \text{Units} = \text{mi} \)
Equation 3 is used to estimate VMT when annual diesel fuel use is inputted instead of annual VMT for on-road heavy-duty and Prop 1B projects.

**Equation 3: Calculated Vehicle Miles Traveled for Heavy-Duty Vehicles**$^6$

\[
VMT = \text{Fuel} \times \text{mpg}
\]

<table>
<thead>
<tr>
<th>Where,</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMT</td>
<td>Annual vehicle miles traveled</td>
</tr>
<tr>
<td>Fuel</td>
<td>Annual diesel fuel consumption</td>
</tr>
<tr>
<td>mpg</td>
<td>Average miles per gallon for vehicle class</td>
</tr>
</tbody>
</table>

Equation 4 is used to estimate the annual VMT for VAVR projects, calculated as the average VMT for the vehicle class between model year 1990 through the calendar year of retirement.

**Equation 4: Calculated Vehicle Miles Traveled for Light-Duty Vehicles**$^7$

\[
VMT = \frac{\sum (VMT_{1990-\text{Ret}} \times 365)}{\text{Pop} \times \text{Years}}
\]

<table>
<thead>
<tr>
<th>Where,</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMT</td>
<td>Annual vehicle miles traveled</td>
</tr>
<tr>
<td>VMT\text{1990-\text{Ret}}</td>
<td>Total daily VMT for model year 1990 or later within the vehicle class operating in the retirement year</td>
</tr>
<tr>
<td>365</td>
<td>Days per year</td>
</tr>
<tr>
<td>Pop</td>
<td>Population of vehicles operating in the retirement year contributing to the total daily VMT within the vehicle class</td>
</tr>
<tr>
<td>Years</td>
<td>Number of years between 1990 and the retirement year</td>
</tr>
</tbody>
</table>

$^6$ The average miles per gallon for each vehicle class are derived from the EMFAC2017 Web Database. [https://www.arb.ca.gov/emfac/2017/](https://www.arb.ca.gov/emfac/2017/)

$^7$ The total daily VMT and population for each vehicle class are derived from the EMFAC2017 Web Database. [https://www.arb.ca.gov/emfac/2017/](https://www.arb.ca.gov/emfac/2017/)
2. Criteria and Toxic Air Pollutant Equations

Equation 5 is used to estimate the air pollutant emission reductions that occur over the project’s entire quantification period for on-road vehicle projects.

**Equation 5: Air Pollutant Emission Reductions from On-Road Vehicles**

\[
ER_{\text{pollutant}} = QP \times AER_{\text{pollutant}} \times 2,000
\]

<table>
<thead>
<tr>
<th>Where,</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>( ER_{\text{pollutant}} )</td>
<td>Emission reductions over quantification period</td>
</tr>
<tr>
<td>( QP )</td>
<td>Quantification period</td>
</tr>
<tr>
<td>( AER_{\text{pollutant}} )</td>
<td>Annual emission reductions from on-road vehicle projects</td>
</tr>
<tr>
<td>2,000</td>
<td>Conversion from US tons to pounds</td>
</tr>
</tbody>
</table>

Equation 6, based upon Carl Moyer Program methods, is used to estimate individual air pollutant emission reductions, calculated as the difference between the baseline and replacement scenarios.

**Equation 6: Annual Air Pollutant Emission Reductions from On-Road Vehicles**

\[
AER_{\text{pollutant}} = AEP_{\text{baseline}} - AEP_{\text{replacement}}
\]

<table>
<thead>
<tr>
<th>Where,</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>( AER_{\text{pollutant}} )</td>
<td>Annual emission reductions from on-road vehicle projects</td>
</tr>
<tr>
<td>( AEP_{\text{baseline}} )</td>
<td>Annual emissions for the baseline vehicles</td>
</tr>
<tr>
<td>( AEP_{\text{replacement}} )</td>
<td>Annual emissions for the replacement vehicles</td>
</tr>
</tbody>
</table>

Gross Vehicle Weight Rating, 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\(_{10}\).

For CAP on-road heavy-duty vehicle and VAVR projects, the annual air pollutant emissions for the baseline and replacement equipment are pulled directly from CARL, which uses Carl Moyer Program methods. However, for projects implemented under the Prop 1B Program, air pollutant emission reductions are estimated within the Benefits Calculator Tool. The following equations document how the annual air pollutant emissions are calculated for Prop 1B projects.

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8 CARB. Carl Moyer Program Guidelines. [https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm](https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm)
Equation 7 is used to estimate the annual air pollutant emissions in the baseline and replacement scenarios, using respective values for emission factors and mile-based deterioration product.

**Equation 7: Annual Emissions for Baseline and Replacement Vehicle**

\[
AEP_i = (EF_i + DP_i) \times AA \times \frac{1}{907,200}
\]

Where,
- \(AEP\) = Annual emissions for the vehicle (US tons/yr)
- \(EF\) = Zero-mile emission factor for the vehicle (g/mi)
- \(DP\) = Mile-based deterioration product for the vehicle (g/mi)
- \(AA\) = Annual activity (mi/yr)
- \(i\) = Baseline or Replacement
- 907,200 = Conversion from US tons to grams (g/US tons)

Equation 8 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 8: Mile-Based Deterioration Product for Baseline and Replacement Vehicle**

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

Where,
- \(DP\) = Mile-based deterioration product for the vehicle (g/mi)
- \(DR\) = Deterioration rate for the vehicle (g/mi-10,000 mi)
- \(TEA\) = Total equipment activity of the vehicle (mi)
- \(i\) = Baseline or Replacement
- 10,000 = Conversion from 10,000 miles to miles (mi/10,000 mi)

Equation 9 is used to determine the total equipment activity in the baseline and replacement scenarios, using respective values for deterioration life.

**Equation 9: Total Equipment Activity for the Baseline and Replacement Vehicle**

\[
TEA_i = AA_i \times DL_i
\]

Where,
- \(TEA\) = Total equipment activity of the vehicle (mi)
- \(AA\) = Annual activity (mi/yr)
- \(DL\) = Deterioration life of the vehicle (yr)
- \(i\) = Baseline or Replacement
Equation 10 is used to determine the deterioration life in the baseline scenario.

**Equation 10: Deterioration Life for the Baseline Vehicle**

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

Where,
- \(DL_{baseline}\) = Deterioration life of the baseline vehicle \(\text{yr}\)
- \(YR_{replacement}\) = Expected first year of operation of the replacement vehicle \(\text{yr}\)
- \(MY_{baseline}\) = Baseline engine model year \(\text{yr}\)
- \(QP\) = Quantification Period (project life or "project implementation time frame" as denoted in the Carl Moyer Guidelines) 

Equation 11 is used to determine the deterioration life in the replacement scenario if the replacement truck is brand new.

**Equation 11: Deterioration Life for the Replacement Vehicle**

\[
DL_{replacement} = \frac{QP}{2}
\]

Where,
- \(DL_{replacement}\) = Deterioration life of the replacement vehicle \(\text{yr}\)
- \(QP\) = Quantification Period (project life or "project implementation time frame" as denoted in the Carl Moyer Guidelines)

Alternatively, Equation 12 is used to calculate deterioration life if the replacement truck is not brand new, but is instead used.

**Equation 12: Deterioration Life for the Replacement Vehicle if it is Used**

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

Where,
- \(DL_{replacement}\) = Deterioration life of the replacement vehicle \(\text{yr}\)
- \(YR_{replacement}\) = Expected first year of operation of the replacement vehicle \(\text{yr}\)
- \(MY_{replacement}\) = Replacement engine model year \(\text{yr}\)
- \(QP\) = Quantification Period (this is essentially project life or "project implementation time frame" as denoted in the Carl Moyer Guidelines)
In some cases, Prop 1B vehicles may be eligible for a two-step cost-effectiveness calculation. This occurs when the replacement 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 vehicle and the replacement vehicle, the Calculator Tool will first perform the equations as the difference between the baseline vehicle and the theoretical 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 vehicle that the applicant would have had to purchase to be in compliance with regulation and the replacement vehicle which is cleaner that the requirement per regulation.

Emissions reductions calculated in the first step are based on the regulation requirements. Emissions reductions calculated in the second step are based on the maximum project life (i.e., five years for Prop 1B).
B. Emission Reductions from Locomotives

1. GHG Equations

Equation 13 is used to estimate GHG emission reductions from locomotive projects, calculated as the difference in fuel and energy use between the baseline and project scenarios over the quantification period.

**Equation 13: GHG Emission Reductions from Locomotives**

\[
ER_{LoCo} = \frac{(Fuel_{Baseline} \times FSEF) - (Fuel_{Replacement} \times FSEF)}{1,000,000} \times Years
\]

Where,
- \( ER_{LoCo} \) = Emission reductions from locomotive equipment replacement
- \( Fuel_{Baseline} \) = Annual fuel usage for baseline equipment
- \( Fuel_{Replacement} \) = Annual fuel usage for replacement equipment
- \( FSEF \) = Fuel-specific emission factor
- \( Years \) = Project-specific project life used in Moyer Program
- \( 1,000,000 \) = Conversion from metric tons to grams

Units:
- MT\( CO_2 \)e
- gal
- unit of fuel
- g/unit of fuel
- yr
- g/MT

2. Criteria and Toxic Air Pollutant Equations

Equation 14 is used to estimate the air pollutant emission reductions that occur over the locomotive’s entire quantification period. The following calculation is repeated for each type of pollutant – i.e., \( NO_x \), ROG, and PM\(_{10} \). The annual air pollutant emissions for the baseline and replacement equipment are pulled directly from CARL, which uses Carl Moyer Program methods.\(^9\)

**Equation 14: Air Pollutant Emission Reductions from Locomotives**

\[
ER_{pollutant} = QP \times (AEP_{baseline} - AEP_{replacement}) \times 2,000
\]

Where,
- \( ER_{pollutant} \) = Emission reductions over quantification period
- \( QP \) = Quantification period
- \( AEP_{baseline} \) = Annual emissions for the baseline equipment
- \( AEP_{replacement} \) = Annual emissions for the replacement equipment
- \( 2,000 \) = Conversion from US tons to pounds

Units:
- lbs
- yr
- US tons/yr
- lbs/US tons

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\(^9\) CARB. Carl Moyer Program Guidelines. [https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm](https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm)
C. Emission Reductions from Marine Vessels

1. GHG Equations

Equation 15 is used to estimate GHG emission reductions from non-hybrid marine vessel projects, calculated as the difference in fuel and energy use between the baseline and project scenarios over the quantification period.

**Equation 15: GHG Emission Reductions from Non-Hybrid Marine Vessels**

\[
ER_{\text{Marine}} = \frac{(Fuel_{\text{Baseline}} \times FSEF) - (Fuel_{\text{Replacement}} \times OR\ Energy_{\text{Replacement}} \times FSEF)}{1,000,000} \times \text{Years}
\]

Where,
- \(ER_{\text{Marine}}\) = Emission reductions from non-hybrid marine vessel
- \(Fuel_{\text{Baseline}}\) = Annual fuel usage for baseline marine vessel engine
- \(Fuel_{\text{Replacement}}\) = Annual fuel usage for replacement marine vessel engine
- \(Energy_{\text{Replacement}}\) = Annual energy usage for replacement marine vessel engine
- \(FSEF\) = Fuel-specific emission factor
- \(\text{Years}\) = Project-specific project life used in Moyer Program
- \(1,000,000\) = Conversion from metric tons to grams

Units:
- \(\text{MTCO}_2\text{e}\)
- \(\text{gal}\)
- \(\text{unit of fuel}\)
- \(\text{kWh}\)
- \(\text{g/unit of fuel}\)
- \(\text{yr}\)
- \(\text{g/MT}\)

Equation 16 is used to determine the equipment fuel use in the baseline scenario.

**Equation 16: Baseline Marine Vessel Annual Fuel Use**

\[
Fuel_{\text{Baseline}} = \frac{BSFC_{\text{Baseline}} \times LF_{\text{Baseline}} \times hp_{\text{Baseline}} \times \text{Hours}}{Fuel\ Density_{\text{Baseline}}}
\]

Where,
- \(Fuel_{\text{Baseline}}\) = Annual fuel usage for baseline marine vessel engine
- \(BSFC_{\text{Baseline}}\) = Brake specific fuel consumption factor
- \(LF_{\text{Baseline}}\) = Load factor of baseline marine vessel engine
- \(hp_{\text{Baseline}}\) = Horsepower of baseline marine vessel engine
- \(\text{Hours}\) = Annual hours of marine vessel engine usage
- \(Fuel\ Density_{\text{Baseline}}\) = Fuel density of marine vessel engine equipment fuel

Units:
- \(\text{gal}\)
- \(\text{lbs/bhp-hr}\)
- \(\text{unitless}\)
- \(\text{hp}\)
- \(\text{hours}\)
- \(\text{lb/gal}\)
Equation 17 is used to determine the equipment fuel use in the project scenario for projects that involve spark ignition or compression ignition engines.

**Equation 17: Replacement Marine Vessel Annual Fuel Use**

\[
Fuel_{Replacement} = \frac{BSFC_{Replacement} \times LF_{Replacement} \times hp_{Replacement} \times Hours}{FD_{Replacement}}
\]

Where,
- \( Fuel_{Replacement} \) = Annual fuel usage for replacement marine vessel engine
- \( BSFC_{Replacement} \) = Brake specific fuel consumption factor (lbs/bhp-hr)
- \( LF_{Replacement} \) = Load factor of replacement marine vessel engine (unitless)
- \( hp_{Replacement} \) = Horsepower of replacement marine vessel engine (hp)
- \( Hours \) = Annual hours of marine vessel engine usage (hours)
- \( FD_{Replacement} \) = Fuel density of replacement marine vessel engine fuel (lb/gal)

Equation 18 is used to determine annual energy use for projects that involve electric motors.

**Equation 18: Replacement Marine Vessel Annual Energy Use for Electric Motor**

\[
Energy_{Replacement} = Fuel_{Baseline} \times ED_{Baseline} \times \frac{1}{ED_{Electricity}} \times \frac{1}{EER}
\]

Where,
- \( Energy_{Replacement} \) = Annual energy usage for replacement marine vessel engine (kWh)
- \( Fuel_{Baseline} \) = Annual fuel usage for baseline marine vessel engine (gal or scf)
- \( ED_{Baseline} \) = Energy density of baseline fuel (MJ/gal or MJ/scf)
- \( ED_{Electricity} \) = Energy density of electricity (MJ/kWh)
- \( EER \) = Energy Efficiency Ratio, relative to baseline equipment fuel type (unitless)
Equation 19 is used to estimate GHG emission reductions from hybrid system marine vessel projects based on a default CO$_2$ reduction factor.\(^\text{10}\)

**Equation 19: GHG Emission Reductions from Hybrid Marine Vessels**

\[ ER_{\text{Hybrid}} = \left( \frac{BSFC_{\text{Baseline}} \times LF_{\text{Baseline}} \times hp_{\text{Baseline}} \times \text{Hours}}{FD_{\text{Baseline}}} \times \frac{FSEF}{1,000,000} \times 70\% \right) \times \text{Years} \]

**Units**
- Emission reductions from hybrid marine vessel: MTCO$_2$e
- Brake specific fuel consumption factor: lbs/bhp-hr
- Load factor of baseline marine vessel engine: unitless
- Horsepower of baseline marine vessel engine: hp
- Annual hours of marine vessel engine usage: hours
- Fuel density of marine vessel engine equipment fuel: lb/unit of fuel
- Fuel-specific emission factor: g/unit of fuel
- Conversion from metric tons to grams: g/MT
- 30% CO$_2$ reduction from hybrid system: percent
- Project-specific project life used in Moyer Program: yr

---

2. Criteria and Toxic Air Pollutant Equations

Equation 20 is used to estimate the air pollutant emission reductions that occur over the marine vessel’s entire quantification period. The following calculation is repeated for each type of pollutant – i.e., NO$_x$, ROG, and PM$_{10}$. The annual air pollutant emissions for the baseline and replacement equipment are pulled directly from CARL, which uses Carl Moyer Program methods.\(^\text{11}\)

**Equation 20: Air Pollutant Emission Reductions from Marine Vessels**

\[ ER_{\text{pollutant}} = QP \times \left( AEP_{\text{baseline}} - AEP_{\text{replacement}} \right) \times 2,000 \]

**Units**
- Emission reductions over quantification period: lbs
- Quantification period: yr
- Annual emissions for the baseline equipment: US tons/yr
- Annual emissions for the replacement equipment: US tons/yr
- Conversion from US tons to pounds: lbs/US tons

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\(^\text{10}\) CARB. Technology Assessment: Ocean-going Vessels. [https://ww3.arb.ca.gov/msprog/tech/techreport/ogv_tech_report.pdf]
\(^\text{11}\) CARB. Carl Moyer Program Guidelines. [https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm]
D. Emission Reductions from Off-Road Equipment

1. GHG Equations

Equation 21 is used to estimate the GHG emission reductions from off-road equipment projects, calculated as the difference in fuel and energy use between the baseline and project scenarios over the quantification period.

**Equation 21: GHG Emission Reductions from Off-Road Equipment**

\[
ER_{\text{off-road}} = \frac{(Fuel_{\text{Baseline}} \times FSEF) - (Fuel_{\text{Replacement}} \times OR\ Energy_{\text{Replacement}} \times FSEF)}{1,000,000} \times Years
\]

*Where,*

- \( ER_{\text{off-road}} \): Emission reductions from off-road equipment (MTCO₂e)
- \( Fuel_{\text{Baseline}} \): Annual fuel usage for baseline off-road equipment (unit of fuel/yr)
- \( Fuel_{\text{Replacement}} \): Annual fuel usage for replacement off-road equipment (unit of fuel/yr)
- \( OR\ Energy_{\text{Replacement}} \): Annual energy usage for replacement off-road equipment (kW/yr)
- \( FSEF \): Fuel-specific emission factor (g/unit of fuel or energy)
- \( Years \): Project-specific project life used in Moyer Program (yr)
- \( 1,000,000 \): Conversion from metric tons to grams (g/MT)

Equation 22 is used to determine the equipment fuel use in the baseline scenario.

**Equation 22: Baseline Off-Road Equipment Annual Fuel Use**

\[
Fuel_{\text{Baseline}} = \frac{BSFC_{\text{Baseline}} \times LF_{\text{Baseline}} \times hp_{\text{Baseline}} \times Hours}{Fuel\ Density_{\text{Baseline}}}
\]

*Where,*

- \( Fuel_{\text{Baseline}} \): Annual fuel usage for baseline off-road equipment (unit of fuel/yr)
- \( BSFC_{\text{Baseline}} \): Brake specific fuel consumption factor (lb/bhp-hr)
- \( LF_{\text{Baseline}} \): Load factor of baseline off-road equipment (unitless)
- \( hp_{\text{Baseline}} \): Horsepower of baseline off-road equipment (hp)
- \( Hours \): Annual hours of off-road equipment usage (hours/yr)
- \( Fuel\ Density_{\text{Baseline}} \): Fuel density of baseline off-road equipment fuel (lb/unit of fuel)
Equation 23 is used to determine the equipment fuel use in the project scenario for projects that involve spark ignition or compression ignition engines.

**Equation 23: Replacement Off-Road Equipment Annual Fuel Use**

\[
F_{\text{Fuel Replacement}} = \frac{BSFC_{\text{Replacement}} \times LF_{\text{Replacement}} \times hp_{\text{Replacement}} \times Hours}{Fuel Density_{\text{Replacement}}} \times (1 - Fuel Eff)
\]

Where,
- \(F_{\text{Fuel Replacement}}\) = Annual fuel usage for replacement off-road equipment
- \(BSFC_{\text{Replacement}}\) = Brake specific fuel consumption factor
- \(LF_{\text{Replacement}}\) = Load factor of replacement off-road equipment
- \(hp_{\text{Replacement}}\) = Horsepower of replacement off-road equipment
- \(Hours\) = Annual hours of off-road equipment usage
- \(Fuel Density_{\text{Replacement}}\) = Fuel density of replacement off-road equipment fuel
- \(Fuel Eff\) = Fuel efficiency increase of 0.5% per year for model years between 1980 and 2007 per CARB Ag Survey Data

For most off-road equipment, the load factor is pulled from the CARL Moyer Program Guidelines. However, for agricultural equipment, the load factor is calculated based on equipment horsepower. Equation 24 is used to determine the load factor of the equipment in the project scenario for projects that involve agricultural equipment.

**Equation 24: Load Factor for Replacement Agricultural Equipment\(^{12,13}\)**

\[
LF_{\text{Replacement}} = \frac{hp_{\text{Baseline}} \times LF_{\text{Baseline}}}{hp_{\text{Replacement}}}
\]

Where,
- \(LF_{\text{Replacement}}\) = Load factor of replacement off-road agricultural equipment
- \(hp_{\text{Baseline}}\) = Horsepower of baseline off-road agricultural equipment
- \(LF_{\text{Baseline}}\) = Load factor of baseline off-road agricultural equipment
- \(hp_{\text{Replacement}}\) = Horsepower of replacement off-road agricultural equipment

\(^{12}\) 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.

\(^{13}\) Load factor of the replacement equipment is limited to a 20.8% change from the baseline load factor, such that based upon CARB’s Ag Survey Data,

\[
LF_{\text{Baseline}} + (0.208 \times LF_{\text{Baseline}}) \geq LF_{\text{Replacement}} \geq LF_{\text{Baseline}} - (0.208 \times LF_{\text{Baseline}}).
\]
Equation 25 is used to estimate annual energy use for projects that involve electric motors.

**Equation 25: Replacement Off-Road Equipment Annual Energy Use for Electric Motor**

\[
\text{Energy}_{\text{Replacement}} = \text{Fuel}_{\text{Baseline}} \times \text{ED}_{\text{Baseline}} \times \frac{1}{\text{ED}_{\text{Electricity}}} \times \frac{1}{\text{EER}}
\]

Where,
- \( \text{Energy}_{\text{Replacement}} \): Annual energy usage for replacement off-road equipment
- \( \text{Fuel}_{\text{Baseline}} \): Annual fuel usage for baseline off-road equipment
- \( \text{ED}_{\text{Baseline}} \): Energy density of baseline fuel
- \( \text{ED}_{\text{Electricity}} \): Energy density of electricity
- \( \text{EER} \): Energy Efficiency Ratio, relative to baseline equipment fuel type

**Units**
- kWh
- gal or scf
- MJ/gal or MJ/scf
- MJ/kWh
- unitless

### 2. Criteria and Toxic Air Pollutant Equations

Equation 26 is used to estimate the air pollutant emission reductions that occur over the off-road equipment project’s entire quantification period. The following calculation is repeated for each type of pollutant – i.e., \( \text{NO}_x \), ROG, and PM\(_{10} \). The annual air pollutant emissions for the baseline and replacement equipment are pulled directly from CARL, which uses Carl Moyer Program methods.\(^{14}\)

**Equation 26: Air Pollutant Emission Reductions from Off-Road Equipment**

\[
\text{ER}_{\text{pollutant}} = QP \times \left( \text{AEP}_{\text{baseline}} - \text{AEP}_{\text{replacement}} \right) \times 2,000
\]

Where,
- \( \text{ER}_{\text{pollutant}} \): Emission reductions over quantification period
- \( QP \): Quantification period
- \( \text{AEP}_{\text{baseline}} \): Annual emissions for the baseline equipment
- \( \text{AEP}_{\text{replacement}} \): Annual emissions for the replacement equipment
- \( 2,000 \): Conversion from US tons to pounds

**Units**
- lbs
- yr
- US tons/yr
- lbs/US tons

\(^{14}\) CARB. Carl Moyer Program Guidelines. [https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm](https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm)
E. Emission Reductions from Agricultural Pump Engines

1. GHG Equations

Equation 27 is used to estimate the GHG emission reductions from agricultural pump engines, calculated as the difference in fuel and energy use between the baseline and project scenarios over the quantification period.

Equation 27: GHG Emission Reductions from Agricultural Pump Engines

\[
ER_{\text{off-road}} = \frac{(Fuel_{\text{Baseline}} \times FSEF) - (Fuel_{\text{Replacement}} \text{ OR Energy}_{\text{Replacement}} \times FSEF)}{1,000,000} \times \text{Years}
\]

Where,
- \( ER_{\text{off-road}} \) = Emission reductions from agricultural pump engines (Units: MTCO₂e)
- \( Fuel_{\text{Baseline}} \) = Annual fuel usage for baseline agricultural pump engine (Unit of fuel/yr)
- \( Fuel_{\text{Replacement}} \) = Annual fuel usage for replacement agricultural pump engine (Unit of fuel/yr)
- \( Energy_{\text{Replacement}} \) = Annual fuel usage for replacement agricultural pump engine (kWh/yr)
- \( FSEF \) = Fuel-specific emission factor (g/unit of fuel or energy)
- \( Years \) = Project-specific project life used in Moyer Program (yr)
- \( 1,000,000 \) = Conversion from metric tons to grams (g/MT)

Equation 28 is used to determine the equipment fuel use in the baseline scenario.

Equation 28: Baseline Agricultural Pump Engine Annual Fuel Use

\[
Fuel_{\text{Baseline}} = \frac{BSFC_{\text{Baseline}} \times LF_{\text{Baseline}} \times hp_{\text{Baseline}} \times Hours}{Fuel\ Density_{\text{Baseline}}}
\]

Where,
- \( Fuel_{\text{Baseline}} \) = Annual fuel usage for baseline agricultural pump engine (Unit of fuel/yr)
- \( BSFC_{\text{Baseline}} \) = Brake specific fuel consumption factor (lb/bhp-hr)
- \( LF_{\text{Baseline}} \) = Load factor of baseline agricultural pump engine (unitless)
- \( hp_{\text{Baseline}} \) = Horsepower of baseline agricultural pump engine (hp)
- \( Hours \) = Annual hours of agricultural pump engine usage (hours/yr)
- \( Fuel\ Density_{\text{Baseline}} \) = Fuel density of baseline agricultural pump engine (lb/unit of fuel)
Equation 29 is used to determine the equipment fuel use in the project scenario for projects that involve spark ignition or compression ignition engines.

**Equation 29: Replacement Agricultural Pump Engine Annual Fuel Use**

\[
Fuel_{\text{Replacement}} = \frac{BSFC_{\text{Replacement}} \times LF_{\text{Replacement}} \times hp_{\text{Replacement}} \times Hours}{Fuel \text{ Density}_{\text{Replacement}}}
\]

Where,

- \(Fuel_{\text{Replacement}}\) = Annual fuel usage for replacement agricultural pump engine
- \(BSFC_{\text{Replacement}}\) = Brake specific fuel consumption factor
- \(LF_{\text{Replacement}}\) = Load factor of replacement agricultural pump engine
- \(hp_{\text{Replacement}}\) = Horsepower of replacement agricultural pump engine
- \(Hours\) = Annual hours of agricultural pump engine usage
- \(Fuel \text{ Density}_{\text{Replacement}}\) = Fuel density of replacement agricultural pump engine fuel
- \(Fuel \text{ Eff}\) = Fuel efficiency increase of 0.5% per year for model years between 1980 and 2007 per CARB Ag Survey

Equation 30 is used to determine the load factor of the equipment in the project scenario for projects that involve spark ignition or compression ignition engines.

**Equation 30: Load Factor for Replacement Agricultural Pump Engine\(^{15}\)**

\[
LF_{\text{Replacement}} = \frac{hp_{\text{Baseline}} \times LF_{\text{Baseline}}}{hp_{\text{Replacement}}}
\]

Where,

- \(LF_{\text{Replacement}}\) = Load factor of replacement agricultural pump engine
- \(hp_{\text{Baseline}}\) = Horsepower of baseline agricultural pump engine
- \(LF_{\text{Baseline}}\) = Load factor of baseline agricultural pump engine
- \(hp_{\text{Replacement}}\) = Horsepower of replacement agricultural pump engine
- 20.8\% = Standard deviation in load factor for agricultural pump engines (from CARB’s Ag Survey)

\(^{15}\) Load factor of the replacement equipment is limited to a 20.8% change from the baseline load factor, such that based upon CARB’s Ag Survey Data,

\[
LF_{\text{Baseline}} + (0.208 \times LF_{\text{Baseline}}) \geq LF_{\text{Replacement}} \geq LF_{\text{Baseline}} - (0.208 \times LF_{\text{Baseline}}).
\]
Equation 31 is used to estimate annual energy use for projects that involve electric motors.

**Equation 31: Replacement Agricultural Pump Engine Annual Energy Use for Electric Motor**

\[
\text{Energy}_{\text{Replacement}} = \text{Fuel}_{\text{Baseline}} \times E\text{D}_{\text{Baseline}} \times \frac{1}{E\text{D}_{\text{Electricity}}} \times \frac{1}{\text{EER}}
\]

*Where,

\(\text{Energy}_{\text{Replacement}}\) = Annual energy usage for replacement agricultural pump engine

\(\text{Fuel}_{\text{Baseline}}\) = Annual fuel usage for baseline agricultural pump engine

\(E\text{D}_{\text{Baseline}}\) = Energy density of baseline fuel

\(E\text{D}_{\text{Electricity}}\) = Energy density of electricity

\(\text{EER}\) = Energy Efficiency Ratio, relative to baseline equipment fuel type

**Units**

kWh

gal or scf

MJ/gal or MJ/scf

MJ/kWh

unitless

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2. **Criteria and Toxic Air Pollutant Equations**

Equation 32 is used to estimate the air pollutant emission reductions that occur over the agricultural pump engine’s entire quantification period. The following calculation is repeated for each type of pollutant – i.e., NO\(_x\), ROG, and PM\(_{10}\). The annual air pollutant emissions for the baseline and replacement equipment are pulled directly from CARL, which uses Carl Moyer Program methods.\(^{16}\)

**Equation 32: Air Pollutant Emission Reductions from Agricultural Pump Engines**

\[
ER_{\text{pollutant}} = QP \times (AEP_{\text{baseline}} - AEP_{\text{replacement}}) \times 2,000
\]

*Where,

\(ER_{\text{pollutant}}\) = Emission reductions over quantification period

\(QP\) = Quantification period

\(AEP_{\text{baseline}}\) = Annual emissions for the baseline agricultural pump engine

\(AEP_{\text{replacement}}\) = Annual emissions for the replacement agricultural pump engine

\(2,000\) = Conversion from US tons to pounds

**Units**

lbs

yr

US tons/yr

US tons

lzs/US tons

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\(^{16}\) CARB. Carl Moyer Program Guidelines. 
https://www.arb.ca.gov/msprog/moyer/guidelines/current.htm
F. Emission Reductions from Lawn and Garden Equipment

1. GHG and Criteria and Toxic Air Pollutant Equations

Equation 33 is used to estimate GHG and air pollutant emission reductions from lawn and garden equipment, calculated as the difference in fuel and energy use between the baseline and project scenarios over the quantification period.

Equation 33: Emission Reductions from Lawn and Garden Equipment

\[ ER_{Lawn} = Vouchers \times LGEF \]

Where,

- \( ER_{Lawn} \) = Emission reductions from lawn and garden equipment
- \( Vouchers \) = Quantity of lawn and garden vouchers distributed
- \( LGEF \) = Lawn and garden equipment-specific emission factor

Units:
- \( MTCO_2e \) or lbs
- Vouchers
- \( MTCO_2e/\text{voucher} \) or lbs/voucher
Section C. References

The following references were used in the development of this Final Quantification Methodology and the Final CAP Funds Benefits Calculator Tool.


California Air Resources Board. (2019). California Climate Investments Quantification Methodology Emission Factor Database. www.arb.ca.gov/cci-resources

California Air Resources Board. (2019). California Climate Investments Quantification Methodology Emission Factor Database Documentation. www.arb.ca.gov/cci-resources

