APPENDIX D

QUANTIFICATION METHODOLOGY FOR DETERMINING EMISSION REDUCTIONS AND COST-EFFECTIVENESS

Low Carbon Transportation and Fuels Investments and the Air Quality Improvement Program

On-Road Advanced Technology Demonstration Projects

Mobile Source Control Division
California Air Resources Board
May 19, 2017
The methodology below must be used to calculate the emission reductions and cost-effectiveness of projects proposed by this Solicitation. All calculations and assumptions made must be shown clearly and in their entirety in the application (Appendix A, Attachment 4).

All calculations will use diesel fuel usage of the 2017 model year baseline vehicle as a basis for the greenhouse gas (GHG) and criteria pollutant emission calculations. This technique may not adequacy capture the emission profiles of all proposed applications however, this technique is used to allow all submitted applications to be scored on a level playing field. Applicants are invited to use alternate calculation methodologies in addition to those required above to illustrate the potential emission reductions from their proposed projects, however, those alternate results will not be used for scoring purposes.

GHG emission calculations are based on life cycle analysis (well-to-wheel). Criteria pollutant and PM emission calculations are based on exhaust emissions (tank-to-wheel). The GHG emission factors below are excerpted from the 2017 Low Carbon Fuel Standard (LCFS) regulatory documents. Please note that while the LCFS fuel carbon intensity values may change during the Solicitation period, project applicants must use the values listed in this appendix. The remaining emission factors and methodology below are from the Board approved 2011 Carl Moyer Program Guidelines (Moyer Guidelines) Appendices C, D, and G, updated in 2016. Language has been modified where necessary for the purposes of this Solicitation. The complete Moyer Guidelines, including all of its appendices, can be found at [http://www.arb.ca.gov/msprog/moyer/guidelines/current.htm](http://www.arb.ca.gov/msprog/moyer/guidelines/current.htm).

Emission factors for Low NOx engines are given for the purpose of this solicitation only and are based on emission factors developed for the FY 2016-17 AQIP/Low Carbon Transportation Investments Funding Plan.

Any examples provided here are for reference only and do not imply additional demonstration project types or categories, nor do Carl Moyer Program funding amounts limit the amount of funding that may be available for demonstration projects. Criteria pollutant and PM table numbers are kept the same as those in the current Moyer Guidelines. While Carl Moyer Program guidelines may change during the Solicitation period, projects applicants must use the values listed in this appendix.
Emission Factors for GHG: 2015 Re-Adoption of LCFS

- Table ORATD App D1: Fuel Energy Density

<table>
<thead>
<tr>
<th>Fuel (units)</th>
<th>Energy Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>CARBOB (gal)</td>
<td>119.53 (MJ/gal)</td>
</tr>
<tr>
<td>CaRFG (gal)</td>
<td>115.83 (MJ/gal)</td>
</tr>
<tr>
<td>Diesel fuel (gal)</td>
<td>134.47 (MJ/gal)</td>
</tr>
<tr>
<td>CNG (scf)</td>
<td>1.04 (MJ/scf)</td>
</tr>
<tr>
<td>LNG (gal)</td>
<td>78.83 (MJ/gal)</td>
</tr>
<tr>
<td>Electricity (KWh)</td>
<td>3.60 (MJ/KWh)</td>
</tr>
<tr>
<td>Hydrogen (kg)</td>
<td>120.00 (MJ/kg)</td>
</tr>
<tr>
<td>Denatured Ethanol (gal)</td>
<td>81.51 (MJ/gal)</td>
</tr>
<tr>
<td>FAME Biodiesel (gal)</td>
<td>126.13 (MJ/gal)</td>
</tr>
<tr>
<td>Renewable Diesel (gal)</td>
<td>129.65 (MJ/gal)</td>
</tr>
</tbody>
</table>

1 LCFS Regulation, Table 3 – Energy Densities of LCFS Fuels and Blendstocks. [https://www.arb.ca.gov/regact/2015/lcfs2015/lcfsfinalregorder.pdf](https://www.arb.ca.gov/regact/2015/lcfs2015/lcfsfinalregorder.pdf)
<table>
<thead>
<tr>
<th>Fuel</th>
<th>Pathway Identifier</th>
<th>Carbon Intensity Values (gCO₂e/MJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ULSD – based on the average crude oil supplied to California refineries and average California refinery efficiencies</td>
<td>ULSD001</td>
<td>102.01</td>
</tr>
<tr>
<td>CaRFG (calculated)</td>
<td>--</td>
<td>98.47</td>
</tr>
<tr>
<td>Fossil CNG</td>
<td>CNG400T</td>
<td>78.37</td>
</tr>
<tr>
<td>Fossil LNG</td>
<td>LNG401T</td>
<td>94.42</td>
</tr>
<tr>
<td>Biomethane CNG</td>
<td>CNG500T</td>
<td>46.42</td>
</tr>
<tr>
<td>Biomethane LNG</td>
<td>LNG501T</td>
<td>64.63</td>
</tr>
<tr>
<td>Biodiesel – any feedstock</td>
<td>BIOD202T</td>
<td>102.01</td>
</tr>
<tr>
<td>Renewable Diesel – any feedstock</td>
<td>RNWD302T</td>
<td>102.01</td>
</tr>
<tr>
<td>Ethanol – corn</td>
<td>ETH100T</td>
<td>75.97</td>
</tr>
<tr>
<td>Ethanol – any starch or sugar feedstock</td>
<td>ETH103T</td>
<td>98.47</td>
</tr>
<tr>
<td>Hydrogen – all sources</td>
<td>HYGN005</td>
<td>88.33</td>
</tr>
<tr>
<td>Electricity – California average</td>
<td>ELC001</td>
<td>105.16</td>
</tr>
</tbody>
</table>

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2 LCFS Temporary Pathway Table. [https://www.arb.ca.gov/fuels/lcfs/fuelpathways/temporarypathwaytable.htm](https://www.arb.ca.gov/fuels/lcfs/fuelpathways/temporarypathwaytable.htm)

Table ORATD App D3: Energy Economy Ratio (EER) Values for Fuels Used in Light- Medium- and Heavy-Duty Applications

<table>
<thead>
<tr>
<th>Fuel/Vehicle Combinations</th>
<th>EER Value Relative to Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel Fuel or Biomass Based Diesel Blends</td>
<td>1.0</td>
</tr>
<tr>
<td>CNG or LNG/Any Vehicles (Spark-Ignition Engines)</td>
<td>0.9</td>
</tr>
<tr>
<td>CNG/LNG /Any Vehicle (Compression-Ignition Engines)</td>
<td>1.0</td>
</tr>
<tr>
<td>Electricity / Battery Electric or Plug-in Hybrid Electric Truck</td>
<td>2.7</td>
</tr>
<tr>
<td>Electricity / Battery Electric or Plug-in Hybrid Electric Bus</td>
<td>4.2</td>
</tr>
<tr>
<td>Electricity / Fixed Guideway, Heavy Rail</td>
<td>4.6</td>
</tr>
<tr>
<td>Electricity / Fixed Guideway, Light Rail</td>
<td>3.3</td>
</tr>
<tr>
<td>Electricity / Trolley Bus, Cable Car, Street Car</td>
<td>3.1</td>
</tr>
<tr>
<td>Electricity/Forklifts or Equipment</td>
<td>3.8</td>
</tr>
<tr>
<td>H₂ / Fuel Cell Vehicle</td>
<td>1.9</td>
</tr>
<tr>
<td>H₂ / Fuel Cell Forklifts</td>
<td>2.1</td>
</tr>
</tbody>
</table>

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4 LCFS Regulation, Table 4 – EER Values for Fuels Used in Light- and Medium-Duty, and Heavy-Duty Applications. [https://www.arb.ca.gov/regact/2015/lcfs2015/lcsfinalregorder.pdf](https://www.arb.ca.gov/regact/2015/lcfs2015/lcsfinalregorder.pdf)
Table ORATD App D4 Low NOx Engine Emission Values

<table>
<thead>
<tr>
<th>Low NOx Standard g/bhp-hr</th>
<th>NOx g/gal</th>
<th>ROG g/gal</th>
<th>PM g/gal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>1.7</td>
<td>0.18</td>
<td>0.148</td>
</tr>
<tr>
<td>0.05</td>
<td>0.85</td>
<td>0.18</td>
<td>0.148</td>
</tr>
<tr>
<td>0.02</td>
<td>0.344</td>
<td>0.18</td>
<td>0.148</td>
</tr>
</tbody>
</table>

Note that Low NOx emission factors have only been established for 0.02 g NOx/bhp-hr as described in the FY 2016/17LCT/AQIP Funding Plan. Emission factors for 0.1 g/bhp-hr and 0.05 g NOx/bhp-hr are extrapolated and only intended for use in applying for funding under this solicitation. Also note that no emission benefit is assumed for ROG and PM from the use of a Low NOx engine.

5 [https://www.arb.ca.gov/msprog/aqip/fundplan/proposed_fy16-17_fundingplan_full.pdf](https://www.arb.ca.gov/msprog/aqip/fundplan/proposed_fy16-17_fundingplan_full.pdf)
Cost-Effectiveness and Emission Reduction Formulas for Calculations of GHG Emissions\(^6\)

A. Well-to-Wheel GHG Emission Calculations

Formula 1 and Formula 2 is used to calculate the greenhouse gas (GHG) emission factor in grams CO\(_2\)e per year of use. Formula 1a is used to determine the fuel usage of the baseline vehicle.

**Formula 1:** Liquid / Natural Gas and Hydrogen Fueled Vehicles

Formula 1 calculates the greenhouse gas emission factor (GHG EF) using the carbon intensity (CI) of the fuel, the fuel’s energy density and the annual fuel usage of the technology employed in the vehicle.

\[
\text{GHG EF} = \text{CI} \times \text{fuel energy density} \times \text{fuel usage} \times \frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}}
\]

\[
= \left( \frac{\text{gram CO2e}}{\text{MJ}} \right) \times \left( \frac{\text{MJ}}{\text{gal or kg or scf}} \right) \times \left( \frac{\text{gal or kg or scf}}{\text{year}} \right) \times \left( \frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}} \right)
\]

Formula 1a should be used to determine the fuel usage for the baseline vehicle based on miles driven and the fuel economy of the baseline vehicle.

**Formula 1a:** Baseline Vehicle Annual Diesel Fuel Usage

\[
\text{Fuel Usage}_{baseline} = \left( \frac{\text{gallon}}{\text{mile}} \right) \times \left( \frac{\text{miles}}{\text{day}} \right) \times \left( \frac{\text{days}}{\text{year}} \right)
\]

**Formula 2:** Electric Vehicles

\[
\text{GHG EF} = \text{CI} \times \text{unit conversion} \times \text{fuel (or electricity) usage}
\]

\[
= \left( \frac{\text{gram CO2e}}{\text{MJ}} \right) \times \left( \frac{3.60 \text{ MJ}}{\text{kWh}} \right) \times \left( \frac{X \text{ kWh}}{\text{year}} \right) \times \left( \frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}} \right)
\]

B. Conversion from Diesel Fuel Usage to Electricity/Hydrogen/CNG Usage

Formula 3 is used to calculate the fuel usage for the advanced technology vehicle (Fuel Usage ATV) using diesel usage of the baseline vehicle calculated using Formula 1a.

**Formula 3:**

\[
\text{Fuel Usage}_{ATV} = \left( \frac{X \text{ gal Diesel}}{\text{yr}} \right) \times \left( \frac{\text{ED}}{1 \text{ gal diesel}} \right) \times \left( \frac{\text{ED NF unit}}{\text{MJ}} \right) \times \left( \frac{1}{\text{EER}} \right)
\]

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\(^6\) GHG emissions are measured in “CO\(_2\) equivalent”, which means the number of metric tons of CO\(_2\) emissions with the same global warming potential as one metric ton of another greenhouse gas.
Where:

- $X$ is the number of gallons diesel fuel used as a basis for the conversion;
- $ED$ is the Energy Density of the replacement fuel (see Table ORATD App D1: Fuel Energy Density);
- $EER$ is the Energy Economy Ratio value for fuels relative to diesel fuel (see Table ORATD App D3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications);
- $NF$ is the new fuel that is proposed to be used as a diesel replacement; and
- $Unit$ is the units associated with the replacement fuel:
  - Electricity: kWh
  - Hydrogen: kg
  - CNG: scf

C. GHG Emission Reduction Calculation

The project's GHG emission reductions are the difference between the GHG emissions of the baseline vehicle and the GHG emissions of the advanced technology vehicle.

Baseline vehicles are the cleanest conventional vehicle that is commercially available at the time the application for funding is submitted, which for the purpose of this solicitation is a 2017 model year Class-8 truck, greater than 33,000 GVWR.

Formula 4 is used to determine the annual GHG emission reductions (GHG ERannual) associated with the ATV.

**Formula 4:**

$$Project \, GHG \, ER_{annual} = GHG \, EF_{baseline} - GHG \, EF_{ATV}$$

Where:

- $GHG \, ER_{annual}$ is the annual GHG emission reductions that are associated with the proposed project.
- $GHG \, EF_{baseline}$ is the GHG emission factor associated with the baseline vehicle that the advanced technology vehicle is compared to.
- $GHG \, ER_{ATV}$ is the GHG emission factor that is associated with the proposed advanced technology vehicle.

D. Cost-Effectiveness Calculations for GHG

The cost-effectiveness of a project is determined by dividing the annualized cost of the potential project by the annual emission reductions that will be achieved by the project as shown in Formula 5 below.

Formula 5 is used to determine the cost effectiveness of the project in dollars per ton of emissions reduced.
Formula 5:

\[
\text{Cost Effectiveness} \left( \frac{\text{\$}}{\text{metric ton}} \right) = \left( \frac{\text{CRF} \times (\text{\$ Advanced Technology Vehicle} - \text{\$ Baseline Diesel Vehicle})}{\text{metric ton emissions reduced per year}} \right)
\]

Where, for the purposes of this solicitation:
- CRF is the Capital Recovery Factor:
  - CRF\(_2\) = 0.515 per Moyer Table G-3a (2-year life); and
  - CRF\(_{10}\) = 0.111 per Moyer Table G-3a (10-year life).

E. Composite Carbon Intensity Calculations

Formula 6 below is used to determine a composite CI value for use in the calculations if two of the same fuel types are to be blended for use in the proposed vehicle or equipment. Using values from Table ORATD App D2: Fuel Carbon Intensity Values above as inputs into Formula 6.

Formula 6:

\[
CI_{\text{composite}} = (\text{fraction of total fuel} \times CI_{fuel\_1}) + (\text{fraction of total fuel} \times CI_{fuel\_2})
\]

F. ITS and Advanced Engine and Powertrain Technology Efficiency Calculation

Formula 7 should be used to determine the new amount of fuel necessary to operate the ATV annually by using ITS technology or advanced engine and powertrain technology that provides a percent efficiency improvement. Use results from Formula 1a to determine the gallons of diesel consumed by the baseline vehicle.

Formula 7:

\[
\text{Diesel Fuel Usage}_{ATV} = \left( \frac{\text{gal diesel}}{\text{year}} \right) \times \left( 1 - \frac{(X \times Y\%\text{ improvement})}{100}\right)
\]

Where:
- X is the fraction of the time the ITS technology or Advanced Engine and Powertrain system is enabled and providing emission reductions. If the advanced engine and powertrain technology is always engaged and providing emission reductions assume that X is equal to 1.
- Y is the percentage fuel economy improvement that is gained by having the ITS technology enabled or advanced engine and powertrains system efficiency improvement over the baseline vehicle’s engine.
G. Cost-Effectiveness and Emission Reduction Calculations for Criteria Pollutant and Particulate Matter Emissions (from the Moyer Guidelines)

Only the relevant language from the Moyer Guidelines is included below. Language has been modified where necessary for the purposes of this Solicitation. Tables that contain emission factors and necessary inputs follow at the end of this section. Updates to the below tables may have been made since the release of this solicitation. Only use the information included in the below tables for criteria and toxic emission reduction and cost effectiveness calculations.

Baseline vehicles for the purpose of this solicitation are the cleanest conventional vehicle that is commercially available at the time the application for funding is submitted, which for the purpose of this solicitation is a 2017 model year Class-8 on-road truck greater than 33,000 lbs. GVWR.

1. Calculating Cost-Effectiveness

The cost-effectiveness of a project is determined by dividing the annualized cost of the potential project by the annual weighted surplus emission reductions that will be achieved by the project as shown in Formula C-1 below.

Formula C-1: Cost-Effectiveness of Weighted Surplus Emission Reductions ($/ton)

\[
\text{Cost-Effectiveness ($/ton)} = \frac{\text{Annualized Cost ($/year(\text{yr})}}{\text{Annual Weighted Surplus Emission Reductions (tons/yr)}}
\]

Descriptions on how to calculate annual emission reductions and annualized cost are provided in the following sections.

2. Determining the Annualized Cost

Annualized cost is the amortization of the one-time incentive grant amount for the life of the project to yield an estimated annual cost. The annualized cost is calculated by multiplying the incremental cost by the capital recovery factor (CRF) from Table G-3. [NOTE: For the purposes of this Solicitation, the CRF is 0.111, which assumes a 10-year life.] The resulting annualized cost is used to complete Formula C-1 above to determine the cost-effectiveness of surplus emission reductions.

Formula C-2: Annualized Cost ($)

\[
\text{Annualized Cost} = \text{CRF} \times \text{incremental cost ($)}
\]

\[
\text{CFR}_2 = 0.515 \text{ per Moyer Table G-3a (2 year life)}
\]

\[
\text{CRF}_{10} = 0.111 \text{ per Moyer Table G-3a (10-year life)}
\]
3. Calculating the Incremental Cost

Formula C-3: Incremental Cost ($)

\[ \text{Incremental Cost} = \text{Cost of New Technology} ($) - \text{Cost of Baseline Diesel Technology} ($) \]

4. Calculating the Annual Weighted Surplus Emission Reductions

Annual weighted emission reductions are estimated by taking the sum of the project's annual surplus pollutant reductions following Formula C-5 below. This will allow projects that reduce one, two, or all three of the covered pollutants to be evaluated for eligibility to receive Carl Moyer Program funding. While oxides of nitrogen (NOx) and reactive organic gases (ROG) emissions are given equal weight, emissions of particulate matter (PM) carry a greater weight in the calculation.

Formula C-5: Annual Weighted Surplus Emission Reductions (tons/yr)

\[
\text{Weighted Emission Reductions} = \text{NOx reductions (tons/yr)} + \text{ROG reductions (tons/yr)} + [20 \times \text{PM reductions (tons/yr)}]
\]

The result of Formula C-5 is used to complete Formula C-1 to determine the cost-effectiveness of surplus emission reductions.

In order to determine the annual surplus emission reductions by pollutant, Formula C-15 below must be completed for each pollutant (NOx, ROG, and PM), for the baseline technology and the reduced technology, totaling up to 6 calculations:

<table>
<thead>
<tr>
<th>Baseline Technology</th>
<th>Reduced Technology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Annual emissions of NOx</td>
<td>4. Annual emissions of NOx</td>
</tr>
<tr>
<td>2. Annual emissions of ROG</td>
<td>5. Annual emissions of ROG</td>
</tr>
<tr>
<td>3. Annual emissions of PM</td>
<td>6. Annual emissions of PM</td>
</tr>
</tbody>
</table>

These calculations are completed for each pollutant by multiplying the engine emission factor or converted emission standard by the annual activity level and by other adjustment factors as specified for the calculation methodologies presented.

5. Calculating Annual Emission Reductions Based on Usage

(A) Calculating Annual Emissions Based on Fuel Consumption

When annual fuel consumption is used for determining emission reductions, the equipment activity level must be based on annual fuel usage within California provided by the applicant.
A fuel consumption rate factor must be used to convert emissions given in g/bhp-hr to units of grams of emissions per gallon of fuel used (g/gal). The fuel consumption rate factor is a number that combines the effects of engine efficiency and the energy content of the fuel used in that engine into an approximation of the amount of work output by an engine for each unit of fuel consumed. The fuel consumption rate factor is found in Table D-24 later in this appendix. Formulas C-8 and C-9 below are the formulas for calculating annual emissions based on annual fuel consumed.

Formula C-8: Estimated Annual Emissions based on Fuel Consumed using Emission Factors or Converted Emission Standard (tons/yr)

\[
\text{Annual Emission Reductions} = \\
Emission Factor or Converted Emission Standard (g/bhp-hr) \times \text{fuel consumption rate factor (bhp-hr/gallon (gal))} \times \text{Activity (gal/yr)} \times \frac{\text{ton}}{907,200g}
\]

Formula C-9: Estimated Annual Emissions based on Fuel using Emission Factors (tons/yr)

\[
\text{Annual Emission Reductions} = \\
Emission Factor (g/gal) \times \text{Activity (gal/yr)} \times \frac{\text{ton}}{907,200g}
\]

(B) Calculating Annual Emissions Based on Annual Miles Traveled

Calculations based on annual miles traveled are used for on-road projects only.

Calculations Using Emission Factors: There is no conversion since the emission factors for on-road projects provided are given in units of g/mile. Formula C-10 describes the method for calculating pollutant emissions based on emission factors and miles traveled.

Formula C-10: Estimated Annual Emissions based on Mileage using Emission Factors (tons/yr)

\[
\text{Annual Emission Reductions} = \\
Emission Factor (g/mile) \times \text{Activity (miles/yr)} \times \text{Percent Operation in CA} \times \frac{\text{ton}}{907,200g}
\]

Calculating Annual Emissions Based on Converted Standards: The unit conversion factors found in Tables D-5 and D-6 (Appendix D) are used to convert the units of the converted emission standard (g/bhp-hr) to g/mile. Formula C-11 describes the method for calculating pollutant emissions using converted emission standards.
Formula C-11: Estimated Annual Emissions based on Mileage using Converted Emission Standards (tons/yr)

\[
\text{Annual Emission Reductions} =
\]
\[
\text{Converted Emission Standard (g/bhp-hr)} \times \text{Unit Conversion (bhp-hr/mile)} \times \text{Activity (miles/yr)} \times \text{Percent Operation in CA} \times \text{ton/907,200 g}
\]

List of Criteria Pollutant Cost Effectiveness Formulas

For an easy reference, the necessary formulas to calculate the cost-effectiveness of surplus emission reductions for a project funded through the Carl Moyer Program are provided below.

Formula C-1: Cost-Effectiveness of Weighted Surplus Emission Reductions ($/ton):

\[
\text{Cost-Effectiveness ($/ton)} = \frac{\text{Annualized Cost ($/year(\text{yr})}}{\text{Annual Weighted Surplus Emission Reductions (tons/yr)}}
\]

Formula C-2: Annualized Cost ($)

\[
\text{Annualized Cost} = \text{CRF} \times \text{incremental cost ($)}
\]

Formula C-3: Incremental Cost ($)

\[
\text{Incremental Cost} = \text{Cost of New Technology ($)} - \text{Cost of Baseline Diesel Technology ($)}
\]

Formula C-5: Annual Weighted Surplus Emission Reductions

\[
\text{Weighted Emission Reductions} =
\text{NOx reductions (tons/yr)} + \text{ROG reductions (tons/yr)} + [20 \times \text{(PM reductions (tons/yr)}]
\]

Formula C-8: Estimated Annual Emissions based on Fuel Consumed using Emission Factors or Converted Emission Standard (tons/yr)

\[
\text{Annual Emission Reductions} =
\text{Emission Factor or Converted Emission Standard (g/bhp-hr)} \times \text{fuel consumption rate factor (bhp-hr/gallon (gal))} \times \text{Activity (gal/yr)} \times \text{Percent Operation in CA} \times \text{ton/907,200 g}
\]
Formula C-9: Estimated Annual Emissions based on Fuel using Emission Factors (tons/yr)

\[
\text{Annual Emission Reductions} = \\
\text{Emission Factor (g/gal)} \times \text{Activity (gal/yr)} \times \text{Percent Operation in CA} \times \\
\text{ton/907,200g}
\]

Formula C-10: Estimated Annual Emissions based on Mileage using Emission Factors (tons/yr)

\[
\text{Annual Emission Reductions} = \\
\text{Emission Factor (g/mile)} \times \text{Activity (miles/yr)} \times \text{Percent Operation in CA} \times \\
\text{ton/907,200g}
\]

Formula C-11: Estimated Annual Emissions based on Mileage using Converted Emission Standards (tons/yr)

\[
\text{Annual Emission Reductions} = \\
\text{Converted Emission Standard (g/bhp-hr)} \times \text{Unit Conversion (bhp-hr/mile)} \times \\
\text{Activity (miles/yr)} \times \text{Percent Operation in CA} \times \text{ton/907,200g}
\]
### Tables for Calculating Criteria and Toxic Pollutant Emission Reductions

#### ON-ROAD TRUCK TABLES

**Table D-1**  
Diesel Heavy-Duty Engines  
Converted Emission Standards for Fuel Based Usage Calculations

<table>
<thead>
<tr>
<th>EO Certification Standards</th>
<th>NOx g/bhp-hr</th>
<th>ROG&lt;sup&gt;(a)&lt;/sup&gt; g/gal</th>
<th>PM10</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0 NOx</td>
<td>0.60 PM10</td>
<td>103.23</td>
<td>5.33</td>
</tr>
<tr>
<td>5.0 NOx</td>
<td>0.25 PM10</td>
<td>86.03</td>
<td>4.44</td>
</tr>
<tr>
<td>5.0 NOx</td>
<td>0.10 PM10</td>
<td>86.03</td>
<td>4.44</td>
</tr>
<tr>
<td>4.0 NOx</td>
<td>0.10 PM10</td>
<td>68.82</td>
<td>3.55</td>
</tr>
<tr>
<td>2.5 NOx + NMHC</td>
<td>0.10 PM10</td>
<td>40.86</td>
<td>2.11</td>
</tr>
<tr>
<td>1.8 NOx + NMHC</td>
<td>0.01 PM10</td>
<td>29.42</td>
<td>1.52</td>
</tr>
<tr>
<td>1.5 NOx + NMHC</td>
<td>0.01 PM10</td>
<td>24.52</td>
<td>1.27</td>
</tr>
<tr>
<td>1.2 NOx + NMHC</td>
<td>0.01 PM10</td>
<td>19.61</td>
<td>1.01</td>
</tr>
<tr>
<td>0.84 NOx + NMHC</td>
<td>0.01 PM10</td>
<td>13.73</td>
<td>0.71</td>
</tr>
<tr>
<td>0.50 NOx</td>
<td>0.01 PM10</td>
<td>8.60</td>
<td>0.44</td>
</tr>
<tr>
<td>0.20 NOx</td>
<td>0.01 PM10</td>
<td>3.44</td>
<td>0.18</td>
</tr>
</tbody>
</table>

<sup>a</sup> - ROG = HC * 1.26639.  
<sup>b</sup> - Fuel based emissions factors were calculated using fuel consumption rate factors from Table D-24.  
<sup>c</sup> - Fuel based factors are for engines less than 750 horsepower only.  
<sup>d</sup> - Emission standards were converted where appropriate, using the NMHC and NOx fraction default values and the ultra-low-sulfur diesel fuel correction factors listed in Tables D-25 and D-26, respectively.

For Low NOx engines see Table ORATD App D4 Low NOx Engine Emission Values
### Table D-2

**Alternative Fuel Heavy-Duty Engines**

**Converted Emission Standards for Fuel Based Usage Calculations**

<table>
<thead>
<tr>
<th>EO Certification Standards</th>
<th>NOx</th>
<th>ROG&lt;sup&gt;(a)&lt;/sup&gt;</th>
<th>PM10</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g/bhp-hr</td>
<td>g/gal&lt;sup&gt;(b)(c)(d)&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>6.0 NOx</td>
<td>0.60 PM10</td>
<td>111.00</td>
<td>35.14</td>
</tr>
<tr>
<td>5.0 NOx</td>
<td>0.25 PM10</td>
<td>92.50</td>
<td>29.29</td>
</tr>
<tr>
<td>5.0 NOx</td>
<td>0.10 PM10</td>
<td>92.50</td>
<td>29.29</td>
</tr>
<tr>
<td>4.0 NOx</td>
<td>0.10 PM10</td>
<td>74.00</td>
<td>23.43</td>
</tr>
<tr>
<td>2.5 NOx + NMHC</td>
<td>0.10 PM10</td>
<td>37.00</td>
<td>11.71</td>
</tr>
<tr>
<td>1.8 NOx + NMHC</td>
<td>0.01 PM10</td>
<td>26.64</td>
<td>8.43</td>
</tr>
<tr>
<td>1.5 NOx + NMHC</td>
<td>0.01 PM10</td>
<td>22.20</td>
<td>7.03</td>
</tr>
<tr>
<td>1.2 NOx + NMHC</td>
<td>0.01 PM10</td>
<td>17.76</td>
<td>5.62</td>
</tr>
<tr>
<td>0.84 NOx + NMHC</td>
<td>0.01 PM10</td>
<td>12.43</td>
<td>3.94</td>
</tr>
<tr>
<td>0.50 NOx</td>
<td>0.01 PM10</td>
<td>9.25</td>
<td>2.93</td>
</tr>
<tr>
<td>0.20 NOX</td>
<td>0.01 PM10</td>
<td>3.70</td>
<td>1.17</td>
</tr>
</tbody>
</table>

<sup>a</sup> ROG = Vol * 1.26639.<br>
<sup>b</sup> Fuel based emissions factors were calculated using fuel consumption rate factors from Table D-24.<br>
<sup>c</sup> Fuel based factors are for engines less than 750 horsepower only.<br>
<sup>d</sup> Emission standards were converted where appropriate, using the NMHC and NOx fraction default values listed in Table D-25.
<table>
<thead>
<tr>
<th>Model Year</th>
<th>Diesel(^{(b)})</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NOx</td>
<td>ROG(^{(c)})</td>
<td>PM10</td>
</tr>
<tr>
<td>Pre-1987</td>
<td>14.52</td>
<td>0.75</td>
<td>0.695</td>
</tr>
<tr>
<td>1987-1990</td>
<td>14.31</td>
<td>0.59</td>
<td>0.755</td>
</tr>
<tr>
<td>1991-1993</td>
<td>10.70</td>
<td>0.26</td>
<td>0.409</td>
</tr>
<tr>
<td>1994-1997</td>
<td>10.51</td>
<td>0.20</td>
<td>0.226</td>
</tr>
<tr>
<td>1998-2002</td>
<td>10.33</td>
<td>0.20</td>
<td>0.249</td>
</tr>
<tr>
<td>2003-2006</td>
<td>6.84</td>
<td>0.13</td>
<td>0.157</td>
</tr>
<tr>
<td>2007-2009</td>
<td>4.01</td>
<td>0.11</td>
<td>0.017</td>
</tr>
<tr>
<td>2007+ (0.21-0.50 g/bhp-hr NOx(^{(d)}))</td>
<td>1.73</td>
<td>0.10</td>
<td>0.017</td>
</tr>
<tr>
<td>2010+ (0.20 g/bhp-hr NOx or cleaner)</td>
<td>0.74</td>
<td>0.09</td>
<td>0.017</td>
</tr>
</tbody>
</table>

- Emission factors incorporate the ultra-low-sulfur diesel fuel correction factors listed in Table D-26.
- ROG = HC * 1.26639.
- Use interpolated values assuming 1.2 g/bhp-hr NOx Standards for 2007-2009 Model Year Grouping and 0.2 g/bhp-hr NOx Standards for 2010+ Model Years.
<table>
<thead>
<tr>
<th>Model Year</th>
<th>Diesel(b)</th>
<th>NOx</th>
<th>ROG(c)</th>
<th>PM10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-1987</td>
<td>21.37</td>
<td>1.09</td>
<td>1.247</td>
<td></td>
</tr>
<tr>
<td>1987-1990</td>
<td>21.07</td>
<td>0.86</td>
<td>1.355</td>
<td></td>
</tr>
<tr>
<td>1991-1993</td>
<td>18.24</td>
<td>0.56</td>
<td>0.562</td>
<td></td>
</tr>
<tr>
<td>1994-1997</td>
<td>17.92</td>
<td>0.42</td>
<td>0.365</td>
<td></td>
</tr>
<tr>
<td>1998-2002</td>
<td>17.61</td>
<td>0.43</td>
<td>0.403</td>
<td></td>
</tr>
<tr>
<td>2003-2006</td>
<td>11.64</td>
<td>0.27</td>
<td>0.254</td>
<td></td>
</tr>
<tr>
<td>2007-2009</td>
<td>6.62</td>
<td>0.23</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>2007+ (0.21-0.50 g/bhp-hr NOx)(d)</td>
<td>2.88</td>
<td>0.20</td>
<td>0.028</td>
<td></td>
</tr>
<tr>
<td>2010+ (0.20 g/bhp-hr NOx or cleaner)</td>
<td>1.27</td>
<td>0.19</td>
<td>0.028</td>
<td></td>
</tr>
</tbody>
</table>

a - EMFAC 2011 Zero-Mile Based Emission Factors.
b - Emission factors incorporate the ultra-low-sulfur diesel fuel correction factors listed in Table D-26.
c - ROG = HC * 1.26639.
d - Use interpolated values assuming 1.2 g/bhp-hr NOx Standards for 2007-2009 Model Year Grouping and 0.2 g/bhp-hr NOx Standards for 2010+ Model Years.
### OFF-ROAD PROJECTS AND NON-MOBILE AGRICULTURAL PROJECTS

#### Table D-12

**Controlled Off-Road Diesel Engines**

**Emission Factors (g/bhp-hr)\(^{(a)}\)**

<table>
<thead>
<tr>
<th>Horsepower</th>
<th>Tier</th>
<th>NOx</th>
<th>ROG</th>
<th>PM10</th>
</tr>
</thead>
<tbody>
<tr>
<td>25-49</td>
<td>1</td>
<td>5.26</td>
<td>1.74</td>
<td>0.480</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4.63</td>
<td>0.29</td>
<td>0.280</td>
</tr>
<tr>
<td></td>
<td>4 Interim</td>
<td>4.55</td>
<td>0.12</td>
<td>0.128</td>
</tr>
<tr>
<td></td>
<td>4 Final</td>
<td>2.75</td>
<td>0.12</td>
<td>0.008</td>
</tr>
<tr>
<td>50-74</td>
<td>1</td>
<td>6.54</td>
<td>1.19</td>
<td>0.552</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4.75</td>
<td>0.23</td>
<td>0.192</td>
</tr>
<tr>
<td></td>
<td>3(^{(b)})</td>
<td>2.74</td>
<td>0.12</td>
<td>0.192</td>
</tr>
<tr>
<td></td>
<td>4 Interim</td>
<td>2.74</td>
<td>0.12</td>
<td>0.112</td>
</tr>
<tr>
<td></td>
<td>4 Final</td>
<td>2.74</td>
<td>0.12</td>
<td>0.008</td>
</tr>
<tr>
<td>75-99</td>
<td>1</td>
<td>6.54</td>
<td>1.19</td>
<td>0.552</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4.75</td>
<td>0.23</td>
<td>0.192</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.74</td>
<td>0.12</td>
<td>0.192</td>
</tr>
<tr>
<td></td>
<td>4 Phase-Out</td>
<td>2.74</td>
<td>0.12</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>4 Phase-In/Alternate NOx</td>
<td>2.14</td>
<td>0.11</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>4 Final</td>
<td>0.26</td>
<td>0.06</td>
<td>0.008</td>
</tr>
<tr>
<td>100-174</td>
<td>1</td>
<td>6.54</td>
<td>0.82</td>
<td>0.274</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4.17</td>
<td>0.19</td>
<td>0.128</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.32</td>
<td>0.12</td>
<td>0.112</td>
</tr>
<tr>
<td></td>
<td>4 Phase-Out</td>
<td>2.32</td>
<td>0.12</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>4 Phase-In/Alternate NOx</td>
<td>2.15</td>
<td>0.06</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>4 Final</td>
<td>0.26</td>
<td>0.06</td>
<td>0.008</td>
</tr>
<tr>
<td>175-299</td>
<td>1</td>
<td>5.93</td>
<td>0.38</td>
<td>0.108</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4.15</td>
<td>0.12</td>
<td>0.088</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.32</td>
<td>0.12</td>
<td>0.088</td>
</tr>
<tr>
<td></td>
<td>4 Phase-Out</td>
<td>2.32</td>
<td>0.12</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>4 Phase-In/Alternate NOx</td>
<td>1.29</td>
<td>0.08</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>4 Final</td>
<td>0.26</td>
<td>0.06</td>
<td>0.008</td>
</tr>
</tbody>
</table>
Table D-12
Controlled Off-Road Diesel Engines
Emission Factors (g/bhp-hr)<sup>(a)</sup>
(Continued)

<table>
<thead>
<tr>
<th>Horsepower</th>
<th>Tier</th>
<th>NOx</th>
<th>ROG</th>
<th>PM10</th>
</tr>
</thead>
<tbody>
<tr>
<td>300-750</td>
<td>1</td>
<td>5.93</td>
<td>0.38</td>
<td>0.108</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3.79</td>
<td>0.12</td>
<td>0.088</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.32</td>
<td>0.12</td>
<td>0.088</td>
</tr>
<tr>
<td></td>
<td>4 Phase-Out</td>
<td>2.32</td>
<td>0.12</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>4 Phase-In/Alternate NOx</td>
<td>1.29</td>
<td>0.08</td>
<td>0.008</td>
</tr>
<tr>
<td></td>
<td>4 Final</td>
<td>0.26</td>
<td>0.06</td>
<td>0.008</td>
</tr>
<tr>
<td>751+</td>
<td>1</td>
<td>5.93</td>
<td>0.38</td>
<td>0.108</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>3.79</td>
<td>0.12</td>
<td>0.088</td>
</tr>
<tr>
<td></td>
<td>4 Interim</td>
<td>2.24</td>
<td>0.12</td>
<td>0.048</td>
</tr>
<tr>
<td></td>
<td>4 Final</td>
<td>2.24</td>
<td>0.06</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Note: Engines that are participating in the “Tier 4 Early Introduction Incentive for Engine Manufacturers” program per California Code of Regulations, Title 13, section 2423(b)(6) are eligible for funding provided the engines are certified to the final Tier 4 emission standards. The ARB Executive Order indicates engines certified under this provision. The emission rates for these engines used to determine cost-effectiveness shall be equivalent to the emission factors associated with Tier 3 engines.

For equipment with baseline engines certified under the flexibility provisions per California Code of Regulations, Title 13, section 2423(d), baseline emission rates shall be determined by using the previous applicable emission standard or Tier for that engine model year and horsepower rating. The ARB Executive Order indicates engines certified under this provision.

a - Emission factors were converted using the ultra-low-sulfur diesel fuel correction factors listed in Table D-27.

b - Alternate compliance option.
## Table D-24
Fuel Consumption Rate Factors (bhp-hr/gal)

<table>
<thead>
<tr>
<th>Category</th>
<th>Horsepower/Application</th>
<th>Fuel Consumption Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-Mobile Agricultural Engines</td>
<td>ALL</td>
<td>17.5</td>
</tr>
<tr>
<td>Locomotive</td>
<td>Line Haul and Passenger (Class I/II)</td>
<td>20.8</td>
</tr>
<tr>
<td></td>
<td>Line Haul and Passenger (Class III)</td>
<td>18.2</td>
</tr>
<tr>
<td></td>
<td>Switcher</td>
<td>15.2</td>
</tr>
<tr>
<td>Other</td>
<td>&lt; 750 hp</td>
<td>18.5</td>
</tr>
<tr>
<td></td>
<td>≥ 750 hp</td>
<td>20.8</td>
</tr>
</tbody>
</table>
Example Calculations

Example calculations are provided to illustrate many of the permutations that staff expects may be included in an application for funding. Example calculations are included for three scenarios providing the six values that are needed for a complete application, those required six values are:

- GHG annual emission reductions from each proposed vehicle
- Criteria pollutant and toxic air contaminant annual pollutant emissions reductions for each propose vehicle
- GHG cost effectiveness for a two-year life during the time of the proposed project field demonstration
- GHG cost effectiveness for a 10-year life, two years after the end of the proposed demonstration project, assuming the technology is commercialized and available in the marketplace.
- Criteria pollutant and toxic air contaminant cost effectiveness for a two-year life during the time of the proposed project field demonstration and
- Criteria pollutant and toxic air contaminant cost effectiveness for a 10-year life, two years after the end of the proposed demonstration project, assuming the technology is commercialized and available to the marketplace.

GHG emission reductions are calculated in a well-to-wheel format and the criteria and toxic pollutant emission reductions calculations are determined under a tank-to-wheel scenario. The example calculations contained in this appendix are illustrations of:

1. **Intelligence Transportation Systems (ITS) on a Line-Haul Truck**
   - This example shows the use of an ITS system on a 2017 diesel fueled on-road truck.

2. **Advanced Engine and Powertrains on a Line-Haul Truck**
   - This example shows the use of a new engine type that is more efficient than a conventional diesel and meets the voluntary Low NOx engine certification levels.

3. **Fuel Cell Regional Delivery Truck**
   - This example demonstrates a project that proposes to utilize a hydrogen fuel cell propulsion system in a regional delivery truck application. The hydrogen fuel cell provides all the motive power to the truck. The hydrogen refueling system that will be used for the demonstration is considered part of the match for the project and therefore does not need to comply with SB 1505 requirements which call for 1/3 of the hydrogen to be from renewable sources.
All of the following examples use diesel fuel usage of the baseline vehicle as a basis for the GHG and criteria pollutant emission calculations. This technique may not adequately capture the emission profiles of all proposed applications however; this technique is used to allow all submitted applications to be scored on a level playing field.
Example 1: Intelligence Transportation Systems on a Line-Haul Truck

Potential GHG emission reductions are determined on a well-to-wheel basis, while criteria pollutant emission reductions are determined using a tank-to-wheel analysis. This example assumes that truck deploying ITS will have the same energy requirements as a diesel counterpart without ITS and will be used the same number of miles. The ITS technology is only functional at freeway speeds and will only be engaged half of the time the truck is on the freeway.

Baseline vehicle:
- 2017 diesel fueled Class-8 truck with a heavy duty 2017 on-road diesel engine
- Usage 5 miles per gallon, 275 miles per day, 210 days per year
- On-road truck cost at demonstration: $100,000
- On-road truck cost two years after demonstration: $100,000

Advanced Technology:
- 2017 diesel fueled Class-8 truck with a heavy duty 2017 on-road diesel engine
- Usage 5 miles per gallon, 275 miles per day, 210 days per year
  - 75% of miles are at freeway speeds
- ITS system provides a 7% increase in fuel economy for half of the freeway speed driving only
- On-road truck with ITS cost at demonstration: $115,000
- On-road truck cost with ITS two years after demonstration: $110,000

Variables Used in Calculation:

**Carbon Intensity**

From Table ORATD App D2: Fuel Carbon Intensity Values

\[ C_I = \text{Carbon Intensity} \]

\[ C_{I_{diesel}} = \frac{102.01 \, g \, CO_2e}{M J} \text{ Table Pathway Identifier ULSD001} \]

**Energy Density**

From Table ORATD App D1: Fuel Energy Density

\[ E_D = \text{Energy Density} \]

\[ E_{D_{diesel}} = \frac{134.47 \, M J}{gal \, diesel} \]
**Step 1:** Calculate the baseline vehicle’s annual fuel usage using Formula 1a above.

**Formula 1a:**

\[ \text{Fuel Usage}_{\text{baseline}} = \left( \frac{\text{gallon}}{\text{mile}} \right) \times \left( \frac{\text{miles}}{\text{day}} \right) \times \left( \frac{\text{days}}{\text{year}} \right) \]

\[ \text{Fuel Usage}_{\text{baseline}} = \left( \frac{1 \text{ gallon}}{5.0 \text{ miles}} \right) \times \left( \frac{275 \text{ miles}}{\text{day}} \right) \times \left( \frac{210 \text{ days}}{\text{year}} \right) = 11,550 \text{ gallons diesel/year} \]

**Step 2:** Determine the GHG emissions that are attributed to the baseline vehicle. Using Formula 1 and the variables identified above.

**Formula 1:**

\[ \text{GHG EF} = \text{CI} \times \text{fuel energy density} \times \text{fuel usage} \times \frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}} \]

\[ \text{GHG EF}_{\text{baseline}} = \left( \frac{102.01 \text{ g CO2e}}{\text{MJ}} \right) \times \left( \frac{134.47 \text{ MJ}}{\text{gal diesel}} \right) \times \left( \frac{11,550 \text{ gallons diesel}}{\text{year}} \right) \times \left( \frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}} \right) \]

\[ \text{GHG EF}_{\text{baseline}} = 158 \text{ metric tons CO2e/year} \]

**Step 3:** Determine the GHG emissions that are attributed to the advanced technology vehicle. First, determine the fuel usage for the advanced technology truck while on the freeway with ITS system enabled by using Formula 7, the results from Step 1 above, and the assumptions regarding the technology given at the start of this example.

**Formula 7:**

\[ \text{Diesel Fuel Usage}_{\text{ATV}} = \left( \frac{\text{gal diesel}}{\text{year}} \right) \times \left( 1 - \frac{(X \times Y\% \text{ improvement})}{100\%} \right) \]

Where:

- **X** is the fraction of the time the ITS technology or Advanced Engine and Powertrain system is enabled and providing emission reductions. If the advanced engine and powertrain technology is always engaged and providing emission reductions assume that X is equal to 1.

- **Y** is the percentage fuel economy improvement that is gained by having the ITS technology enabled or advanced engine and powertrains system efficiency improvement over the baseline vehicle’s engine.
\[
\text{Diesel Fuel Usage}_{ATV} = \left(\frac{11,550 \text{ gal diesel}}{\text{year}}\right) \times \left(1 - \frac{(0.75 \times 0.5) \times 7\% \text{ improvement}}{100\%}\right)
\]
\[
= \frac{11,247 \text{ gallons diesel}}{\text{year}}
\]

Use the output above in Formula 1 to calculate the greenhouse gas emission factor for the Advanced Technology Vehicle (GHG EF\textsubscript{ATV}).

**Formula 1:**

\[
\text{GHG EF} = \text{Cl} \times \text{fuel energy density} \times \text{fuel usage} \times \frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}}
\]

\[
= \left(\frac{\text{gram CO2e}}{\text{MJ}}\right) \times \left(\frac{\text{MJ}}{\text{gal}} \text{ or } \frac{\text{MJ}}{\text{kg}} \text{ or } \frac{\text{MJ}}{\text{scf}}\right) \times \left(\frac{\text{gal}}{\text{year}} \text{ or } \frac{\text{kg}}{\text{year}} \text{ or } \frac{\text{scf}}{\text{year}}\right) \times \left(\frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}}\right)
\]

\[
\text{GHG EF}_{ATV} = \left(\frac{102.01 \text{ g CO2e}}{\text{MJ}}\right) \times \left(134.47 \text{ MJ/gal diesel}\right) \times \left(\frac{11,247 \text{ gal diesel}}{\text{year}}\right) \times \left(\frac{1 \text{ metric ton}}{1,000,000 \text{ grams}}\right)
\]
\[
= 154 \frac{\text{metric tons CO2e}}{\text{year}}
\]

**Step 4:** Determine the annual GHG emission reductions that are associated with the proposed project. Using Formula 4 above populated by results from Step 2 and Step 3 from the above examples to give the annual GHG emission benefit from the proposed project.

**Formula 4:**

\[
\text{Project GHG ER}_{\text{annual}} = \text{GHG EF}_{\text{baseline}} - \text{GHG EF}_{\text{ATV}}
\]

\[
\text{Project GHG ER}_{\text{annual}} = \left(\frac{158 \text{ metric tons CO2e}}{\text{year}}\right) - \left(\frac{154 \text{ metric tons CO2e}}{\text{year}}\right)
\]
\[
= 4 \frac{\text{metric tons CO2e}}{\text{year}}
\]

**Step 5:** Determine the annual criteria and toxic pollutant emission reductions that are associated with the proposed project. Since the baseline vehicle is using an on-road engine certified to the 2010 standard, inputs from Table D-1 and the result of Step 1 above will be used to populate Formula C-9. Since the fuel economy improvement for the ITS technology only takes place during freeway driving the same process as described in Steps 2 and 3 above are used to determine the reducing in criteria pollutant emissions. Assume that the 7\% increase in fuel economy reduces criteria pollutant emissions by the same amount.

For a 2017 on-road engine with EO Certification Standard of 0.20 g NOx/bhp-hr, Table D-1 gives emissions per gallon of diesel consumed. Therefore:
Determine Criteria Pollutants from the baseline vehicle

**Annual Emissions** =  

\[ \text{Emission Factor (g/gal)} \times \text{Activity (gal/yr)} \times \frac{\text{ton}}{907,200 \text{g}} \]

Annual Emissions (Annual\text{base EM}) is the calculated annual emission from the baseline vehicle using Formula C-9:

\[
\text{Annual}_{\text{base EMNOx}} = \left( \frac{3.44 \text{ g NOx}}{\text{gal diesel}} \right) \times \left( \frac{11550 \text{ gal diesel}}{\text{year}} \right) \times \left( \frac{1 \text{ ton}}{907,200 \text{ g}} \right) = 0.0438 \text{ tons NOx per year}
\]

\[
\text{Annual}_{\text{base EMROG}} = \left( \frac{0.18 \text{ g ROG}}{\text{gal diesel}} \right) \times \left( \frac{11550 \text{ gal diesel}}{\text{year}} \right) \times \left( \frac{1 \text{ ton}}{907,200 \text{ g}} \right) = 0.00229 \text{ tons ROG per year}
\]

\[
\text{Annual}_{\text{base EMPM10}} = \left( \frac{0.148 \text{ g PM}}{\text{gal diesel}} \right) \times \left( \frac{11550 \text{ gal diesel}}{\text{year}} \right) \times \left( \frac{1 \text{ ton}}{907,200 \text{ g}} \right) = 0.00188 \text{ tons PM per year}
\]

**Step 6**: Determine the annual criteria and toxic pollutant emission reductions that are associated with the advanced technology truck. Since the advanced technology diesel on-road truck is using an on-road engine certified to the 2010 standard, inputs from Table D-1 and the result of Step1 above will be used to populate Formula C-9. Since the fuel economy improvement for the ITS technology only takes place during freeway driving the same process as described in Steps 2 and 3 above are used to determine the reducing in criteria pollutant emissions. Assume that the 7% increase in fuel economy reduces criteria pollutant emissions by the same amount.

For a 2017 on-road engine with EO Certification Standard of 0.20 g NOx/bhp-hr, Table D-1 gives emissions per gallon of diesel consumed. Therefore:

\[
\text{NOx} = 3.44 \frac{\text{g NOx}}{\text{gal diesel}} \quad \text{ROG} = 0.18 \frac{\text{g ROG}}{\text{gal diesel}} \quad \text{PM10} = 0.148 \frac{\text{g PM}}{\text{gal}}
\]

Using Formula C-9:

**Formula C-9**: Estimated Annual Emissions based on Fuel using Emission Factors (tons/yr).

Determine Criteria Pollutant emissions from the advanced technology truck

**Annual Emissions** =  

\[ \text{Emission Factor (g/gal)} \times \text{Activity (gal/yr)} \times \frac{\text{ton}}{907,200 \text{g}} \]
Annual Emissions (Annual_{ATV} EM) is the calculated annual criteria emission from the advanced technology vehicle.

Calculate the criteria pollutant emissions from the use of the ATV using Formula C-9 and the Fuel Usage ATV results from Step 3 above:

$$\text{Annual}_{ATV} \text{ EM}_{\text{NOx}} = \frac{3.44 \, \text{g NOx}}{\text{gal diesel}} \times \left( \frac{11.247 \, \text{gal diesel}}{\text{year}} \right) \times \left( \frac{1 \, \text{ton}}{907,200 \, \text{g}} \right) = 0.0426 \, \text{tons NOx/yr}$$

$$\text{Annual}_{ATV} \text{ EM}_{\text{ROG}} = \frac{0.18 \, \text{g ROG}}{\text{gal diesel}} \times \left( \frac{11.247 \, \text{gal diesel}}{\text{year}} \right) \times \left( \frac{1 \, \text{ton}}{907,200 \, \text{g}} \right) = 0.00223 \, \text{tons ROG/yr}$$

$$\text{Annual}_{ATV} \text{ EM}_{\text{PM10}} = \frac{0.148 \, \text{g NOx}}{\text{gal diesel}} \times \left( \frac{11.247 \, \text{gal diesel}}{\text{year}} \right) \times \left( \frac{1 \, \text{ton}}{907,200 \, \text{g}} \right) = 0.00183 \, \text{tons PM10/yr}$$

**Step 7**: Calculate the criteria emission reductions that are associated with the proposed project using Formula C-8. The emission reductions that are associated with the use of the advanced technology on-road truck are the criteria pollutant emissions that are associated with the baseline diesel vehicle, calculated in Step 6 above, minus the criteria pollutant emissions that are associated with the advanced technology truck, calculated in Step 8 above, as follows:

$$\text{Project ER} = \text{Baseline Emissions} - \text{Advanced Technology Emissions}$$

$$\text{Project ER}_{\text{NOx}} = (0.0438 \, \text{tons NOx/yr}) - (0.0426 \, \text{tons NOx/yr}) = 0.0012 \, \text{tons NOx/yr}$$

$$\text{Project ER}_{\text{ROG}} = (0.00229 \, \text{tons ROG/yr}) - (0.00223 \, \text{tons ROG/yr}) = 0.00006 \, \text{tons ROG/yr}$$

$$\text{Project ER}_{\text{PM}} = (0.00188 \, \text{tons PM/yr}) - (0.00183 \, \text{tons PM/yr}) = 0.00005 \, \text{tons PM/yr}$$

**Step 8**: Determine the weighted annual surplus emission reductions that are associated with the proposed project. Use the results from Step 6 and Step 7 to populate Formula C-5.

**Formula C-5: Annual Weighted Surplus Emission Reductions (tons/yr)**

$$\text{Weighted Emission Reductions} = \text{NOx reductions (tons/yr) + ROG reductions (tons/yr) + [20 * (PM reductions (tons/yr)]}$$

Therefore using the results from Step 6 above and Formula C-5:

$$\text{WER} = (0.0012 \, \text{tons NOx/yr}) + (0.00006 \, \text{tons ROG/yr}) \times 20 \left( 0.00005 \, \text{tons NOx/yr} \right) = 0.0023 \, \text{tons}$$

Therefore, $$\text{WER} = 0.0023 \, \text{tons criteria pollutants reduced/yr}$$
Step 9: Determine the Incremental cost of the proposed technology using Formula C-3 and the vehicle costs for the baseline vehicle and the fuel cell on-road truck given at the start of this example. Cost effectiveness is to be calculated for two scenarios; for two years during the demonstration and for 10 years, two years after the completion of the demonstration project.

Baseline vehicle:
- On-Road truck cost at Demonstration: $100,000
- On-Road truck cost two years after demonstration: $100,000

Advanced Technology:
- ITS equipped on-road truck cost at demonstration: $115,000
- ITS equipped on-road truck cost two years after demonstration: $110,000

Formula C-3: Incremental Cost ($)

\[
\text{Incremental Cost} = \text{Cost of New Technology} ($) - \text{Cost of Baseline Diesel Technology} ($)
\]

Incremental Cost\text{2 years} = $115,000 - $100,000 = $15,000
Incremental Cost\text{10 years} = $110,000 - $100,000 = $10,000

Step 10: Determine the GHG emission reduction cost effectiveness for the proposed project using the results from Step 5, Step 8 and Formula 5

Formula 5:

\[
\text{Cost Effectiveness} (\frac{\text{\$}}{\text{metric ton}}) = \left( \frac{\text{CRF} \times ($\text{Advanced Technology Vehicle} \ - $\text{Baseline Diesel Technology})}{\text{metric ton emissions reduced}} \right) \left( \frac{\text{year}}{\text{year}} \right)
\]

Where, for the purposes of this solicitation:
- CRF is the Capital Recovery Factor:
  - CRF\text{2} = 0.515 per Moyer Table G-3a (2-year life); and
  - CRF\text{10} = 0.111 per Moyer Table G-3a (10-year life).

Therefore:

\[
\text{GHG C/E 2 years} = \left( \frac{(0.515 \times $15,000)}{\text{4 metric tons CO2e}} \right) = \frac{1930}{\text{metric tons CO2e reduced}}
\]

\[
\text{GHG C/E 10 years} = \left( \frac{(0.111 \times $10,000)}{\text{4 metric tons CO2e}} \right) = \frac{280}{\text{metric tons CO2e reduced}}
\]
**Step 11:** Determine the criteria pollutant cost effectiveness for the proposed technology. Use the results from Step 7 and Step 8 to populate Formula C-1.

**Formula C-1: Cost-Effectiveness of Weighted Surplus Emission Reductions ($/ton)**

\[
\text{Cost-Effectiveness ($/ton)} = \frac{\text{Annualized Cost ($/year(yr))}}{\text{Annual Weighted Surplus Emission Reductions (tons/yr)}}
\]

Criteria Pollutant C/E_{2\ years} = \left( \frac{0.515 \times $15,000}{0.0023 \text{ tons WER}} \right) = \frac{$3.3 \ million}{\text{tons criteria pollutants reduced}}

Criteria Pollutant C/E_{10\ years} = \left( \frac{0.111 \times $10,000}{0.0023 \text{ tons WER}} \right) = \frac{$480,000}{\text{tons criteria pollutants reduced}}
Example 2: Advanced Engine and Powertrains on a Line-Haul Truck

Potential GHG emission reductions are determined on a well-to-wheel basis, while criteria pollutant emission reductions are determined using a tank-to-wheel analysis. This example assumes that a new engine type is utilized in a class-8 line-haul truck. The new engine type is diesel fueled and is 20% more efficient than a conventional diesel engine. The truck is assumed to have the same energy needs as a conventional diesel-fueled truck. The proposed project will be using renewable diesel fuel.

Baseline vehicle:
- 2017 diesel fueled on-road truck with an on-road engine certified to the 2010 diesel engine standard of 0.20 g/bhp-hr
- Usage 6 miles per gallon, 400 miles per day, 300 days per year
- On-road truck cost at demonstration: $100,000
- On-road truck cost two years after demonstration: $100,000

Advanced Technology:
- Advanced engine installed on Class-8 truck chassis
- Advanced engine is 20% more efficient than a conventional diesel engine
- Advanced engine is certified to the optional Low NOx engine standard of 0.02 g/bhp-hr
- Advanced technology on-road truck cost at demonstration: $1,000,000
- Advanced technology on-road truck cost two years after demonstration: $175,000

Variables Used in Calculation:

**Carbon Intensity**

From Table ORATD App D2: Fuel Carbon Intensity Values

\[ CI = \text{Carbon Intensity} \]

\[ CI_{\text{renewable diesel}} = \frac{102.01 \text{ g CO}_2 \text{e}}{\text{MJ}} \quad \text{Table Pathway Identifier RNWD302T} \]

**Energy Density**

From Table ORATD App D1: Fuel Energy Density

\[ ED = \text{Energy Density} \]

\[ ED_{\text{diesel}} = \frac{134.47 \text{ MJ}}{\text{gal diesel}} \]
**Step 1:** Calculate the baseline vehicle’s annual fuel usage using formula 1a.

**Formula 1a:**

$$\text{Fuel Usage}_{baseline} = \left( \frac{\text{gallon}}{\text{mile}} \right) \times \left( \frac{\text{miles}}{\text{day}} \right) \times \left( \frac{\text{days}}{\text{year}} \right)$$

Inputting values given at the start of this example for the baseline vehicle gives:

$$\text{Fuel Usage}_{baseline} = \left( \frac{1 \text{ gallon}}{6 \text{ miles}} \right) \times \left( \frac{400 \text{ miles}}{\text{day}} \right) \times \left( \frac{300 \text{ days}}{\text{year}} \right) = \frac{20,000 \text{ gallons diesel}}{\text{year}}$$

**Step 2:** Determine the GHG emissions that are attributed to the baseline vehicle. Using Formula 1 and the variables identified above.

**Formula 1:**

$$\text{GHG EF} = CI \times \text{fuel energy density} \times \text{fuel usage} \times \frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}}$$

$$= \left( \frac{\text{gram CO2e}}{\text{MJ}} \right) \times \left( \frac{\text{MJ}}{\text{gal or kg or scf}} \right) \times \left( \frac{\text{gal or kg or scf}}{\text{year}} \right) \times \left( \frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}} \right)$$

$$\text{GHG EF}_{baseline} = \left( \frac{102.01 \text{ g CO2e}}{\text{MJ}} \right) \times \left( \frac{134.47 \text{ MJ}}{\text{gal diesel}} \right) \times \left( \frac{20,000 \text{ gallons diesel}}{\text{year}} \right) \times \left( \frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}} \right)$$

$$= \frac{274 \text{ metric tons CO2e}}{\text{year}}$$

**Step 3:** Determine the GHG emissions that are attributed to the advanced technology on-road truck. First, determine the fuel usage for the advanced technology vehicle and then using the result from Step 2, the variables identified above as inputs into Formula 1 and the assumption that there is a 20% increase in engine efficiency, populate Formula 7.

**Formula 7:**

$$\text{Diesel Fuel Usage}_{ATV} = \left( \frac{\text{gal diesel}}{\text{year}} \right) \times \left( 1 - \frac{(X \times Y\% \text{ improvement})}{100\%} \right)$$

Where:

- **X** is the fraction of the time the ITS technology or Advanced Engine and Powertrain system is enabled and providing emission reductions. If the advanced engine and powertrain technology is always engaged and providing emission reductions assume that X is equal to 1.
- **Y** is the percentage fuel economy improvement that is gained by having the ITS technology enabled or advanced engine and powertrains system efficiency improvement over the baseline vehicle’s engine.
In this example X is equal to one since the advanced engine and powertrain technology is the primary motive engine for the truck and is always in use.

\[
\text{Diesel Fuel Usage}_{\text{ATV}} = \left(20,000 \frac{\text{gal diesel}}{\text{year}}\right) \times \left(1 - \frac{(1 \times 20\% \text{ improvement})}{100\%}\right) = 16,000 \frac{\text{gallons diesel}}{\text{year}}
\]

Using Formula 1, calculate the emissions associated when the Advanced Engine and Powertrain system in use on the Advanced Technology Vehicle (ATV).

**Formula 1:**

\[
\text{GHG EF} = CI \times \text{fuel energy density} \times \text{fuel usage} \times \frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}}
\]

\[
= \left(\frac{\text{gram CO2e}}{\text{MJ}}\right) \times \left(\frac{\text{MJ}}{\text{gal}} \text{ or } \frac{\text{MJ}}{\text{kg}} \text{ or } \frac{\text{MJ}}{\text{scf}}\right) \times \left(\frac{\text{gal}}{\text{year}} \text{ or } \frac{\text{kg}}{\text{year}} \text{ or } \frac{\text{scf}}{\text{year}}\right) \times \left(\frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}}\right)
\]

\[
\text{GHG EF}_{\text{ATV}} = \left(102.01 \frac{\text{g CO2e}}{\text{MJ}}\right) \times \left(134.47 \frac{\text{MJ}}{\text{gal diesel}}\right) \times \left(16,000 \frac{\text{gal diesel}}{\text{year}}\right) \times \left(\frac{1 \text{ metric ton}}{1,000,000 \text{ grams}}\right)
\]

\[
= 219 \frac{\text{metric tons CO2e}}{\text{year}}
\]

**Step 4:** Determine the annual GHG emission reductions that are associated with the proposed project. Using Formula 4 above populated by results from Step 2 and Step 3 from the above examples to give the annual GHG emission benefit from the proposed project.

**Formula 4:**

\[
\text{Project GHG ER}_{\text{annual}} = \text{GHG EF}_{\text{baseline}} - \text{GHG EF}_{\text{ATV}}
\]

\[
\text{Project GHG ER}_{\text{annual}} = \left(274 \frac{\text{metric tons CO2e}}{\text{year}}\right) - \left(219 \frac{\text{metric tons CO2e}}{\text{year}}\right)
\]

\[
= 55 \frac{\text{metric tons CO2e}}{\text{year}}
\]

**Step 5:** Determine the annual criteria and toxic pollutant emission reductions that are associated with the proposed project. Since the baseline vehicle is using an on-road engine certified to the 2010 standard, inputs from Table D-1 and the result of Step 1 above will be used to populate Formula C-9. The advanced engine technology is certified to the Low NOx engine standard of 0.02 g/bhp-hr use the emission factors found in Table ORATD App D4 Low NOx Engine Emission Values.
For a 2017 on-road engine with EO Certification Standard of 0.20 g NOx/bhp-hr, Table D-1 gives emissions per gallon of diesel consumed. Therefore:

\[ \text{NOx} = 3.44 \frac{g \text{ NOx}}{\text{gal diesel}} ; \text{ROG} = 0.18 \frac{g \text{ ROG}}{\text{gal diesel}} ; \text{PM10} = 0.148 \frac{g \text{ PM 10}}{\text{gal}} \]

Using Formula C-9:

**Formula C-9: Estimated Annual Emissions based on Fuel using Emission Factors (tons/yr).**

Determine Criteria Pollutants from the baseline vehicle

Annual Emissions =

\[ \text{Emission Factor (g/gal)} \times \text{Activity (gal/yr)} \times \text{ton/907,200g} \]

Annual Emissions (Annual\textsubscript{base} EM) is the calculated annual emission from the baseline vehicle using Formula C-9:

\begin{align*}
\text{Annual}\textsubscript{base} \text{ EMNOx} &= \left(3.44 \frac{g \text{ NOx}}{\text{gal diesel}}\right) \times \left(\frac{20,000 \text{ gal diesel}}{\text{year}}\right) \times \left(\frac{1 \text{ ton}}{907,200 \text{ g}}\right) = 0.0758 \frac{\text{tons NOx}}{\text{year}} \\
\text{Annual}\textsubscript{base} \text{ EMROG} &= \left(0.18 \frac{g \text{ ROG}}{\text{gal diesel}}\right) \times \left(\frac{20,000 \text{ gal diesel}}{\text{year}}\right) \times \left(\frac{1 \text{ ton}}{907,200 \text{ g}}\right) = 0.00367 \frac{\text{tons ROG}}{\text{year}} \\
\text{Annual}\textsubscript{base} \text{ EMPM10} &= \left(0.148 \frac{g \text{ PM 10}}{\text{gal diesel}}\right) \times \left(\frac{20,000 \text{ gal diesel}}{\text{year}}\right) \times \left(\frac{1 \text{ ton}}{907,200 \text{ g}}\right) = 0.00326 \frac{\text{tons PM}}{\text{year}}
\end{align*}

**Step 6:** Determine the annual criteria and toxic pollutant emission reductions that are associated with the advanced technology truck. Since the advanced technology diesel on-road truck is using an on-road engine certified to the Low NOx standard of 0.02 g/bhp-hr, The advanced engine technology is certified to the Low NOx engine standard of 0.02 g/bhp-hr. Use the fuel usage calculated in step 1 for the advanced technology truck engine as inputs into Formula C-9.

For a 2017 on-road engine with Low NOx Engine Standard of 0.02 g NOx/bhp-hr, Table ORATD App D4 Low NOx Engine Emission Values gives emissions per gallon of diesel consumed. Therefore:

\[ \text{NOx} = 0.344 \frac{g \text{ NOx}}{\text{gal diesel}} ; \text{ROG} = 0.18 \frac{g \text{ ROG}}{\text{gal diesel}} ; \text{PM10} = 0.148 \frac{g \text{ PM 10}}{\text{gal}} \]

Using Formula C-9:

**Formula C-9: Estimated Annual Emissions based on Fuel using Emission Factors (tons/yr).**

Determine Criteria Pollutant emissions from the advanced technology truck

Annual Emissions =

\[ \text{Emission Factor (g/gal)} \times \text{Activity (gal/yr)} \times \text{ton/907,200g} \]
Annual Emissions (Annual\textsubscript{ATV} EM) is the calculated annual emission from the advanced technology truck using Formula C-5 and the results from Step:

\begin{align*}
\text{Annual\textsubscript{ATV} EM\textsubscript{NOx}} &= \left( \frac{0.344 \text{ g NO}\textsubscript{x}}{\text{gal diesel}} \right) \times \left( \frac{16,000 \text{ gal diesel}}{\text{year}} \right) \times \left( \frac{1 \text{ ton}}{907,200 \text{ g}} \right) = 0.000607 \text{ tons NO}\textsubscript{x} \text{ year}^{-1} \\
\text{Annual\textsubscript{ATV} EM\textsubscript{ROG}} &= \left( \frac{0.18 \text{ g ROG}}{\text{gal diesel}} \right) \times \left( \frac{16,000 \text{ gal diesel}}{\text{year}} \right) \times \left( \frac{1 \text{ ton}}{907,200 \text{ g}} \right) = 0.000317 \text{ tons ROG} \text{ year}^{-1} \\
\text{Annual\textsubscript{ATV} EM\textsubscript{PM10}} &= \left( \frac{0.148 \text{ g PM\textsubscript{10}}}{\text{gal diesel}} \right) \times \left( \frac{16,000 \text{ gal diesel}}{\text{year}} \right) \times \left( \frac{1 \text{ ton}}{907,200 \text{ g}} \right) = 0.000261 \text{ tons PM\textsubscript{10}} \text{ year}^{-1}
\end{align*}

\textbf{Step 7}: Calculate the criteria emission reductions that are associated with the proposed project using Formula C-8. The emission reductions that are associated with the use of the advanced technology on-road truck are the criteria pollutant emissions that are associated with the baseline vehicle, calculated in Step 6 above, minus the criteria pollutant emissions that are associated with the advanced technology truck, calculated in Step 8 above, as follows:

\begin{align*}
\text{Project ER} &= \text{Baseline Emissions} - \text{Advanced Technology Emissions} \\
\text{Project ER\textsubscript{NOx}} &= (0.0758 \text{ tons NO}\textsubscript{x} \text{ year}^{-1}) - (0.000607 \text{ tons NO}\textsubscript{x} \text{ year}^{-1}) = 0.0752 \text{ tons NO}\textsubscript{x} \text{ year}^{-1} \\
\text{Project ER\textsubscript{ROG}} &= (0.00367 \text{ tons ROG} \text{ year}^{-1}) - (0.000317 \text{ tons ROG} \text{ year}^{-1}) = 0.000350 \text{ tons ROG} \text{ year}^{-1} \\
\text{Project ER\textsubscript{PM}} &= (0.00326 \text{ tons PM\textsubscript{10}} \text{ year}^{-1}) - (0.000261 \text{ tons PM\textsubscript{10}} \text{ year}^{-1}) = 0.000065 \text{ tons PM\textsubscript{10}} \text{ year}^{-1}
\end{align*}

\textbf{Step 8}: Determine the weighted annual surplus emission reductions that are associated with the proposed project. Use the results from Step 6 and Step 7 to populate Formula C-5.

\textbf{Formula C-5: Annual Weighted Surplus Emission Reductions (tons/yr)}

\begin{equation}
\text{Weighted Emission Reductions} = \text{NOx reductions (tons/yr)} + \text{ROG reductions (tons/yr)} + [20 \times \text{PM reductions (tons/yr)}]
\end{equation}

Therefore using the results from Step 6 above and Formula C-5:

\begin{align*}
\text{WER} &= (0.0752 \text{ tons NO}\textsubscript{x} \text{ year}^{-1}) + (0.000350 \text{ tons ROG} \text{ year}^{-1}) \times 20 \times (0.000065 \text{ tons NO}\textsubscript{x} \text{ year}^{-1}) = 0.089 \text{ tons} \\
\text{Therefore, WER} &= 0.089 \text{ tons criteria pollutants reduced year}^{-1}
\end{align*}

\textbf{Step 9}: Determine the Incremental cost of the proposed technology using Formula C-3 and the vehicle costs for the baseline vehicle and the fuel cell on-road truck given at the start of this example. Cost effectiveness is to be calculated for two scenarios; for two
years during the demonstration and for 10 years, two years after the completion of the
demonstration project.

**Baseline vehicle:**
- On-Road truck cost at Demonstration: $100,000
- On-Road truck cost two years after demonstration: $100,000

**Advanced Technology:**
- Advanced technology engine equipped on-road truck cost at demonstration: $1,000,000
- Advanced technology engine equipped on-road truck cost two years after
demonstration: $175,000

**Formula C-3: Incremental Cost ($)**

\[
\text{Incremental Cost} = \text{Cost of New Technology ($)} - \text{Cost of Baseline Diesel Technology ($)}
\]

Incremental Cost\textsubscript{2 years} = $1,000,000 - $100,000 = $900,000
Incremental Cost\textsubscript{10 years} = $175,000 - $100,000 = $75,000

**Step 10:** Determine the GHG emission reduction cost effectiveness for the proposed
project using the results from Step 5, Step 9 and Formula 5

**Formula 5:**

\[
\text{Cost Effectiveness (\$ metric ton\textsuperscript{-1})} = \frac{\text{CRF} \times (\text{Advanced Technology Vehicle} - \text{Baseline Diesel Vehicle})}{\text{metric ton emissions reduced year}}
\]

Where, for the purposes of this solicitation:
- **CRF** is the Capital Recovery Factor:
  - CRF\textsubscript{2} = 0.515 per Moyer Table G-3a (2-year life); and
  - CRF\textsubscript{10} = 0.111 per Moyer Table G-3a (10-year life).

Therefore:

GHG C/E is the GHG Cost Effectiveness

\[
\text{GHG C/E}_{\text{2 years}} = \frac{(0.515 \times $900,000)}{(55 \text{ metric tons CO}_2\text{e year})} = \frac{$8427}{\text{metric tons CO}_2\text{e reduced}}
\]

\[
\text{GHG C/E}_{\text{10 years}} = \frac{(0.111 \times $75,000)}{(55 \text{ metric tons CO}_2\text{e year})} = \frac{$151}{\text{metric tons CO}_2\text{e reduced}}
\]
Step 11: Determine the criteria pollutant cost effectiveness for the proposed technology. Use the results from Step 7 and Step 8 to populate Formula C-1.

Formula C-1: Cost-Effectiveness of Weighted Surplus Emission Reductions ($/ton)

\[
\text{Cost-Effectiveness ($/ton)} = \frac{\text{Annualized Cost ($/year)}}{\text{Annual Weighted Surplus Emission Reductions (tons/yr)}}
\]

Criteria Pollutant C/E_{2\text{years}} = \left(\frac{(0.515 \times $900,000)}{0.089 \text{tons WER}}\right) \frac{\text{year}}{\text{year}} = \frac{$5.2 \text{ million}}{\text{tons criteria pollutants reduced}}

Criteria Pollutant C/E_{10\text{years}} = \left(\frac{(0.111 \times $75,000)}{0.089 \text{tons WER}}\right) \frac{\text{year}}{\text{year}} = \frac{$94,000}{\text{tons criteria pollutants reduced}}
Example 3: Fuel Cell Regional Haul Truck

Potential GHG emission reductions are determined on a well-to-wheel basis, while criteria pollutant emission reductions are determined using a tank-to-wheel analysis. This example assumes that a fuel cell on-road regional haul truck will have the same energy requirements as a diesel counterpart and will be used the same number of miles. The proposed truck in this example will not be plugged in to the electrical grid to charge on-board battery packs, but will use the on-board fuel cell. Further, it is assumed that this project will use hydrogen that is produced from natural gas and compressed for use in the project.

Baseline vehicle:
- 2017 diesel fueled regional haul truck with a heavy duty 2017 on-road diesel engine
- Usage 5 miles per gallon, 175 miles per day, 210 days per year
- On-road truck cost at demonstration: $100,000
- On-road truck cost two years after demonstration: $100,000

Advanced Technology:
- Hydrogen fuel cell on-road truck
- Hydrogen fuel cell on-road truck cost at demonstration: $750,000
- Hydrogen fuel cell on-road truck cost two years after demonstration: $500,000

Variables Used in Calculation:

Carbon Intensity
From Table ORATD App D2: Fuel Carbon Intensity Values

\[ CI = \text{Carbon Intensity} \]

\[ CI_{\text{diesel}} = \frac{102.01 \text{g CO}_2 \text{e}}{\text{MJ}} \]  
Table Pathway Identifier ULSD001

\[ CI_{\text{hydrogen}} = \frac{88.33 \text{g CO}_2 \text{e}}{\text{MJ}} \]  
Pathway Identifier HYGN005

Energy Density
From Table ORATD App D1: Fuel Energy Density

\[ ED = \text{Energy Density} \]

\[ ED_{\text{diesel}} = \frac{134.47 \text{MJ}}{\text{gal diesel}} \]

\[ ED_{\text{hydrogen}} = \frac{120.00 \text{MJ}}{\text{kg H}_2} \]
Energy Efficiency Ratio

From Table ORATD App D3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications

EER = Energy Efficiency Ratio (unit less)

EER_{hydrogen} = 1.9

**Step 1:** Calculate the baseline vehicle’s annual fuel usage using Formula 1a:

**Formula 1a:**

\[
\text{Fuel Usage}_{baseline} = \left( \frac{\text{gallon}}{\text{mile}} \right) \times \left( \frac{\text{miles}}{\text{day}} \right) \times \left( \frac{\text{days}}{\text{year}} \right)
\]

\[
\text{Fuel Usage}_{baseline} = \left( \frac{1 \text{ gallon}}{5 \text{ miles}} \right) \times \left( \frac{175 \text{ miles}}{\text{day}} \right) \times \left( \frac{210 \text{ days}}{\text{year}} \right) = \frac{7,350 \text{ gallons diesel}}{\text{year}}
\]

**Step 2:** Convert the diesel used per year from the baseline vehicle to the amount of hydrogen needed to do the same work. Using Formula 3 and the variable identified above.

**Formula 3:**

\[
\text{Fuel Usage}_{ATV} = \left( \frac{X \text{ gal Diesel}}{\text{yr}} \right) \times \left( \frac{\text{ED MJ}}{1 \text{ gal diesel}} \right) \times \left( \frac{\text{ED NF unit MJ}}{\text{MJ}} \right) \times \left( \frac{1}{\text{EER}} \right)
\]

Where:

- **X** is the number of gallons diesel fuel used as a basis for the conversion;
- **ED** is the Energy Density of the replacement fuel (see Table ORATD App D1: Fuel Energy Density);
- **EER** is the Energy Economy Ratio value for fuels relative to diesel fuel (see Table ORATD App D3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications);
- **NF** is the new fuel that is proposed to be used as a diesel replacement; and
- **Unit** is the units associated with the replacement fuel:
  - Electricity: kWh
  - Hydrogen: kg
  - CNG: scf

\[
\text{Fuel Usage}_{ATV} = \left( \frac{7,350 \text{ gal Diesel}}{\text{yr}} \right) \times \left( \frac{134.47 \text{ MJ}}{1 \text{ gal diesel}} \right) \times \left( \frac{1 \text{ kg H2}}{120.00 \text{ MJ}} \right) \times \left( \frac{1}{1.9} \right) = 4,335 \frac{\text{kg H2}}{\text{year}}
\]

**Step 3:** Determine the GHG emissions that are attributed to the baseline on-road truck. Using Formula 1 and the variables identified above.
**Formula 1:**

\[ \text{GHG EF} = CI \times \text{fuel energy density} \times \text{fuel usage} \times \frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}} \]

\[ = \left( \frac{\text{gram CO2e}}{\text{MJ}} \right) \times \left( \frac{\text{MJ}}{\text{gal or kg or scf}} \right) \times \left( \frac{\text{gal or kg or scf}}{\text{year}} \right) \times \left( \frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}} \right) \]

\[ \text{GHG EF}_{\text{baseline}} = \left( \frac{102.01 \text{ g CO2e}}{\text{MJ}} \right) \times \left( \frac{134.47 \text{ MJ}}{\text{gal diesel}} \right) \times \left( \frac{7,350 \text{ gallons diesel}}{\text{year}} \right) \times \left( \frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}} \right) \]

\[ = 101 \frac{\text{metric tons CO2e}}{\text{year}} \]

**Step 4:** Determine the GHG emissions (GHG EF\text{ATV}) that are attributed to the advanced technology fuel cell on-road truck. Using the result from Step 2, the variables identified above as inputs into Formula 1.

**Formula 1:**

\[ \text{GHG EF} = CI \times \text{fuel energy density} \times \text{fuel usage} \times \frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}} \]

\[ = \left( \frac{\text{gram CO2e}}{\text{MJ}} \right) \times \left( \frac{\text{MJ}}{\text{gal or kg or scf}} \right) \times \left( \frac{\text{gal or kg or scf}}{\text{year}} \right) \times \left( \frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}} \right) \]

\[ \text{GHG EF}_{\text{ATV}} = \left( \frac{88.33 \text{ g CO2e}}{\text{MJ}} \right) \times \left( \frac{120.00 \text{ MJ}}{\text{kg H2}} \right) \times \left( \frac{4,335 \text{ kg H2}}{\text{year}} \right) \times \left( \frac{1 \text{ metric ton CO2e}}{1,000,000 \text{ grams}} \right) \]

\[ = 46 \frac{\text{metric tons CO2e}}{\text{year}} \]

**Step 5:** Determine the annual GHG emission reductions that are associated with the proposed project. Using Formula 4 above populated by results from Step 3 and Step 4 from the above example to give the annual GHG emission benefit from the proposed project.

**Formula 4:**

\[ \text{Project GHG ER}_{\text{annual}} = \text{GHG EF}_{\text{baseline}} - \text{GHG EF}_{\text{ATV}} \]

\[ \text{Project GHG ER}_{\text{annual}} = \left( 101 \frac{\text{metric tons CO2e}}{\text{year}} \right) - \left( 46 \frac{\text{metric tons CO2e}}{\text{year}} \right) \]

\[ = 55 \frac{\text{metric tons CO2e}}{\text{year}} \]
Step 6: Determine the annual criteria and toxic pollutant emission reductions that are associated with the proposed project. Since the baseline vehicle is using an on-road engine certified to the 2010 standard, inputs from Table D-1 and the result of Step 1 above will be used to populate Formula C-9. Since there are not any criteria or toxic air contaminant pollutant emissions associated with the use of the advanced technology on-road truck, all the emissions associated with the baseline vehicle are considered to be the criteria and toxic air contaminant emission reductions for the proposed project.

For a 2010 on-road engine with EO Certification Standard of 0.20 g NOx/bhp-hr, Table D-1 gives emissions per gallon of diesel consumed. Therefore:

\[
\text{NOx} = 3.44 \frac{g}{\text{gal diesel}}; \quad \text{ROG} = 0.18 \frac{g}{\text{gal diesel}}; \quad \text{PM10} = 0.148 \frac{g}{\text{PM10 gal}}
\]

Using Formula C-9:

**Formula C-9: Estimated Annual Emissions based on Fuel using Emission Factors (tons/yr).** All the emission reductions are taking place in CA.

Annual Emission Reductions =

\[
\text{Emission Factor (g/gal)} \times \text{Activity (gal/yr)} \times \frac{\text{ton}}{907,200 g}
\]

Annual ER is the calculated annual emission reductions

\[
\text{Annual ER}_{\text{NOx}} = \left(3.44 \frac{g \text{ NOx}}{\text{gal diesel}}\right) \times \left(7350 \frac{\text{gal diesel}}{\text{year}}\right) \times \left(\frac{1 \text{ ton}}{907,200 g}\right) = 0.0279 \frac{\text{tons NOx}}{\text{year}}
\]

\[
\text{Annual ER}_{\text{ROG}} = \left(0.18 \frac{g \text{ ROG}}{\text{gal diesel}}\right) \times \left(7350 \frac{\text{gal diesel}}{\text{year}}\right) \times \left(\frac{1 \text{ ton}}{907,200 g}\right) = 0.00146 \frac{\text{tons ROG}}{\text{year}}
\]

\[
\text{Annual ER}_{\text{PM10}} = \left(0.148 \frac{g \text{ PM10}}{\text{gal diesel}}\right) \times \left(7350 \frac{\text{gal diesel}}{\text{year}}\right) \times \left(\frac{1 \text{ ton}}{907,200 g}\right) = 0.00120 \frac{\text{tons PM10}}{\text{year}}
\]

Step 7: Determine the weighted annual surplus emission reductions that are associated with the proposed project. Using the results from Step 6 above along with the realization that the proposed fuel cell on-road truck will not produce any criteria pollutant emissions in a tank-to-wheel scenario populate Formula C-5.

**Formula C-5: Annual Weighted Surplus Emission Reductions (tons/yr)**

\[
\text{Weighted Emission Reductions} = \text{NOx reductions (tons/yr)} + \text{ROG reductions (tons/yr)} + [20 \times \text{PM reductions (tons/yr)}]
\]

Therefore using the results from Step 6 above and Formula C-5:

WER is the Weighted Emission Reductions

\[
\text{WER} = (0.0279 \frac{\text{tons NOx}}{\text{year}}) + \left(0.00146 \frac{\text{tons ROG}}{\text{year}}\right) \times 20 \left(0.00120 \frac{\text{tons NOx}}{\text{year}}\right) = 0.0534 \text{ tons}
\]

Therefore, WER = 0.053 \frac{\text{tons criteria pollutants reduced}}{\text{year}}
Step 8: Determine the Incremental cost of the proposed technology using Formula C-3 and the vehicle costs for the baseline vehicle and the fuel cell on-road truck given at the start of this example. Cost effectiveness is to be calculated for two scenarios; for two years during the demonstration and for 10 years, two years after the completion of the demonstration project.

Baseline vehicle:
- On-Road truck cost at Demonstration: $100,000
- On-Road truck cost two years after demonstration: $100,000

Advanced Technology:
- Fuel cell on-road truck cost at demonstration: $750,000
- Fuel cell on-road truck cost two years after demonstration: $500,000

Formula C-3: Incremental Cost ($)

$$\text{Incremental Cost} = \text{Cost of New Technology ($)} - \text{Cost of Baseline Diesel Technology ($)}$$

Incremental Cost$_{2 \text{ years}}$ = $750,000 - $100,000 = $650,000
Incremental Cost$_{10 \text{ years}}$ = $500,000 - $100,000 = $400,000

Step 9: Determine the GHG emission reduction cost effectiveness for the proposed project using the results from Step 5, Step 8 and Formula 5

Formula 5:

$$\text{Cost Effectiveness (\$ per metric ton)} = (\text{CRF} \times \frac{(\text{Advanced Technology Vehicle} - \text{Baseline Diesel Vehicle})}{\text{metric ton emissions reduced}}}$$

Where, for the purposes of this solicitation:
- **CRF** is the Capital Recovery Factor:
  - CRF$_2$ = 0.515 per Moyer Table G-3a (2-year life); and
  - CRF$_{10}$ = 0.111 per Moyer Table G-3a (10-year life).

Therefore:

GHG C/E is the GHG Cost Effectiveness

$$\text{GHG C/E }_{2 \text{ years}} = \left(\frac{(0.515 \times $650,000)}{55 \text{ metric tons CO2e}}\right) = $6086$$

$$\text{GHG C/E }_{10 \text{ years}} = \left(\frac{(0.111 \times $400,000)}{55 \text{ metric tons CO2e}}\right) = $807$$
Step 10: Determine the criteria pollutant cost effectiveness for the proposed technology. Use the results from Step 7 and Step 8 to populate Formula C-1.

Formula C-1: Cost-Effectiveness of Weighted Surplus Emission Reductions ($/ton)

Cost-Effectiveness ($/ton) = \frac{Annualized\ Cost\ ($/year(\ yr))}{Annual\ Weighted\ Surplus\ Emission\ Reductions\ (tons/yr)}

Criteria Pollutant C/E_{2\ years} = \frac{(0.515 \times $650,000)\ year}{0.053\ tons\ WER\ year} = \frac{$6.3\ million}{tons\ criteria\ pollutants\ reduced}

Criteria Pollutant C/E_{10\ years} = \frac{(0.111 \times $400,000)\ year}{0.053\ tons\ WER\ year} = \frac{$2,350}{tons\ criteria\ pollutants\ reduced}