APPENDIX D

METHODOLOGY FOR DETERMINING EMISSION REDUCTIONS AND COST-EFFECTIVENESS

Zero-Emission Drayage Truck and Infrastructure Pilot Project Solicitation

Mobile Source Control Division
California Air Resources Board
November 19, 2020

Note:
CARB released the Draft Quantification Methodology for public comment on July 16, 2020. This Final Quantification Methodology has been updated to address public comments, where appropriate, and for consistency with updates to the Zero-Emission Drayage Truck and Infrastructure Pilot Project solicitation.

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ABBREVIATIONS

The following abbreviations are used in this appendix:

"AQIP" means the Air Quality Improvement Program.
"ATV" means advanced technology vehicle.
"bhp-hr" means brake-horsepower-hour.
"CARB" means the California Air Resources Board.
"CI" means carbon intensity.
"CO2e" means carbon dioxide equivalent.
"CNG" means compressed natural gas.
"CRF" means capital recovery factor.
"ED" means fuel energy density.
"EER" means energy economy ratio.
"EF" means emission factor.
"ER" means emission reduction.
"g/bhp-hr" means grams per brake-horsepower-hour.
"gal" means gallon.
"GHG" means greenhouse gas.
"GVWR" means gross vehicle weight rating.
"HC" means hydrocarbon.
"hp" means horsepower.
"kWh" means kilowatt-hour.
"MJ" means megajoule.
"NMHC" means non-methane hydrocarbon.
"NOx" means oxides of nitrogen.
"PM" means particulate matter.
"PM10" means particulate matter less than 10 microns in diameter.
"TRU" means a transportation refrigeration unit.
"ROG" means reactive organic gases.
"scf" means standard cubic foot.
"ULSD" means ultra-low sulfur diesel.
"WER" means weighted surplus emission reduction.
"yr" means year.

Overview

The methodology described within this appendix must be used to calculate the emission reductions and cost-effectiveness of projects proposed under this Solicitation. All calculations and assumptions made must be shown clearly and in their entirety in the application. All calculations will use the cleanest commercially available diesel-fueled engine for determining baseline emission rates of greenhouse gas (GHG) and criteria pollutant emissions for any vehicle or pieces of equipment proposed to be used as part of the project. This technique may not adequately capture the emission profiles of all the vehicles included in an application; however to ensure all applications are scored on an objective basis, this technique will be used for scoring all submitted applications.

A "well-to–wheel" analysis to quantify GHG emission reductions is required for all vehicles funded under this Solicitation. The applicant is required to determine the resulting emission reductions associated with their project. All emission reductions are associated with the use of advanced technology vehicles and not the supporting infrastructure. All calculations must be shown in their entirety and included in the application. Incomplete illustration of the mathematical processes used could result in reduced or no points being allocated for scoring criteria related to emission reductions and cost-effectiveness. If the applicant believes that the methodology for determining emission reductions and cost-effectiveness does not accurately represent the emission potential of the proposed project, the applicant may submit, in addition to using the required methodology as outlined above, an alternative methodology for determining emission benefits and cost-effectiveness to illustrate the potential emission reductions of the proposed technology or strategy that the applicant is proposing. Regardless of inclusion of an alternate methodology, the applicant must still utilize the required methodology as outlined in Appendix D and required under Appendix A, Attachment 3. Projects will only be scored based on the required methodology for determining emission reduction and cost-effectiveness. The GHG emission factors used in this appendix are excerpted from the CCI Quantification Methodology Emission Factor Database dated May 7, 2020. The remaining emission factors and methodology are from the approved 2017 Carl Moyer Program Guidelines (2017 Moyer Guidelines), as updated in 2017. If an applicant's proposed project uses fuels or technologies that are not anticipated by this appendix the applicant may use emission factors that are found in the CCI Quantification Methodology Emission Factor Database and the Moyer Guidelines only. Please note that while emission factors may change during the Solicitation period, project applicants must use the values listed in this appendix.

The GHG Emission Calculation Section of this appendix provides the formulas that are needed to calculate the emission reductions and the cost-effectiveness for proposed projects. Please see the example calculations provided in the Example Calculations Section of this Appendix to better understand how the following formulas are used to calculate emission reduction and cost-effectiveness values. Any examples provided herein are for reference only and do not imply additional project types or categories, nor do 2017 Moyer Program funding amounts limit the amount of funding that may be available for projects funded under this solicitation. While Carl Moyer Program guidelines may change during the Solicitation period, project applicants must use the values listed in this appendix or Appendix C of the 2017 Moyer Program Guidelines.

GHG Emission Calculations[1]

A. Well-to-Wheel GHG Emission Calculations

The amount of fuel used in the baseline vehicle must be determined. Formula 1 is used to calculate the amount of fuel that is being consumed by the baseline vehicle. The output from Formula 1 will be used in other formulas, such as Formula 2. Formula 8 can be used to modify the result of Formula 1 to account for advanced technology systems that provide an incremental improvement in vehicle efficiency.

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

Formula 1: Annual Fuel Usage

$$Fuel\ Usage\left(\frac{gal}{year}\right) = \left(\frac{gal}{mile}\right) * \left(\frac{miles}{day}\right) * \left(\frac{days}{year}\right)$$

Formula 2 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 (Formula 1) for the technology employed in the vehicle or piece of equipment.

Formula 2: GHG Emission Factor Based on Fuel Usage

$$GHG\ EF\left(\frac{metric\ \ tons\ \ CO2e}{year}\right) = CI * fuel\ energy\ density * fuel\ usage * \frac{1\ metric\ \ ton\ \ CO2e}{1{,}000{,}000\ grams}$$

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

Where CI is provided in the Values for Emission Calculations section of this appendix.

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

Formula 3 is used to calculate the advanced technology vehicle (ATV) fuel usage based on the diesel usage of the baseline vehicle or equipment calculated from Formula 2.

[1] GHG emission factors are from the CCI Quantification Methodology Emission Factor Database, available at: https://www.arb.ca.gov/cc/capandtrade/auctionproceeds/cci_emissionfactordatabase.xlsx

Formula 3: Advanced Technology Vehicle Fuel Usage

$$ATV\ Fuel\ Usage\left(\frac{unit}{year}\right) = Baseline\ fuel\ usage * ED_{diesel} * \left(\frac{1}{ED_{replacement\quad fuel}}\right) * \left(\frac{1}{EER}\right)$$

Where:

- *ED* is the fuel energy density (see Values for Calculations section);
- *EER* is the Energy Economy Ratio value for fuels relative to diesel (see Values for Calculations section); and
- *Unit* is the units associated with the replacement fuel. Electricity usage is in units of kWh, hydrogen is in kg, and CNG is in standard cubic feet (scf).

C. GHG Emission Reduction Calculation

The project's GHG emission reduction value is determined by taking the difference between the GHG emissions of the baseline vehicle or equipment and the advanced technology vehicle or equipment.

Baseline vehicles or equipment are those using the cleanest engines commercially available at the time the application for funding is submitted, which for the purposes of this solicitation is a heavy-duty on-road engine certified for the 2020 Model Year, even if the actual baseline vehicle or piece of equipment used in a proposed project is a different model year. If a TRU is being proposed as part of the project, the baseline engine will be a U.S. E.P.A Tier-4 final off-road diesel engine.

Formula 4 is used to determine the annual GHG emission reductions ($GHG\ ER_{annual}$) associated with the ATV.

Formula 4: Annual GHG Emission Reductions from Advanced Technology Vehicle

$$ATV\ GHG\ ER_{annual}\left(\frac{metric\ tons\ CO2e}{year}\right) = GHG\ EF_{base} - GHG\ EF_{ATV}$$

Where:

- $ATV\ GHG\ ER_{annual}$ is the annual GHG emission reductions that are associated with the one of the proposed projects vehicles;
- $GHG\ EF_{base}$ is the GHG emissions associated with the baseline vehicle that the advanced technology vehicle is compared against; and
- $GHG\ ER_{ATV}$ is the GHG emissions 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: GHG Cost-Effectiveness

$$Cost\text{-}Effectiveness\left(\frac{annualized\ cost\ \$}{metric\ ton\ reduced}\right) = \frac{CRF * Incremental\ Cost}{Project\ GHG\ ER_{annual}}$$

Where:
- ***Metric ton reduced*** is the amount of GHG emissions reduced for one year
- ***CRF*** is the Capital Recovery Factor (see Values for Calculations section);
- ***Incremental Cost*** is the difference between the cost of the baseline vehicle or equipment and the advanced technology vehicle or equipment (result from Formula 6);
- ***Project GHG*** ER_{annual} is the calculated annual emission reduction in metric ton of CO2e (result from Formula 4).

Incremental cost is determined by subtracting the cost of a baseline vehicle from the cost from the advanced technology vehicle. Formula 6 is used to determine incremental cost.

Formula 6: Incremental Cost of Advanced Technology Vehicle

$$Incremental\ Cost = Cost\ of\ ATV - Cost\ of\ Baseline\ Vehicle$$

E. Composite Carbon Intensity Calculations

Formula 7 below is used to determine a composite carbon intensity value in the calculations if two of the same fuel types are to be blended for use in the proposed vehicle or equipment. Use Carbon Intensities from the Values for Calculations section as inputs into Formula 7.

Formula 7: Composite Carbon Intensity

$$CI_{composite} = (fraction\ of\ total\ fuel * CI_{fuel\ 1}) + (fraction\ of\ total\ fuel * CI_{fuel\ 2})$$

F. Advanced Technology Efficiency Calculation

Technologies such as advanced aerodynamic trailers or Intelligent Transportations Systems can provide incremental decreases in truck energy usage. Formula 8 should be used to determine the amount of fuel per year necessary to operate an advanced technology vehicle or equipment that has included a technology to provide a percent efficiency improvement. Use results from Formula 1 to determine the annual fuel usage for the baseline vehicle or equipment and then use the resultant of Formula 8 as an input for Formula 2.

Formula 8: Annual Fuel Usage of Advanced Technology Vehicle with Efficiency Improvement

$$Fuel\ Usage_{ATV}\left(\frac{gal}{year}\right) = fuel\ usage * \left(1 - \frac{(X * Y\%\ improvement)}{100\%}\right)$$

Where:

- ***X*** is the fraction of the time the advanced operational efficiency technology or logistic strategy is enabled and providing emission reductions. If the advanced operational efficiency technology is always engaged and providing emission reductions, assume that X is equal to 1; and
- ***Y*** is the percentage fuel economy improvement that is gained by having the advanced operational efficiency technology or logistic strategy efficiency improvement over the baseline engine.

Criteria Pollutant Calculations

This sections provides the formulas that are needed to calculate the criteria pollutant emissions results and cost-effectiveness for proposed projects, necessary to submit a successful application. Inputs for criteria pollutant cost-effectiveness calculations are taken from Appendix C of the 2017 Moyer Guidelines. Updates to these Guidelines may have been made since the release of this Solicitation. Only use the information included in the 2017 Moyer Guidelines for criteria pollutant emission reduction and cost-effectiveness calculations in response to this solicitation.

Baseline vehicles or equipment for the purpose of this Solicitation are the cleanest vehicle or equipment commercially available at the time the application for funding is submitted.

A. Calculating Emission Reductions

Criteria pollutant emissions are determined by multiplying the emission factor found in the Values for Calculations section of this appendix by the amount of fuel that is being consumed by the baseline vehicle. The criteria pollutant emissions from the advanced technology vehicle or piece of equipment is then subtracted from the baseline vehicle's emissions to determine the criteria pollutant emission reduction from the advanced technology vehicle. Criteria pollutant emissions are determined on a tank-to-wheel basis; therefore, zero-emission tailpipe technologies have no criteria pollutant emissions.

Fuel usage from Formula 1 Annual Fuel Usage, is multiplied by the Criteria Pollutant Emission Factors given in the Values for Calculations Section of this appendix and converted from metric to standard units.

Formula 9 is used to determine the annual emission reductions for each of the three criteria pollutant species that are required to be included in an application for funding.

Formula 9: Estimated Annual Emissions based on Fuel using Emission Factors

$$Annual\ Emissions = Emission\ Factor\left(\frac{g}{gal}\right) * fuel\ usage\left(\frac{gal}{year}\right) * \left(\frac{ton}{907{,}200\ g}\right)$$

B. Calculating the Weighted Emission Reduction

Annual weighted emission reductions (WER) are determined by taking the sum of the project's annual criteria pollutant reductions following Formula 10 below. While NOx and ROG emissions are given equal weight, emissions of PM carry a greater weight in the calculation.

Formula 10: Annual Weighted Surplus Emission Reductions

$$WER = NOx\ Reductions\ \left(\frac{tons}{year}\right) + ROG\ Reductions\ \left(\frac{tons}{year}\right) + \left(20 * \ PM\ Reductions\ \left(\frac{tons}{year}\right)\right)$$

The result of Formula 10 is used in Formula 11 to determine the cost-effectiveness of surplus emission reductions.

C. Calculating Cost-Effectiveness

The cost-effectiveness of a potential project is determined by dividing the annualized cost of the project by the annual weighted emission reductions that will be achieved by the project, as shown in Formula 11 below.

Formula 11: Cost-Effectiveness of Weighted Surplus Emission Reductions:

$$Cost\ Effectiveness\ \left(\frac{\$}{WER\ ton}\right) = \frac{CRF * Incremental\ Cost}{WER}$$

Where:

- ***WER ton*** is a ton of weighted emission reductions of criteria pollutant emissions on an annual basis;
- ***CRF*** is the Capital Recovery Factor (see Values for Calculations section);
- ***Incremental Cost*** is the result from Formula 6; and
- ***WER*** is the calculated annual emission reduction in ton of criteria pollutant (result from Formula 9 Annual Emissions).

Example Calculations

Example calculations are provided to illustrate the typical calculations that staff expects may be included in an application for funding. Example calculations are included for three scenarios providing the values that are needed for a complete application. Those required values are:

- GHG annual emission reductions from each proposed vehicle;
- Criteria pollutant and toxic air contaminant annual pollutant emission reductions for each proposed vehicle;
- GHG reduction cost-effectiveness for a two-year life during the time of the proposed project;
- GHG reduction cost-effectiveness for a 10-year life, two years after the end of the proposed project, assuming the zero-emission vehicle is fully commercialized and integrated into the marketplace at numbers described in the application;
- Criteria pollutant and toxic air contaminant reduction cost-effectiveness for a two-year life during the time of the proposed project;
- Criteria pollutant and toxic air contaminant reduction cost-effectiveness for a 10-year life, two years after the end of the proposed project, assuming the technology is fully commercialized and integrated into the marketplace at numbers described in the application;
- GHG reduction cost-effectiveness for an entire proposed project, during the time of the proposed project, assuming a two-year life and a 10-year life 2 years after the close of the project; and
- Criteria pollutant and toxic air contaminant reduction cost-effectiveness for an entire proposed project during the time of the proposed project, assuming a two-year life and a 10-year life 2 years after the close of the project.

GHG emission reductions are calculated on a well-to-wheel basis, while criteria pollutant emission reductions are calculated on a tank-to-wheel basis. The example calculations contained in this appendix are illustrations of:

- Example A: Battery-Electric Drayage or Regional Haul Truck
- Example B: Fuel Cell Drayage or Regional Haul Truck
- Example C: Project-Wide Summation of Emission Reductions and Cost-Effectiveness Determination

A. Example 1: Battery-Electric Drayage or Regional Haul Truck

Potential GHG emission reductions are determined on a well-to-wheel basis, while criteria pollutant emission reductions are determined on a tank-to-wheel basis. This example assumes that a battery-electric 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 is fully electric with a range of 200 miles on a single charge and will be plugged into the electrical grid to charge on-board battery packs.

Baseline vehicle:

- 2020 diesel fueled regional haul truck with a heavy duty 2020 on-road diesel engine
- Usage: 5 miles per gallon, 175 miles per day, 210 days per year
- On-road truck cost at start of project: $150,000
- On-road truck cost, two years after end of the proposed project: $160,000

Advanced Technology Vehicle:

- Battery-electric on-road truck with 200 mile range
- Battery-electric on-road truck cost during proposed project: $400,000
- Battery-electric on-road truck cost, two years after the proposed project: $300,000

Variables Used in Calculation:

Carbon Intensity

From Values for Calculations Section:

CI = Carbon Intensity

$$CI_{\ diesel} = 100.45 \frac{g\ CO2e}{MJ} \ ; \ CI_{\ electricity} = 81.49 \frac{g\ CO2e}{MJ}$$

Energy Density

From Values for Calculations Section:

ED = Energy Density

$$ED_{\ diesel} = 134.47 \frac{MJ}{gal\ diesel} \ ; \ ED_{\ electricity} = 3.60 \frac{MJ}{KWh}$$

Energy Efficiency Ratio

From Values for Calculations Section:

EER = Energy Efficiency Ratio (unitless)

$EER_{electricity}$ = 5.0

Step 1: Calculate the baseline vehicle's annual fuel usage using Formula 1.

Formula 1: Annual Fuel Usage

$$Fuel\ Usage_{baseline} = \left(\frac{gallon}{mile}\right) * \left(\frac{miles}{day}\right) * \left(\frac{days}{year}\right)$$

$$Fuel\ Usage_{baseline} = \left(\frac{1\ gallon}{5\ miles}\right) * \left(\frac{175\ miles}{day}\right) * \left(\frac{210\ days}{year}\right)$$

$$Fuel\ Usage_{baseline} = 7{,}350\,\frac{gallons\ \ diesel}{year}$$

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: Advanced Technology Vehicle Fuel Usage

$$Fuel\ Usage_{ATV} = \left(\frac{X\ gal\ Diesel}{yr}\right) * \left(ED\ \frac{MJ}{1\ gal\ diesel}\right) * \left(ED\ \frac{NF\ unit}{MJ}\right) * \left(\frac{1}{EER}\right)$$

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 Values for Calculations section for Fuel Energy Density);
- *EER* is the Energy Economy Ratio value for fuels relative to diesel fuel (see Section I. EMISSION FACTORS FOR GHG REDUCTIONS);
- *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

$$Fuel\ Usage_{ATV} = \left(\frac{7{,}350\ gal\ Diesel}{yr}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{1\ KWh}{3.60\ MJ}\right) * \left(\frac{1}{5.0}\right)$$

$$Fuel\ Usage_{ATV} = 54{,}909\,\frac{KWh}{year}$$

Step 3: Determine the GHG emissions that are attributed to the baseline on-road truck, using Formula 2 and the variables identified above.

Formula 2: GHG Emission Factor Based on Fuel Usage (for baseline vehicle)

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

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

$$GHG\ EF_{baseline} = \left(\frac{100.45\ g\ CO2e}{MJ}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{7{,}350\ gallons\ \ diesel}{year}\right) * \left(\frac{1\ metric\ \ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$= 99.28\,\frac{metric\ tons\ CO2e}{year}$$

Step 4: Determine the GHG emissions (*GHG EF_{ATV}*) that are attributed to the advanced technology battery-electric on-road truck, using Formula 2 and the variables identified above.

Formula 2: GHG Emission Factor Based on Fuel Usage (for Advanced Technology Vehicle)

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

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

$$GHG\ EF_{ATV} = \left(\frac{81.49\ g\ CO2e}{MJ}\right) * \left(\frac{3.60\ MJ}{KWh}\right) * \left(\frac{54{,}909\ KWh}{year}\right) * \left(\frac{1\ metric\ \ ton\ CO2e}{1{,}000{,}000\ grams}\right)$$

$$= 16.1\,\frac{metric\ \ tons\ \ CO2e}{year}$$

Step 5: Determine the annual GHG emission reductions that are associated with the proposed project. Using Formula 4, populated by results from Step 3 and Step, gives the annual GHG emission benefit from the proposed project.

Formula 4: Annual GHG Emission Reductions from Advanced Technology Vehicle

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

$$Project\ GHG\ ER_{annual} = \left(99.28\,\frac{metric\ \ tons\ \ CO2e}{year}\right) - \left(16.1\,\frac{metric\ \ tons\ \ CO2e}{year}\right)$$

$$= 83.2\,\frac{metric\ \ tons\ \ CO2e}{year}$$

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 Section II. Emission Factors for Diesel Fueled and the result of Step 1 above will be used to populate Formula 9. Since there are no 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.

The emission factors for diesel vehicles is given in the Values for Calculation section. For a 2020 on-road engine with EO Certification Standard of 0.20 g NOx/bhp-hr:

$$NOx = 3.44\ \frac{g\ NOx}{gal\ diesel}\ ;\ ROG = 0.18\ \frac{g\ ROG}{gal\ diesel}\ ;\ PM10 = 0.148\ \frac{g\ PM10}{gal}$$

Formula 9 is used to determine the Annual Emission Reductions using the emission factors for criteria pollutants found in the Values for Calculations section.

Formula 9: Estimated Annual Emissions based on Fuel using Emission Factors

$$Annual\ Emission\ Reductions = Emission\ Factor\ \left(\frac{g}{gal}\right) * fuel\ usage\ \left(\frac{gal}{year}\right) * \left(\frac{ton}{907{,}200\ g}\right)$$

Annual ER is the calculated annual emission reductions:

$$Annual\ ER_{NOx} = \left(\frac{3.44\ g\ NOx}{gal\ diesel}\right) * \left(\frac{7350\ gal\ diesel}{year}\right) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.0279\ \frac{tons\ NOx}{year}$$

$$Annual\ ER_{ROG} = \left(\frac{0.18\ g\ ROG}{gal\ diesel}\right) * \left(\frac{7350\ gal\ diesel}{year}\right) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.00146\ \frac{tons\ ROG}{year}$$

$$Annual\ ER_{PM10} = \left(\frac{0.148\ g\ NOx}{gal\ diesel}\right) * \left(\frac{7350\ gal\ diesel}{year}\right) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.00120\ \frac{tons\ PM}{year}$$

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 battery-electric on-road truck will not produce any criteria pollutant emissions in a tank-to-wheel scenario, populate Formula 10.

Formula 10: Annual Weighted Surplus Emission Reductions

$$WER = NOx\ Reductions\ \left(\frac{tons}{year}\right) + ROG\ Reductions\ \left(\frac{tons}{year}\right) + \left(20 * PM\ Reductions\ \left(\frac{tons}{year}\right)\right)$$

WER is the Weighted Emission Reduction:

$$WER = \left(0.0279\frac{tons\ NOx}{year}\right) + \left(0.00146\ \frac{tons\ ROG}{year}\right) + 20 * \left(0.00120\frac{tons\ PM}{year}\right)$$

$$WER = 0.0534\frac{tons}{year}$$

Therefore, $WER = 0.053\frac{tons\ criteria\ pollutants\ reduced}{year}$

Step 8: Determine the incremental cost of the proposed technology using Formula 6 and the vehicle costs for the baseline vehicle and the battery-electric 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:

- 2020 diesel fueled regional haul truck with a heavy duty 2020 on-road diesel engine
- Usage: 5 miles per gallon, 175 miles per day, 210 days per year
- On-road truck cost at start of project: $150,000
- On-road truck cost two years after end of the proposed project: $160,000

Advanced Technology:

- Battery-electric on-road truck cost during proposed project: $400,000
- Battery-electric on-road truck cost two years after the proposed project: $300,000

Formula 6: Incremental Cost of Advanced Technology Vehicle

$$Incremental\ Cost = Cost\ of\ ATV - Cost\ of\ Baseline\ Vehicle$$

$$Incremental\ Cost_{2\ years} = \$400{,}000 - \$150{,}000 = \$250{,}000$$
$$Incremental\ Cost_{10\ years} = \$300{,}000 - \$160{,}000 = \$140{,}000$$

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: GHG Cost-Effectiveness

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

Where:

- **CRF** is the Capital Recovery Factor:
  - CRF_2 = 0.508 (2-year life); and
  - CRF_{10} = 0.106 (10-year life).

Therefore:

GHG C/E is the GHG Cost-Effectiveness

$$GHG\ C/E_{2\ years} = \left(\frac{\frac{(0.508 * \$250{,}000)}{year}}{\frac{83.2\ metric\ tons\ CO2e}{year}} \right) = \frac{\$1{,}526}{metric\ tons\ CO2e\ reduced}$$

$$GHG\ C/E_{10\ years} = \left(\frac{\frac{(0.106 * \$140{,}000)}{year}}{\frac{83.2\ metric\ tons\ CO2e}{year}} \right) = \frac{\$178}{metric\ tons\ CO2e\ reduced}$$

Step 10: Determine the criteria pollutant cost-effectiveness for the proposed technology. Use the results from Step 7 and Step 8 to populate Formula 11.

Formula 11: Cost-Effectiveness of Weighted Surplus Emission Reductions

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

$$Criteria\ Pollutant\ C/E_{2\ years} = \left(\frac{\frac{(0.508 * \$250{,}000)}{year}}{\frac{0.053\ tons\ WER}{year}} \right)$$

$$= \frac{\$2.40\ million}{tons\ criteria\ pollutants\ reduced}$$

$$Criteria\ Pollutant\ C/E_{10\ years} = \left(\frac{\frac{(0.106 * \$140{,}000)}{year}}{\frac{0.053\ tons\ WER}{year}} \right)$$

$$= \frac{\$280{,}000}{tons\ criteria\ pollutants\ reduced}$$

B. Example 2: Fuel Cell Drayage or Regional Haul Truck

Potential GHG emission reductions are determined on a well-to-wheel basis, while criteria pollutant emission reductions are determined on a tank-to-wheel basis. 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 has a range of 300 miles on a single fill and 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:

- 2020 diesel fueled regional haul truck with a heavy duty 2020 on-road diesel engine
- Usage: 5 miles per gallon, 175 miles per day, 210 days per year
- On-road truck cost at start of project: $150,000
- On-road truck cost, two years after end of the proposed project: $160,000

Advanced Technology:

- Hydrogen fuel cell on-road truck cost during proposed project: $1,000,000
- Hydrogen fuel cell on-road truck cost, two years after the end of the proposed project: $500,000

Variables Used in Calculation:

Carbon Intensity

From Values for Calculations Section

CI = Carbon Intensity

$CI_{diesel} = 100.45 \frac{g\ CO2e}{MJ}$; $CI_{hydrogen} = 111.61 \frac{g\ CO2e}{MJ}$

Energy Density

From Values for Calculations Section

ED = Energy Density

$ED_{diesel} = 134.47 \frac{MJ}{gal\ diesel}$; $ED_{hydrogen} = 120.00 \frac{MJ}{kg\ H2}$

Energy Efficiency Ratio

From Values for Calculation Section

EER = Energy Efficiency Ratio (unit less)

$EER_{hydrogen}$ = 1.9

Step 1: Calculate the baseline vehicle's annual fuel usage using Formula 2.

Formula 1: Annual Fuel Usage

$$Fuel\ Usage_{baseline} = \left(\frac{gallon}{mile}\right) * \left(\frac{miles}{day}\right) * \left(\frac{days}{year}\right)$$

$$Fuel\ Usage_{baseline} = \left(\frac{1\ gallon}{5\ miles}\right) * \left(\frac{175\ miles}{day}\right) * \left(\frac{210\ days}{year}\right)$$

$$Fuel\ Usage_{baseline} = 7{,}350\,\frac{gallons\ \ diesel}{year}$$

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: Advanced Technology Vehicle Fuel Usage

$$Fuel\ Usage_{ATV} = \left(\frac{X\ gal\ Diesel}{yr}\right) * \left(ED\ \frac{MJ}{1\ gal\ diesel}\right) * \left(ED\ \frac{NF\ unit}{MJ}\right) * \left(\frac{1}{EER}\right)$$

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 Values for Calculations section);
- ***EER*** is the Energy Economy Ratio value for fuels relative to diesel fuel (see Values for Calculations section);
- ***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

$$Fuel\ Usage_{ATV} = \left(\frac{7{,}350\ gal\ Diesel}{yr}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{1\ kg\ H2}{120.00\ MJ}\right) * \left(\frac{1}{1.9}\right)$$

$$Fuel\ Usage_{ATV} = 4{,}335\,\frac{kg\ H2}{year}$$

Step 3: Determine the GHG emissions that are attributed to the baseline on-road truck, using Formula 2 and the variables identified above.

Formula 2: GHG Emission Factor Based on Fuel Usage (for baseline vehicle)

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

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

$$GHG\ EF_{baseline}\ \ = \left(\frac{100.45\ g\ CO2e}{MJ}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \ \left(\frac{7{,}350\ gallons\ \ diesel}{year}\right) * \left(\frac{1\ metric\ \ ton\ \ CO2e}{1{,}000{,}000\ grams}\right)$$

$$= 99.28\,\frac{metric\ \ tons\ \ CO2e}{year}$$

Step 4: Determine the GHG emissions (*$GHG\ EF_{ATV}$*) that are attributed to the advanced technology fuel cell on-road truck, using Formula 2 and the variables identified above.

Formula 2: GHG Emission Factor Based on Fuel Usage (for Advanced Technology Vehicle)

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

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

$$GHG\ EF_{ATV}\ = \left(\frac{111.61\ g\ CO2e}{MJ}\right) * \left(\frac{120.00\ MJ}{kg\ H2}\right) * \ \left(\frac{4{,}335\ kg\ H2}{year}\right) * \left(\frac{1\ metric\ \ ton\ \ CO2e}{1{,}000{,}000\ grams}\right)$$

$$= 58.06\,\frac{metric\ \ tons\ \ CO2e}{year}$$

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

Formula 4: Annual GHG Emission Reductions from Advanced Technology Vehicle

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

$$Project\ GHG\ ER_{annual}\ \ = \left(99.28\,\frac{metric\ \ tons\ \ CO2e}{year}\right) - \left(58.06\,\frac{metric\ \ tons\ \ CO2e}{year}\right)$$

$$= 41.22\,\frac{metric\ \ tons\ \ CO2e}{year}$$

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 Section II. Emission Factors for Diesel Fueled Trucks and the result of Step 1 above will be used to populate Formula 9. Since there are no 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.

The emission factors for diesel vehicles is given in the Values for Calculation section. For a 2020 on-road engine with EO Certification Standard of 0.20 g NOx/bhp-hr:

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

Formula 9 is used to determine the Annual Emission Reductions using the emission factors for criteria pollutants found in the Values for Calculations section.

Formula 9: Annual Emissions based on Fuel using Emission Factors

$$Annual\ Emission\ Reductions = Emission\ Factor\left(\frac{g}{gal}\right) * fuel\ usage\left(\frac{gal}{year}\right) * \left(\frac{ton}{907{,}200\ g}\right)$$

Annual ER is the calculated annual emission reductions

$$Annual\ ER_{NOx} = \left(\frac{3.44\ g\ NOx}{gal\ diesel}\right) * \left(\frac{7350\ gal\ diesel}{year}\right) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.0279\ \frac{tons\ NOx}{year}$$

$$Annual\ ER_{ROG} = \left(\frac{0.18\ g\ ROG}{gal\ diesel}\right) * \left(\frac{7350\ gal\ diesel}{year}\right) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.00146\ \frac{tons\ ROG}{year}$$

$$Annual\ ER_{PM10} = \left(\frac{0.148\ g\ NOx}{gal\ diesel}\right) * \left(\frac{7350\ gal\ diesel}{year}\right) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.00120\ \frac{tons\ PM}{year}$$

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 10.

Formula 10: Annual Weighted Surplus Emission Reductions

$$WER = NOx\ Reductions\ \left(\frac{tons}{year}\right) + ROG\ Reductions\ \left(\frac{tons}{year}\right) + \left(20 * PM\ Reductions\ \left(\frac{tons}{year}\right)\right)$$

Therefore, using the results from Step 6 above and Formula 9:

WER is the Weighted Emission Reductions:

$$WER = \left(0.0279 \frac{tons\ NOx}{year}\right) + \left(0.00146\ \frac{tons\ ROG}{year}\right) + 20 * \left(0.00120 \frac{tons\ PM}{year}\right)$$

$$WER = 0.0534 \frac{tons}{year}$$

Therefore, $WER = 0.053\ \frac{tons\ criteria\ \ pollutants\ \ reduced}{year}$

Step 8: Determine the incremental cost of the proposed technology using Formula 6 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 start of project: $150,000
- On-road truck cost, two years after end of the proposed project: $160,000

Advanced Technology:
- Hydrogen fuel cell on-road truck cost during proposed project: $1,000,000
- Hydrogen fuel cell on-road truck cost, two years after the end of the proposed project : $500,000

Formula 6: Incremental Cost of Advanced Technology Vehicle

$$Incremental\ Cost = Cost\ of\ ATV - Cost\ of\ Baseline\ Vehicle$$

$$Incremental\ Cost_{2 years} = \$1{,}000{,}000 - \$150{,}000 = \$850{,}000$$
$$Incremental\ Cost_{10\ years} = \$500{,}000 - \$160{,}000 = \$340{,}000$$

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: GHG Cost-Effectiveness

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

Where:
- **CRF** is the Capital Recovery Factor:
  - CRF_2 = 0.508 (2-year life); and
  - CRF_{10} = 0.106 (10-year life).

Therefore:

GHG C/E is the GHG Cost-Effectiveness

$$GHG\ C/E_{2\ years} = \left(\frac{\frac{(0.508 * \$850{,}000)}{year}}{\frac{41.22\ metric\ tons\ CO2e}{year}} \right) = \frac{\$10{,}475}{metric\ tons\ CO2e\ reduced}$$

$$GHG\ C/E_{10\ years} = \left(\frac{\frac{(0.106 * \$340{,}000)}{year}}{\frac{41.22\ metric\ tons\ CO2e}{year}} \right) = \frac{\$874}{metric\ tons\ CO2e\ reduced}$$

Step 10: Determine the criteria pollutant cost-effectiveness for the proposed technology. Use the results from Step 7 and Step 8 to populate Formula 11.

Formula 11: Cost-Effectiveness of Weighted Surplus Emission Reductions

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

$$Criteria\ Pollutant\ C/E_{2\ years} = \left(\frac{\frac{(0.508 * \$850{,}000)}{year}}{\frac{0.053\ tons\ WER}{year}} \right)$$

$$= \frac{\$8.15\ million}{tons\ criteria\ pollutants\ reduced}$$

$$Criteria\ Pollutant\ C/E_{10\ years} = \left(\frac{\frac{(0.106 * \$340{,}000)}{year}}{\frac{0.053\ tons\ WER}{year}} \right)$$

$$= \frac{\$680{,}000}{tons\ criteria\ pollutants\ reduced}$$

C. Example 3: Project Wide Summation of Emission Reductions and Cost-Effectiveness Determination

This example shows the summation of the emission reductions and cost-effectiveness from an entire project utilizing the example calculations for battery-electric and fuel cell powered trucks. The total project will have a one-to-one match and the total project cost is $36,000,000 with a request for funding of $18,000,000. The summation calculation will be required for a two-year period during the proposed project and calculation for a 10 year period after the end of the project.

A proposed project wants to deploy 10 fuel cell trucks and 40 battery-electric trucks:

- **10 Fuel Cell Regional Haul Trucks**
    - Total cost of each hydrogen fuel cell on-road truck at start of the project: $1,000,000

  Emission Reductions:

    - 41.22 metric tons CO2e per fuel cell truck (from Example 2, Step 5)
    - 0.053 tons WER per fuel cell truck

- **40 Battery-Electric Trucks**
    - Total cost of the battery-electric truck at start of the project: $400,000

  Emission Reductions:

    - 83.2 metric tons CO2e per battery-electric truck (from Example 1, Step 5)
    - 0.053 tons WER per battery-electric truck

Determination of the Total Cost of the Project:

$$Total\ Cost\ for\ Fuel\ Cell\ Trucks = 10\ trucks * \frac{\$1{,}000{,}000}{truck} = \$10{,}000{,}000$$

$$Total\ Cost\ for\ Battery\text{-}Electric\ Trucks = 40\ trucks * \frac{\$400{,}000}{truck} = \$16{,}000{,}000$$

The balance of the project includes refueling infrastructure for hydrogen truck and recharging infrastructure for battery-electric trucks. There are no emission reductions associated with infrastructure. The project also includes funding for data collation, project administration, outreach, hydrogen, electricity, vehicle maintenance, and workforce development. The total balance of the project is $10,000,000.

Therefore, the total project cost = $36,000,000

Determination of the total emission reductions from the project:

Annual GHG Emission Reduction from trucks =

$$10 \text{ fuel cell trucks} * \frac{41.22\, metric\ tons\ CO2e}{truck} = 412\ \frac{metric\ tons\ CO2e}{year}$$

$$40 \text{ battery-electric trucks} * \frac{83.2\, metric\ tons\ CO2e}{truck} = 3{,}328\ \frac{\text{metric tons CO2e}}{year}$$

Therefore, the sum of annual GHG emission reductions:

$$Total\ GHG\ Emission\ Reductions = \left(\frac{412\ metric\ tons\ CO2e}{year}\right) + \left(\frac{3{,}328\ metric\ tons\ CO2e}{year}\right)$$

$$= 3{,}740\ \frac{metric\ tons\ CO2e}{year}$$

Criteria Pollutant Emissions from Trucks =

$$10 \text{ fuel cell trucks} * \frac{0.053\ tons\ WER}{truck} = 0.53\ \frac{tons\ WER}{year}$$

$$40 \text{ battery-electric trucks} * \frac{0.053\ tons\ WER}{truck} = 2.12\ \frac{\text{tons WER}}{year}$$

Therefore, the sum of emission reductions:

$$Total\ Emission\ Reductions = \left(\frac{0.53\ tons\ WER}{year}\right) + \left(\frac{2.12\ tons\ WER}{year}\right) = 2.65\ \frac{tons\ WER}{year}$$

Use Formula 5 and 12 to determine the cost-effectiveness for both GHG and criteria pollutant emissions.

Formula 5: GHG Cost-Effectiveness

$$Cost\text{-}Effectiveness\ \left(\frac{\$}{metric\ ton}\right) = \left(\frac{\frac{CRF * (\$\ Total\ Project\ Cost)}{year}}{\frac{metric\ ton\ emissions\ reduced}{year}}\right)$$

Where:

- **CRF** is the Capital Recovery Factor:
  - CRF_2 = 0.508 (2-year life); and
  - CRF_{10} = 0.106 (10-year life).

Therefore:

GHG C/E is the GHG Cost-Effectiveness

$$GHG\ C/E_{2\ years} = \left(\frac{\frac{(0.508 * \$36{,}000{,}000)}{year}}{\frac{3{,}740\ metric\ tons\ CO2e}{year}} \right) = \frac{\$4{,}890}{metric\ tons\ CO2e\ reduced}$$

$$GHG\ C/E_{10\ years} = \left(\frac{\frac{(0.106 * \$36{,}000{,}000)}{year}}{\frac{3{,}740\ metric\ tons\ CO2e}{year}} \right) = \frac{\$1020}{metric\ tons\ CO2e\ reduced}$$

Determine the criteria pollutant cost-effectiveness for the proposed technology. Use the results from Step 6 and Step 7 to populate Formula 11.

Formula 11: Cost-Effectiveness of Weighted Surplus Emission Reductions

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

$$Criteria\ Pollutant\ C/E_{2\ years} = \left(\frac{\frac{(0.508 * \$36{,}000{,}000)}{year}}{\frac{2.65\ tons\ WER}{year}} \right)$$

$$= \frac{\$6.90\ million}{tons\ criteria\ pollutants\ reduced}$$

$$Criteria\ Pollutant\ C/E_{10\ years} = \left(\frac{\frac{(0.106 * \$36{,}000{,}000)}{year}}{\frac{2.65\ tons\ WER}{year}} \right)$$

$$= \frac{\$1.44\ million}{tons\ criteria\ pollutants\ reduced}$$

Values for Calculations

GHG Emission Factors

The following emission factors apply when calculating emission reductions and cost-effectiveness for Zero-Emission Drayage Truck and Infrastructure Pilot Project applications. Values are from the California Climate Investments Quantification Methodology Emission Factor Database, dated May 7, 2020.

Fuel Energy Density Values

Diesel: 134.47 MJ/gal

Electricity: 3.6 MJ/KWh

Hydrogen: 120.00 MJ/Kg

Fuel Carbon Intensity Values

Diesel: 100.45 gCO2e/MJ

Hydrogen: 111.61 gCO2/MJ

Hydrogen from zero-emission sources: 0.0 gCO2e/MJ

Electricity: 81.49 gCO2/MJ

Electricity from zero-emission sources: 0.0 gCO2e/MJ

EER Values for Fuels Used in Heavy-Duty Truck Applications

Diesel: 1.00

Electricity: 5.0

Hydrogen: 1.9

Criteria Pollutant Emission Factors

The following emission factors will be used for determining baseline emission values for criteria pollutants and are per gallon of diesel fuel used:

NOx: 3.44 g NOx/gal

ROG: 0.18 g ROG/gal

PM10: 0.148 g PM10/gal

Capital Recovery Factor (CRF) for Various Project Lives

At a 1% Discount Rate

Project Life	CRF
1	1.010
2	0.508
3	0.340
4	0.256
5	0.206
6	0.173
7	0.149
8	0.131
9	0.117
10	0.106
11	0.096
12	0.089
13	0.082
14	0.077
15	0.072
16	0.068
17	0.064
18	0.061
19	0.058
20	0.055