APPENDIX D

AIR QUALITY IMPROVEMENT PROGRAM (AQIP) AND LOW CARBON TRANSPORTATION GREENHOUSE GAS REDUCTION FUND (GGRF) INVESTMENTS

ZERO-EMISSION DRAYAGE TRUCK DEMONSTRATION PROJECT

METHODOLOGY FOR DETERMINING EMISSION REDUCTIONS AND COST-EFFECTIVENESS

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 baseline truck 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.

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 2015 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, as amended in July 2014 and updated in December 2014. 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.

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.

Emission Factors for GHG: 2015 Proposed Re-Adoption of LCFS

- Table Drayage App D1: Fuel Energy Density[1]

Fuel (units)	***Energy Density***
CARBOB (gal)	119.53 (MJ/gal)
CaRFG (gal)	115.63 (MJ/gal)
Diesel fuel (gal)	134.47 (MJ/gal)
CNG (scf)	0.98 (MJ/scf)
LNG (gal)	78.83 (MJ/gal)
Electricity (KWh)	3.60 (MJ/KWh)
Hydrogen (kg)	120.00 (MJ/kg)

[1] Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Proposed Re-Adoption of the Low Carbon Fuel Standard, December 2014 (http://www.arb.ca.gov/regact/2015/lcfs2015/lcfs15isor.pdf)

Denatured Ethanol (gal)	81.51 (MJ/gal)
FAME Biodiesel (gal)	126.13 (MJ/gal)
Renewable Diesel (gal)	129.65 (MJ/gal)

- Table Drayage App D2: Fuel Carbon Intensity Values[2]

Fuel		Pathway Identifier	Carbon Intensity Values (gCO_2e/MJ)
Baseline Fuels	CARBOB – based on the average crude oil supplied to California refineries and average California refinery efficiencies	CBOB001	100.53
	ULSD – based on the average crude oil supplied to California refineries and average California refinery efficiencies	ULSD001	102.76
	CaRFG (calculated)	--	99.11
Natural Gas	North American NG – CNG	CNG002	79.46
	North American NG – LNG (90% liquefaction eff.)	LNG002	86.57
Biomethane	Landfill Gas – CNG	CNG003	19.21
	Landfill Gas – LNG (90% liquefaction eff.)	LNG007	26.35
	Dairy and feedlot waste CNG	CNG004	30.13
Biodiesel	Soybean Biodiesel	BIOD001	22.73
	Tallow Biodiesel	BIOD008	32.83
	UCO Biodiesel	BIOD004	19.87
	Canola Biodiesel	BIOD006	35.73
	Corn Oil Biodiesel (from Wet DGS)	BIOD021	28.68
Renewable Diesel	Soybean RD	RNWD001	22.01
	Tallow RD	RNWD002	31.22
	UCO RD	--	18.21
	Canola RD	--	30.39
	Corn Oil RD (from Wet DGS)	--	28.49
Ethanol	Sugarcane Base Case; no credit	ETHS001	41.43
	Sugarcane; mechanized harvest and power export	ETHS002	31.09

[2] Direct values (without energy efficiency ratio adjustments). Source: California Air Resources Board, CA-GREET 1.8b versus 2.0 CI Comparison Table, April 1, 2015; http://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/040115_pathway_ci_comparison.pdf.

Fuel		Pathway Identifier	Carbon Intensity Values (gCO_2e/MJ)
	Sugarcane; mechanized harvest (harvest only)	--	32.17
	Sugarcane; power export only	ETHS003	40.35
	Sorghum Ethanol; 100% natural gas	ETHG001	67.29
	Corn Ethanol; 100% natural gas	ETHC004	60.29
Hydrogen	Hydrogen Gas; compressed H_2 from central reforming of NG; liquefaction and re-gasification	HYGN001	151.01
	Hydrogen Gas; liquid H_2 from central reforming of NG	HYGN002	143.51
	Hydrogen Gas; compressed H_2 from central reforming of NG (no liquefaction and re-gasification steps)	HYGN003	105.65
	Hydrogen Gas; compressed H_2 from on-site reforming of NG	HYGN004	105.13
	Hydrogen Gas; compressed H_2 from on-site reforming with renewable feedstocks (2/3 NA-NG and 1/3 biomethane)	HYGN005	89.84
Electricity	Average California Electricity	ELC001	105.16
Anaerobic Digestion	Biomethane CNG derived from the high solids anaerobic digestion (HSAD) of food and green wastes	CNG005	-34.70
	Biomethane CNG from anaerobic digestion of wastewater sludge at a small-to-medium-sized wastewater treatment plant	CNG021	30.98
	Biomethane CNG from anaerobic digestion of wastewater sludge at a medium-to-large-sized wastewater treatment plant	CNG020	7.80

- Table Drayage App D3: EER Values for Fuels Used in Light- Medium- and Heavy-Duty Applications[3]

Fuels Used as a Diesel Replacement for Heavy-Duty and Off-Road Applications	
Fuel/Vehicle Combinations	**EER Value Relative to Diesel**
Diesel Fuel or Biomass Based Diesel Blends	1.0
CNG or LNG/Any Vehicles (Spark-Ignition Engines)	0.9
CNG/LNG /Any Vehicle (Compression-Ignition Engines)	1.0
Electricity / Battery Electric or Plug-in Hybrid Electric Truck	2.7
Electricity / Fixed Guideway, Heavy Rail	4.6
Electricity / Fixed Guideway, Light Rail	3.3
Electricity / Trolley Bus, Cable Car, Street Car	3.1
Electricity/Forklifts or Equipment	3.8
H_2 / Fuel Cell Vehicle	1.9

[3] Staff Report: Initial Statement of Reasons for Proposed Rulemaking, Proposed Re-Adoption of the Low Carbon Fuel Standard, December 2014 (http://www.arb.ca.gov/regact/2015/lcfs2015/lcfs15isor.pdf). For gasoline as a fuel replacement, see Table III-3, page III-22.

Cost-Effectiveness and Emission Reduction Formulas for Calculations of GHG Emissions[4]

A. Well-to-Wheel GHG Emission Calculations

Formula 1: Liquid / Natural Gas and Hydrogen Fueled Vehicles

$$GHG\ EF = carbon\ intensity * \frac{fuel\ energy\ density}{efficiency} * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

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

Formula 2: Electric Vehicles

$$GHG\ EF = \frac{metric\ ton\ CO2e}{year} = carbon\ intensity * unit\ conversion * efficiency$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{3.60\ MJ}{kWh}\right) * \left(\frac{X\ kWh}{year}\right) * \frac{1\ metric\ ton}{1{,}000{,}000\ grams}$$

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

Formula 3:

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

Where:
X is the number of gallons diesel fuel used as a basis for the conversion;
NF is the new fuel that is proposed to be used as a diesel replacement;
ED is the Energy Density of the replacement fuel (see Table Drayage App D1: Fuel Energy Density); and
Unit is the units associated with the replacement fuel:

Electricity:	kWh
Hydrogen:	kg
CNG:	scf

[4] 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.

C. GHG Emission Reduction Calculation

Using the results from determining the GHG emissions that are associated with the base case truck and the advanced technology truck, taking their difference gives the estimated GHG emission reductions that are associated with the proposed project.

Base case trucks for the purpose of this solicitation are the cleanest vehicle that is commercially available at the time the application for funding is submitted, which for the purpose of this solicitation is an engine that meets the 2010 heavy-duty diesel engine emission standards.

Formula 4:

Project GHG ER_{annual} = GHG EF_{base} - GHG $EF_{adv\ tech}$

Where:

- GHG ER_{annual} is the annual GHG emission reductions that are associated with the proposed project.
- GHG EF_{base} is the GHG emission factor associated with the base case truck that the advanced technology vehicle is compared too.
- GHG $ER_{adv\ tech}$ is the GHG emission factor that is associated with the proposed technology.

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 4 below.

Formula 5:

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

For the purposes of this Solicitation:

CRF = Capitol Recover Factor

CRF_2 = 0.515 per Moyer Table G-3b (2-year life)

CRF_{10} = 0.111 per Moyer Table G-3b (10-year life)

E. Composite Carbon Intensity Calculations

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

Formula 6:

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

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 or equipment for the purpose of this solicitation are the cleanest vehicle or equipment that is commercially available at the time the application for funding is submitted.

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)

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

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 0.106, 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 ($)

*Annualized Cost = CRF * incremental cost ($)*

CFR_2 = 0.515 per Moyer Table G-3b (2 year life)
CRF_{10} = 0.111 per Moyer Table G-3b (10-year life)

3. **Calculating the Incremental Cost**

Formula C-3: Incremental Cost ($)

Incremental Cost = Cost of New Technology ($) – Cost of Baseline Diesel Technology ($)

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)

Weighted Emission Reductions =

*NOx reductions (tons/yr) + ROG reductions (tons/yr) + [20 * (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 4 calculations:

Baseline Technology	Reduced Technology
1. Annual emissions of NOx	4. Annual emissions of NOx
2. Annual emissions of ROG	5. Annual emissions of ROG
3. Annual emissions of PM	6. Annual emissions of PM

These calculations are completed for each pollutant by multiplying the engine emission factor or converted emission standard (found in Appendix D) 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. Fuel records must be maintained by the engine owner as described in the relevant source category chapter for additional information on this topic.

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)

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * fuel consumption rate factor (bhp-hr/gallon (gal)) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

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

Annual Emission Reductions =

*Emission Factor (g/gal) * Activity (gal/yr) * Percent Operation in CA * 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. Mileage records must be maintained by the engine owner as described in Chapter 4: On-road Heavy-Duty Vehicles.

<u>Calculations Using Emission Factors</u>: 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)

Annual Emission Reductions =

*Emission Factor (g/mile) * Activity (miles/yr) * Percent Operation in CA * ton/907,200g*

<u>Calculating Annual Emissions Based on Converted Standards</u>: 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)

Annual Emission Reductions =

*Converted Emission Standard (g/bhp-hr) * Unit Conversion (bhp-hr/mile) * Activity (miles/yr) * Percent Operation in CA * 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):

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

Formula C-2: Annualized Cost ($)

*Annualized Cost = 0.106 * incremental cost ($)*

Formula C-3: Incremental Cost ($)

Incremental Cost = Cost of New Technology ($) – Cost of Baseline Diesel Technology ($)

Formula C-5: Annual Weighted Surplus Emission Reductions

Weighted Emission Reductions =

*NOx reductions (tons/yr) + ROG reductions (tons/yr) + [20 * (PM reductions (tons/yr)]*

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

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * fuel consumption rate factor (bhp-hr/gallon (gal)) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

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

Annual Emission Reductions =

*Emission Factor (g/gal) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

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

Annual Emission Reductions =

*Emission Factor (g/mile) * Activity (miles/yr) * Percent Operation in CA * ton/907,200g*

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

Annual Emission Reductions =

*Converted Emission Standard (g/bhp-hr) * Unit Conversion (bhp-hr/mile) * Activity (miles/yr) * Percent Operation in CA * 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

EO Certification Standards g/bhp-hr		NOx	ROG[(a)]	PM10
		g/gal[(b)(c)(d)]		
6.0 NOx	0.60 PM10	103.23	5.33	7.992
5.0 NOx	0.25 PM10	86.03	4.44	3.330
5.0 NOx	0.10 PM10	86.03	4.44	1.332
4.0 NOx	0.10 PM10	68.82	3.55	1.332
2.5 NOx + NMHC	0.10 PM10	40.86	2.11	1.332
1.8 NOx + NMHC	0.01 PM10	29.42	1.52	0.148
1.5 NOx + NMHC	0.01 PM10	24.52	1.27	0.148
1.2 NOx + NMHC	0.01 PM10	19.61	1.01	0.148
0.84 NOx + NMHC	0.01 PM10	13.73	0.71	0.148
0.50 NOx	0.01 PM10	8.60	0.44	0.148
0.20 NOX	0.01 PM10	3.44	0.18	0.148

a - ROG = HC * 1.26639.
b - Fuel based emissions factors were calculated using fuel consumption rate factors from Table D-24.
c - Fuel based factors are for engines less than 750 horsepower only.
d - 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.

Table D-2
Alternative Fuel Heavy-Duty Engines
Converted Emission Standards for Fuel Based Usage Calculations

EO Certification Standards g/bhp-hr		NOx	ROG[(a)]	PM10
		g/gal[(b)(c)(d)]		
6.0 NOx	0.60 PM10	111.00	35.14	11.100
5.0 NOx	0.25 PM10	92.50	29.29	4.625
5.0 NOx	0.10 PM10	92.50	29.29	1.850
4.0 NOx	0.10 PM10	74.00	23.43	1.850
2.5 NOx + NMHC	0.10 PM10	37.00	11.71	1.850
1.8 NOx + NMHC	0.01 PM10	26.64	8.43	0.185
1.5 NOx + NMHC	0.01 PM10	22.20	7.03	0.185
1.2 NOx + NMHC	0.01 PM10	17.76	5.62	0.185
0.84 NOx + NMHC	0.01 PM10	12.43	3.94	0.185
0.50 NOx	0.01 PM10	9.25	2.93	0.185
0.20 NOX	0.01 PM10	3.70	1.17	0.185

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

Table D-3
Heavy-Duty Vehicles
14,001-33,000 pounds (lbs) Gross Vehicle Weight Rating (GVWR)
Emission Factors for Mileage Based Calculations (g/mile)[a]

Model Year	Diesel[b]		
	NOx	ROG[c]	PM10
Pre-1987	14.52	0.75	0.69
1987-1990	14.31	0.59	0.75
1991-1993	10.70	0.26	0.41
1994-1997	10.51	0.20	0.23
1998-2002	10.33	0.20	0.25
2003-2006	6.84	0.13	0.16
2007-2009	4.01	0.11	0.02
2007-2009 (0.50 g/bhp-hr NOx or Cleaner)[d]	1.73	0.10	0.017
2010+	0.74	0.09	0.02

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.

Table D-4
Heavy-Duty Vehicles
Over 33,000 lbs GVWR
Emission Factors for Mileage Based Calculations (g/mile)[(a)]

Model Year	Diesel[(b)]		
	NOx	ROG[(c)]	PM10
Pre-1987	21.37	1.09	1.25
1987-1990	21.07	0.86	1.35
1991-1993	18.24	0.56	0.56
1994-1997	17.92	0.42	0.37
1998-2002	17.61	0.43	0.40
2003-2006	11.64	0.27	0.25
2007-2009	6.62	0.23	0.03
2007-2009 (0.50 g/bhp-hr NOx or Cleaner)[(d)]	2.88	0.20	0.028
2010+	1.27	0.19	0.03

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.

Table D-12
Controlled Off-Road Diesel Engines
Emission Factors (g/bhp-hr)[(a)]

Horsepower	Tier	NOx	ROG	PM10
25-49	1	5.26	1.74	0.480
	2	4.63	0.29	0.280
	4 Interim	4.55	0.12	0.128
	4 Final	2.75	0.12	0.008
50-74	1	6.54	1.19	0.552
	2	4.75	0.23	0.192
	3[(b)]	2.74	0.12	0.192
	4 Interim	2.74	0.12	0.112
	4 Final	2.74	0.12	0.008
75-99	1	6.54	1.19	0.552
	2	4.75	0.23	0.192
	3	2.74	0.12	0.192
	4 Phase-Out	2.74	0.12	0.008
	4 Phase-In/ Alternate NOx	2.14	0.11	0.008
	4 Final	0.26	0.06	0.008
100-174	1	6.54	0.82	0.274
	2	4.17	0.19	0.128
	3	2.32	0.12	0.112
	4 Phase-Out	2.32	0.12	0.008
	4 Phase-In/ Alternate NOx	2.15	0.06	0.008
	4 Final	0.26	0.06	0.008
175-299	1	5.93	0.38	0.108
	2	4.15	0.12	0.088
	3	2.32	0.12	0.088
	4 Phase-Out	2.32	0.12	0.008
	4 Phase-In/ Alternate NOx	1.29	0.08	0.008
	4 Final	0.26	0.06	0.008

Table D-12
Controlled Off-Road Diesel Engines
Emission Factors (g/bhp-hr)[(a)]
(Continued)

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

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.

ALL ENGINES

Table D-24
Fuel Consumption Rate Factors (bhp-hr/gal)

Category	Horsepower/Application	Fuel Consumption Rate
Non-Mobile Agricultural Engines	ALL	17.5
Locomotive	Line Haul and Passenger (Class I/II)	20.8
	Line Haul and Passenger (Class III)	18.2
	Switcher	15.2
Other	< 750 hp	18.5
	≥ 750 hp	20.8

Example Calculations

Example Calculations are provided to illustrate all 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
- 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. **Fuel Cell Drayage Truck**
   - This example demonstrates a project that proposes to utilize a hydrogen fuel cell propulsion system in a drayage 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 for H2 to be from renewable sources.

2. **Battery-Electric Drayage Truck**
   - This example shows the use of a battery-electric drayage truck where all the power needs for the truck come from on-board batteries that are charged from the electrical grid.

3. **Range Extending Battery-Dominant Drayage Truck**
   - This example shows the use of a CNG spark ignited internal combustion engine being used as a range extender for a battery-dominant on-road truck. The truck will use both grid charging and on-board natural gas for the range extending engine. The natural gas in

this example will have a 15% renewable component. This example also shows how to calculate a composite carbon intensity value.

All of the following examples use diesel fuel usage of the baseline truck as a basis for the 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.

Example 1: Fuel Cell Drayage 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 drayage 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:

- 2014 diesel fueled Drayage truck with a heavy duty 2014 on-road diesel engine
- Usage 4 miles per gallon, 120 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 Drayage App D2: Fuel Carbon Intensity Values

CI = Carbon Intensity

$CI_{diesel} = \frac{102.76\ g\ CO2e}{MJ}$ Table Pathway Identifier ULSD001

$CI_{hydrogen} = \frac{105.65\ g\ CO2e}{MJ}$ Pathway Identifier HYGN003

Energy Density

From Table Drayage App D1: Fuel Energy Density

ED = Energy Density

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

Energy Efficiency Ratio

From Table Drayage 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 on-road trucks annual fuel usage:

$$\frac{gal\ diesel}{year} = \left(\frac{1\ gallon}{4\ miles}\right) * \left(\frac{120\ miles}{day}\right) * \left(\frac{210\ days}{year}\right) = \frac{6300\ gallons\ diesel}{year}$$

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

Formula 3:

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

Where:
X is the number of gallons diesel fuel used annually as a basis for the conversion;
NF is the new fuel that is proposed to be used as a diesel replacement;
ED is the Energy Density of the replacement fuel see Table Drayage App D1: Fuel Energy Density; and
Unit is the units associated with the replacement fuel:

Electricity: kWh
Hydrogen: kg
CNG: scf

$$\frac{kg\ H2}{year} = \left(\frac{6300 gal\ diesel}{year}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{1\ kg\ H2}{120.00\ MJ}\right) * \left(\frac{1}{1.9}\right) = 3716\ \frac{kg\ H2}{year}$$

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

Formula 1:

$$GHG\ EF = carbon\ intensity * \frac{fuel\ energy\ density}{efficiency} * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

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

$$\text{GHG EF}_{base} = \left(\frac{102.76\ g\ CO2e}{MJ}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{6300\ gal}{year}\right) * \left(\frac{1\ metric\ ton}{1{,}000{,}000\ grams}\right) = 87\ \frac{metric\ tons\ CO2e}{year}$$

Step 4: Determine the GHG emissions 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.

$$\text{GHG EF}_{adv\ tech} = \left(\frac{105.65\ g\ CO2e}{MJ}\right) * \left(\frac{120.00\ MJ}{kg\ H2}\right) * \left(\frac{3716\ kg\ H2}{year}\right) * \left(\frac{1\ metric\ ton}{1{,}000{,}000\ grams}\right) = 47\ \frac{metric\ tons\ CO2e}{year}$$

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:

$$\text{Project GHG ER}_{annual} = \text{GHG EF}_{base} - \text{GHG EF}_{adv\ tech}$$

$$\text{Project GHG ER}_{annual} = \left(\frac{87\ metric\ tons\ CO2e}{year}\right) - \left(\frac{47\ metric\ tons\ CO2e}{year}\right) = 40\ \frac{metric\ tons\ CO2e}{year}$$

Step 6: Determine the annual criteria and toxic pollutant emission reductions that are associated with the proposed project. Since the base case 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 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 base case diesel on-road truck 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:

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

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 =

*Emission Factor (g/gal) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

Annual ER is the calculated annual emission reductions

Annual ER_{NOx} = $\left(\frac{3.44\ g\ NOx}{gal\ diesel}\right) * \left(\frac{6300 gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.024 \frac{tons\ NOx}{year}$

Annual ER_{ROG} = $(\frac{0.18\ g\ ROG}{gal\ diesel}) * \left(\frac{6300\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.0013\ \frac{tons\ ROG}{year}$

Annual ER_{PM10} = $\left(\frac{0.148\ g\ NOx}{gal\ diesel}\right) * \left(\frac{6300 gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.0010 \frac{tons\ PM}{year}$

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 C-5.

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

Weighted Emission Reductions =

*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:

WER is the Weighted Emission Reductions

WER = $(0.024 \frac{tons\ NOx}{year}) + \left(\ 0.0013\ \frac{tons\ ROG}{year}\right) * 20 \left(0.0010 \frac{tons\ NOx}{year}\right) = 0.045\ tons$

Therefore, WER = 0.045 $\frac{tons\ criteria\ pollutants\ reduced}{year}$

Step 8: Determine the Incremental cost of the proposed technology using Formula C-3 and the vehicle costs for the base case on-road truck 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 ($)

Incremental Cost = Cost of New Technology ($) – Cost of Baseline Diesel Technology ($)

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

$\text{Incremental Cost}_{10\ years}$ = $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:

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

For the purposes of this Solicitation:

CRF_2 = 0.515 per Moyer Table G-3b (2-year life)

CRF_{10} = 0.111 per Moyer Table G-3b (10-year life)

Therefore:

GHG C/E is the GHG Cost Effectiveness

$$\text{GHG C/E}_{2\ years} = \left(\frac{\frac{(0.515*\$650{,}000)}{year}}{\frac{40\ metric\ tons\ CO2e}{year}}\right) = \frac{\$8{,}369}{metric\ tons\ CO2e\ reduced}$$

$$\text{GHG C/E}_{10\ years} = \left(\frac{\left(\frac{(0.111*\$400{,}000)}{year}\right)}{\frac{40\ metric\ tons\ CO2e}{year}}\right) = \frac{\$1{,}110}{metric\ tons\ CO2e\ reduced}$$

Step 10: Determine the criteria pollutant cost effectiveness for the proposed technology. Use the results from Step 7 and Step 8 to populate Formula C-1.

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

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

$$\text{Criteria Pollutant C/E}_{2\text{ years}} = ((\frac{\frac{(0.515*\$650{,}000)}{year}}{\frac{0.045\ tons\ WER}{year}}) = \frac{\$7.4\ million}{tons\ criteria\ pollutants\ reduced}$$

$$\text{Criteria Pollutant C/E}_{10\text{ years}} = ((\frac{\frac{(0.111*\$400{,}000)}{year}}{\frac{0.045\ tons\ WER}{year}}) = \frac{\$987{,}000}{tons\ criteria\ pollutants\ reduced}$$

Example 2: Battery Electric Drayage 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 battery electric on-road drayage 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 be plugged in to the electrical grid to charge on-board battery packs. All on-board energy requirements will come from electricity stored in on-board battery packs.

Baseline vehicle:

- 2014 diesel fueled on-road drayage truck with an on-road engine certified to the 2010 on-road diesel emission standard
- Usage 4 miles per gallon, 120 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:

- Battery electric on-road truck
- Battery electric on-road truck cost at demonstration: $750,000
- Battery-electric on-road truck cost two years after demonstration: $500,000

Variables Used in Calculation:

Carbon Intensity

From Table Drayage App D2: Fuel Carbon Intensity Values

CI = Carbon Intensity

$CI_{diesel} = \frac{102.76\ g\ CO2e}{MJ}$ Table Pathway Identifier ULSD001

From Table Drayage App D2: Fuel Carbon Intensity Values

$CI_{electricity} = \frac{105.16\ g\ CO2e}{MJ}$ Pathway Identifier ELC001

Energy Density

From Table Drayage App D1: Fuel Energy Density

ED = Energy Density

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

Energy Efficiency Ratio

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

EER = Energy Efficiency Ratio (unit less)

$EER_{electricity}$ = 2.7

Step 1: Calculate the baseline drayage truck's annual fuel usage:

$$\frac{gal\ diesel}{year} = \left(\frac{1\ gallon}{4\ miles}\right) * \left(\frac{120\ miles}{day}\right) * \left(\frac{210\ days}{year}\right) = \frac{6300\ gallons\ diesel}{year}$$

Step 2: Convert the diesel used per year from the baseline on-road truck to the amount of electricity needed to do the same work. Using Formula 3 and the variable identified above.

Formula 3:

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

Where:
X is the number of gallons diesel fuel used annually as a basis for the conversion;
NF is the new fuel that is proposed to be used as a diesel replacement;
ED is the Energy Density of the replacement fuel see Table Drayage App D1: Fuel Energy Density; and
Unit is the units associated with the replacement fuel:

Electricity: kWh
Hydrogen: kg
CNG: scf

$$\frac{Kwh}{year} = \left(\frac{6300 gal\ diesel}{year}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{1\ Kwh}{3.60\ MJ}\right) * \left(\frac{1}{2.7}\right) = 87{,}156\ \frac{Kwh}{year}$$

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

Formula 1:

$$GHG\ EF = carbon\ intensity * \frac{fuel\ energy\ density}{efficiency} * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

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

$$\text{GHG EF}_{base} = \left(\frac{102.76\ g\ CO2e}{MJ}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{6300\ gal}{year}\right) * \left(\frac{1\ metric\ ton}{1{,}000{,}000\ grams}\right) = 87\ \frac{metric\ tonc\ CO2e}{year}$$

Step 4: Determine the GHG emissions 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.

$$\text{GHG EF}_{adv\ tech} = \left(\frac{105.15\ g\ CO2e}{MJ}\right) * \left(\frac{3.60\ MJ}{Kwh}\right) * \left(\frac{87{,}156\ Kwh}{year}\right) * \left(\frac{1\ metric\ ton}{1{,}000{,}000\ grams}\right) = 33\ \frac{metric\ tons\ CO2e}{year}$$

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:

Project GHG ER_{annual} = GHG EF_{base} - GHG $EF_{adv\ tech}$

$$\text{Project GHG ER}_{annual} = \left(\frac{87\ metric\ tons\ CO2e}{year}\right) - \left(\frac{33\ metric\ tons\ CO2e}{year}\right) = 54\ \frac{metric\ tons\ CO2e}{year}$$

Step 6: Determine the annual criteria and toxic pollutant emission reductions that are associated with the proposed project. Since the base case diesel on-road truck is using an on-road engine certified to the 2010 standard, inputs from Table D-1 and the result of Step1above will be used to populate Formula C-9. Since there are not any criteria or toxic emissions associated with the use of the advanced technology on-road truck, therefore all the emissions associated with the base case diesel on-road truck are considered to be the criteria and toxic emission reductions for the proposed project.

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

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

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 =

*Emission Factor (g/gal) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

Annual ER is the calculated annual emission reductions

$$\text{Annual ER}_{NOx} = \left(\frac{3.44\ g\ NOx}{gal\ diesel}\right) * \left(\frac{6300 gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.024\,\frac{tons\ NOx}{year}$$

$$\text{Annual ER}_{ROG} = \left(\frac{0.18\ g\ ROG}{gal\ diesel}\right) * \left(\frac{6300\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.0013\ \frac{tons\ ROG}{year}$$

$$\text{Annual ER}_{PM10} = \left(\frac{0.148\ g\ NOx}{gal\ diesel}\right) * \left(\frac{6300 gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.0010\,\frac{tons\ PM}{year}$$

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 C-5.

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

Weighted Emission Reductions =

*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:

WER is the Weighted Emission Reductions

$$\text{WER} = \left(0.024\,\frac{tons\ NOx}{year}\right) + \left(0.0013\ \frac{tons\ ROG}{year}\right) * 20\left(0.0010\,\frac{tons\ NOx}{year}\right) = 0.045\ tons$$

$$\text{Therefore, WER} = 0.045\ \frac{tons\ criteria\ pollutants\ reduced}{year}$$

Step 8: Determine the Incremental cost of the proposed technology using Formula C-3 and the vehicle costs for the base case on-road truck 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 ($)

Incremental Cost = Cost of New Technology ($) – Cost of Baseline Diesel Technology ($)

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

$\text{Incremental Cost}_{10\ years}$ = $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:

CRF is the Capitol Recovery Factor

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

For the purposes of this Solicitation:

CRF_2 = 0.515 per Moyer Table G-3b (2-year life)

CRF_{10} = 0.111 per Moyer Table G-3b (10-year life)

Therefore:

GHG C/E is the GHG Cost Effectiveness

$$GHG\ C/E_{\ 2\ years} = \left(\frac{\frac{(0.515 * \$650{,}000)}{year}}{\frac{54\ metric\ tons\ CO2e}{year}} \right) = \frac{\$6199}{metric\ tons\ CO2e\ reduced}$$

$$\text{GHG C/E}_{10\text{ years}} = \left(\frac{\left(\frac{(0.111*\$400{,}000)}{year}\right)}{\frac{54\ metric\ tons\ CO2e}{year}}\right) = \frac{\$822}{metric\ tons\ CO2e\ reduced}$$

Step 10: Determine the criteria pollutant cost effectiveness for the proposed technology. Use the results from Step 7 and Step 8 to populate Formula C-1.

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

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

$$\text{Criteria Pollutant C/E}_{2\text{ years}} = \left(\left(\frac{\frac{(0.515*\$650{,}000)}{year}}{\frac{0.045\ tons\ WER}{year}}\right) = \frac{\$7.4\ million}{ton\ criteria\ pollutants\ reduced}\right.$$

$$\text{Criteria Pollutant C/E}_{10\text{ years}} = \left(\left(\frac{\frac{(0.111*\$400{,}000)}{year}}{\frac{0.045\ tons\ WER}{year}}\right) = \frac{\$987{,}000}{ton\ criteria\ pollutants\ reduced}\right.$$

<u>Example 3: Battery-Electric Drayage Truck with Internal Combustion Range Extender</u>

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 an internal combustion range extending battery-electric on-road heavy-duty drayage truck will have the same energy requirements as a diesel counterpart and will be used the same number of miles. Further, it is assumed that this project will use grid electricity for on-board battery charging and on-board CNG for the range extending, spark ignited internal combustion engine. It is assumed that 2/3rds of the advanced technology vehicle’s energy needs will come from the on-board battery pack and that 1/3 of the trucks energy needs will come from the on-board range extending engine. The CNG used in this example will be 85% pipeline and 15% renewable from high solids anaerobic digestion of food and green wastes.

This example demonstrates the use of two fuel types in one advanced technology application with one of those fuel types, CNG, having a composite Carbon Intensity that is not directly given in Table Drayage App D2: Fuel Carbon Intensity Values, but rather needs to be calculated.

Baseline On-Road Truck:

- 2014 diesel fueled on-road drayage truck with an on-road engine certified to the 2010 on-road diesel emission standard
- Fuel usage is 4 miles per gallon at 150 miles per day for 210 days a year
- On-road truck cost at demonstration: $100,000
- On-road truck cost two years after demonstration: $100,000

Advanced Technology:

- CNG range extending battery dominant on-road truck
- CNG range extending engine meet the 2010 heavy-duty diesel emission standard of 0.20 gram NOx per bhp-hr
- Truck cost at demonstration: $750,000
- Truck cost two years after demonstration: $550,000

Variables Used in Calculation:

Carbon Intensity

From Table Drayage App D2: Fuel Carbon Intensity Values

CI = Carbon Intensity

$CI_{diesel} = \frac{102.76\ g\ CO2e}{MJ}$ Table Pathway Identifier ULSD001

From Table Drayage App D2: Fuel Carbon Intensity Values

$CI_{electricity} = \frac{105.16\ g\ CO2e}{MJ}$ Pathway Identifier ELC001

$CI_{pipeline\ cng} = \frac{79.46\ g\ CO2e}{MJ}$ Pathway Identifier CNG002

$CI_{renewable\ cng} = \frac{-34.70\ g\ CO2e}{MJ}$ Pathway Identifier CNG0005

Energy Density

From Table Drayage App D1: Fuel Energy Density

ED = Energy Density

$ED_{diesel} = \frac{134.47\ MJ}{gal\ diesel}$ $ED_{electricity} = \frac{3.60\ MJ}{kWh}$ $ED_{cng} = \frac{0.98\ MJ}{scf}$

Energy Efficiency Ratio

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

EER = Energy Efficiency Ratio (unit less)

The EER for electricity in use on electric, battery electric or hybrid electric trucks are selected and the EER for CNG in spark ignition engines. Those EER values are show below:

$EER_{\ electricity} = 2.7$ $EER_{\ cng} = 0.9$

Conversion for CNG Standard Cubic Feet (scf) to Diesel Gallon Equivalent (DGE)

For the purpose of this solicitation assume:

1 DGE = 139.30 scf CNG[5]

Step 1: Calculate the baseline on-road trucks annual fuel usage:

$$\frac{gal\ diesel}{year} = \left(\frac{1 gallon}{4\ miles}\right) * \left(\frac{150\ miles}{yearday}\right)\left(\frac{210\ days}{year}\right) = \frac{7875\ gallons\ diesel}{year}$$

[5] CNG scf to DGE conversion Source: U.S. Department of Energy Alternative Fuels Data Center http://www.afdc.energy.gov/fuels/equivalency_methodology.html

Step 2: Convert the diesel used per year to the amount of electricity and CNG needed to do the same work. Using Formula 3, the variable identified above and the realization that 2/3 of the energy needs of the truck will come from electricity and 1/3 of the energy needs will come from CNG.

Formula 3:

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

Where:

X is the number of gallons diesel fuel used as a basis for the conversion;

NF is the new fuel that is proposed to be used as a diesel replacement;

ED is the Energy Density of the replacement fuel see Table Drayage App D1: Fuel Energy Density; and

Unit is the units associated with the replacement fuel:

Electricity:	kWh
Hydrogen:	kg
CNG:	scf

First calculate the number of kilowatt hours needed to supply the power needs for 2/3rds of the diesel.

Electric need = $0.67 * 7875\ gallons$ = 5276 gallons diesel

CNG need = $0.33 * 7875\ gallons$= 2599 gallons diesel

$$Electricity = \left(\frac{5276\ gal\ diesel}{year}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{1\ Kw{-}hr}{3.60MJ}\right) * \left(\frac{1}{2.7}\right) = 72{,}990\ \frac{kWh}{year}$$

$$CNG = \left(\frac{2599\ gal\ diesel}{year}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{1\ scf}{0.98MJ}\right) * \left(\frac{1}{0.9}\right) = 396{,}244\ \frac{scf}{year}$$

Step 3: Determine the GHG emissions that are attributed to the base case diesel fueled drayage truck. Using Formula 1 and the variables identified above.

Formula 1:

$$GHG\ EF = carbon\ intensity * \frac{fuel\ energy\ density}{efficiency} * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

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

GHG $EF_{base} = \left(\frac{102.76\ g\ CO2e}{MJ}\right) * \left(\frac{134.47\ MJ}{gal\ diesel}\right) * \left(\frac{7875\ gal}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right) = 109\ \frac{metric\ tons\ CO2e}{year}$

Step 4: Determine the composite Carbon Intensity (CI) value for the CNG blend that is proposed to be used in this project. The proposal for this project will use 85% pipeline CNG and 15% renewable CNG from anaerobic digestion of food and green waste. Use Formula 6 for this calculation.

Formula 6:

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

$$CI_{cng\ composite} = \left(\frac{2}{3} * \left(\frac{79.46\ g\ CO2e}{MJ}\right)\right) + \left(\frac{1}{3} * \left(\frac{-34.70\ g\ CO2e}{MJ}\right)\right) = \frac{41.79\ g\ CO2e}{MJ}$$

Use this result for the Carbon Intensity calculations using CNG.

Step 5: Determine the well-to-wheel GHG emissions that are attributed to the advanced technology drayage truck. This calculation will need to be performed for each of the two fuel types that will be used in the proposed advanced technology on-road truck. Using Formula 1 and Formula 2, the result from Step 2, the composite CI value determined in Step 4 and the variables identified above, calculate the GHG emissions associated with the advanced technology on-road truck. .

Formula 1: Liquid / Natural Gas and Hydrogen Fueled Vehicles

$$GHG\ EF = carbon\ intensity * \frac{fuel\ energy\ density}{efficiency} * \frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}$$

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

Formula 2: Electric Vehicles

$$GHG\ EF = \frac{metric\ ton\ CO2e}{year} = carbon\ intensity * unit\ conversion * efficiency$$

$$= \left(\frac{gram\ CO2e}{MJ}\right) * \left(\frac{3.60\ MJ}{kWh}\right) * \left(\frac{X\ kWh}{year}\right) * \frac{1\ metric\ ton}{1{,}000{,}000\ grams}$$

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

Formula 2 will be used for the electric portion of the energy requirements.

$$\text{GHG EF}_{\text{adv tech electricity}} = \left(\frac{105.16\ g\ CO2e}{MJ}\right) * \left(\frac{3.60\ MJ}{kWh}\right) * \left(\frac{41{,}711\ kWh}{year}\right) * \frac{1\ metric\ ton}{1{,}000{,}000\ grams}$$

$$\text{GHG EF}_{\text{adv tech electricity}} = 28\,\frac{metric\ tons\ CO2e}{year}$$

Formula 1 will be used for the CNG energy portion of the energy requirements

$$\text{GHG EF}_{\text{adv tech CNG}} = \left(\frac{41.79\ g\ CO2e}{MJ}\right) * \left(\frac{0.98\ MJ}{scf}\right) * \left(\frac{396{,}244\ scf}{year}\right) * \left(\frac{1\ metric\ ton\ CO2e}{1{,}000{,}000\ grams}\right) =$$

$$\text{GHG EF}_{\text{adv tech CNG}} = 16\ \frac{metric\ tons\ CO2e}{year}$$

Sum the GHG emissions from the electricity and the CNG to get the total GHG emissions from the advanced technology truck.

$$\text{GHG EF}_{\text{adv tech}} = 28\,\frac{metric\ tons\ CO2e}{year} + 16\ \frac{metric\ tons\ CO2e}{year} = 44\ \frac{metric\ tons\ CO2e}{year}$$

Step 6: 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 5 from the above example to give the annual GHG emission benefit from the proposed project.

Formula 4:

Project GHG ER_{annual} = GHG EF_{base} - GHG $EF_{adv\ tech}$

$$\text{Project GHG ER}_{\text{annual}} = \left(\frac{109\ metric\ tons\ CO2e}{year}\right) - \left(\frac{44\ metric\ tons\ CO2e}{year}\right) = 65\ \frac{metric\ tons\ CO2e}{year}$$

Step 7: Determine the annual criteria pollutant emission reductions that are associated with the proposed project. The base case diesel on-road truck meets the 2010 emission standard, therefore, using emission values from Table D-12 and fuel consumption rate factors from Table D-24, the result of Step1 above to populate Formula C-8. The trucks will be used 100% of the time in California. There are criteria pollutant emissions associated with the use of the advanced technology truck and therefore those emissions need to be considered.

For an on-road 2010 emission standard diesel heavy duty truck Table D-12 gives criteria pollutant emissions per bhp-hr, the conversion factor, for the relevant engine hp from Table D-24 allows for the conversion from gram per bhp-hr to gram per gallon of fuel consumed. Therefore:

NOx = 2.32 $\frac{g\ NOx}{bhp-hr}$; ROG =0.12 $\frac{g\ ROG}{bhp-hr}$; PM10 = 0.008 $\frac{g\ PM\ 10}{bhp-hr}$

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

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * fuel consumption rate factor (bhp-hr/gallon (gal)) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

$$\text{Annual Em}_{NOx} = \left(\frac{2.32 g\ NOx}{bhp-hr}\right) * \left(\frac{18.5\ bhp-hr)}{gal\ diesel}\right) * \left(\frac{7875\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) =$$

$$\text{Annual Em}_{NOx} = 0.37\ \frac{tons\ NOs}{year}$$

$$\text{Annual Em}_{ROG} = \left(\frac{0.12\ g\ ROG}{bhp-hr}\right) * \left(\frac{18.5\ bhp-hr)}{gal\ diesel}\right) * \left(\frac{7875\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) =$$

$$\text{Annual Em}_{ROG} = 0.0037\ \frac{tons\ ROG}{year}$$

$$\text{Annual Em}_{PM10} = \left(\frac{0.008\ g\ PM\ 10}{bhp-hr}\right) * \left(\frac{18.5\ bhp-hr)}{gal\ diesel}\right) * \left(\frac{7875\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) =$$

$$\text{Annual ER}_{PM10} = 0.00059\ \frac{tons\ PM}{year}$$

Step 8: Calculate the criteria pollutant emissions that are associated with the advanced technology on-road truck. Since the proposed heavy-duty on-road range extending battery dominant truck has criteria pollutant emissions associated with its operation those emissions need to be determined and subtracted from the emissions from the base case diesel truck calculated in Step 6 above. Using inputs from Table D-2 with the understanding that the CNG range extending engine is an on-road engine certified to the 2010 emission standard for NOx at 0.20 g per bhp-hr and DGE is diesel gallons equivalent. Therefore, Table D-2 gives:

NOx = 3.70 $\frac{g\ NOx}{DGE}$ ROG = 1.17 $\frac{g\ NOx}{DGE}$ PM = 0.185 $\frac{g\ PM}{DGE}$

To calculate the DGE for the CNG sourced emissions from the advanced technology truck, for the purpose of this solicitation use the conversion factor of 139.30 scf of CNG per DGE and the output from Step 2 above, therefore:

$$DGE = \left(\frac{1\ DGE}{139.30\ scf}\right) * (226{,}404\ \frac{scf}{year}) = 1{,}625\ DGE$$

Using Formula C-9 with the criteria pollutant emission levels identified above and the DGE that was calculate above as inputs.

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

Annual Emission Reductions =

*Emission Factor (g/gal) * Activity (gal/yr) * Percent Operation in CA * ton/907,200g*

ADV Tech Em is the Advanced Technology Criteria pollutant emission factor for the identified criteria pollutant.

ADV Tech Em $_{NOx}$ = $\left(\frac{3.70\ g\ NOx}{gal\ diesel}\right) * \left(\frac{1625\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.0066\frac{tons\ NOx}{year}$

ADV Tech Em $_{ROG}$ = $(\frac{1.17\ g\ ROG}{gal\ diesel}) * \left(\frac{1625\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.0021\ \frac{tons\ ROG}{year}$

ADV Tech Em $_{PM10}$ = $\left(\frac{0.185\ g\ NOx}{gal\ diesel}\right) * \left(\frac{1625\ gal\ diesel}{year}\right) * (1) * \left(\frac{1\ ton}{907{,}200\ g}\right) = 0.00033\frac{tons\ PM}{year}$

Step 9: Calculate the criteria emission reductions that are associated with the proposed project. 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 truck, 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:

Project ER = Baseline Emissions – Advanced Technology Emissions

Project ER_{NOX} = (0.21 $\frac{tons\ NOs}{year}$) $-\left(0.0066\frac{tons\ NOx}{year}\right) = 0.36\ \frac{tons\ NOx}{year}$

Project ER_{ROG} = $(0.011\ \frac{tons\ ROG}{year}) - (0.0021\ \frac{tons\ ROG}{year}) = 0.015\ \frac{tons\ ROG}{year}$

Project ER_{PM} = $(0.00073\frac{tons\ PM}{year}) - \left(0.00033\frac{tons\ PM}{year}\right) = 0.00071\ \frac{tons\ PM}{year}$

Step 10: Determine the weighted annual surplus emission reductions that are associated with the proposed project. Using the results from Step 9 above populate Formula C-5.

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

WER is the Weighted Emission Reductions

Weighted Emission Reductions =

*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:

WER = $(0.36\frac{tons\ NOx}{year}) + \left(0.015\ \frac{tons\ ROG}{year}\right) * 20\left(0.00071\frac{tons\ NOx}{year}\right) = 0.39\ \frac{tons}{year}$

Therefore, WER = 0.39 $\frac{tons\ criteria\ pollutants\ reduced}{year}$

Step 11: Determine the incremental cost of the proposed technology using Formula C-3, the vehicle costs for the base case diesel fueled on-road truck and the range extending battery-dominant advanced technology 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 Equipment:

- On-road diesel truck cost at demonstration: $100,000
- On-road diesel truck cost two years after demonstration: $100,000

Advanced Technology:

- Advanced technology truck cost at demonstration: $750,000
- Advanced technology truck cost two years after demonstration: $550,000

Formula C-3: Incremental Cost ($)

Incremental Cost = Cost of New Technology ($) – Cost of Baseline Diesel Technology ($)

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

Incremental Cost$_{10\ years}$ = $550,000 - $100,000 = $450,000

Step 12: Determine the GHG emission reduction cost effectiveness for the proposed project using the results from Step 5, Step 11 and Formula 5

Formula 5:

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

For the purposes of this Solicitation:

CFR is the Capital Recover Factor for a specific useful life

CRF_2 = 0.515 per Moyer Table G-3b (2-year life)

CRF_{10} = 0.111 per Moyer Table G-3b (10-year life)

Therefore,

GHG C/E is the GHG Cost Effectiveness

$$\text{GHG C/E}_{\text{2 years}} = (\frac{\frac{(0.515 * \$650{,}000)}{year}}{\frac{65\ metric\ tons\ CO2e}{year}}) = \frac{\$5150}{metric\ tons\ CO2e\ reduced}$$

$$\text{GHG C/E}_{\text{10 years}} = (\frac{(\frac{(0.111 * \$450{,}000)}{year})}{\frac{65\ metric\ tons\ CO2e}{year}}) = \frac{\$768}{metric\ tons\ CO2e\ reduced}$$

Step 13: Determine the criteria pollutant cost effectiveness for the proposed technology. Use the results from Step 10 and Step 11 to populate Formula C-1.

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

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

$$\text{Criteria Pollutant C/E}_{\text{2 years}} = ((\frac{\frac{(0.515 * \$650{,}000)}{year}}{\frac{0.22\ tons\ WER}{year}}) = \frac{\$\ 858{,}000}{tons\ criteria\ pollutants\ reduced}$$

$$\text{Criteria Pollutant C/E}_{\text{10 years}} = ((\frac{\frac{(0.111 * \$450{,}000)}{year}}{\frac{0.22\ tons\ WER}{year}}) = \frac{\$128{,}000}{tons\ criteria\ pollutants\ reduced}$$