APPENDIX C

METHODOLOGY FOR DETERMINING COST EFFECTIVENESS

This appendix is an excerpt from the Board approved
2011 Carl Moyer Program Guidelines Appendixes C, D and G

The complete Carl Moyer Program Document including all appendices can be found at:
http://www.arb.ca.gov/msprog/moyer/guidelines/current.htm

TABLES FOR EMISSION REDUCTION AND COST-EFFECTIVENESS CALCULATIONS

This appendix presents tables summarizing the data and instructions needed to calculate the emission reductions and cost-effectiveness of potential locomotive demonstration project, examples provided below are for reference only and do not constitute additional demonstration project types or categories nor do Carl Moyer funding amounts limit the amount of funding that may be available for demonstration projects.

Table G-3
Capital Recovery Factors (CRF) for Various Project Lives
At a Two Percent Discount Rate (As of April 2011)

Project Life	CRF
1	1.020
2	0.515
3	0.347
4	0.263
5	0.212
6	0.179
7	0.155
8	0.137
9	0.123
10	0.111
11	0.102
12	0.095
13	0.088
14	0.083
15	0.078
16	0.074
17	0.070
18	0.067
19	0.064
20	0.061

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

Tier	Horsepower	NOx	ROG	PM10
1	25 – 49	5.26	1.74	0.480
	50 – 119	6.54	1.19	0.552
	120 – 174	6.54	0.82	0.274
	175 +	5.93	0.38	0.108
2	25 – 49	4.63	0.29	0.280
	50 – 119	4.75	0.23	0.192
	120 – 174	4.17	0.19	0.128
	175 – 250	4.15	0.12	0.088
	251+	3.79	0.12	0.088
3	50 – 120	2.74	0.12	0.160
	121 – 750	2.32	0.12	0.112
4 Interim	25 – 49	4.55	0.12	0.128
	50 – 120	2.40	0.11	0.056
	121 – 174	2.15	0.11	0.008
	175 – 750	1.29	0.08	0.008
	>750	2.24	0.12	0.048
4 Final	25 – 49	2.75	0.12	0.008
	50 – 120	1.33	0.08	0.008
	121 – 750	0.26	0.06	0.008
	>750	2.24	0.06	0.016

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

Table D17-b
Locomotive Emission Factors (g/bhp-hr)
Based on 2008 Federal Standards

Engine Model Year	Type	NOx[a]	ROG[b]	PM10[a]
1973-2001 Tier 0+	Line-haul and Passenger	6.77	0.32	0.172
	Switcher	9.98	0.60	0.198
2002-2004 Tier 1+	Line-haul and Passenger	6.30	0.31	0.172
	Switcher	9.31	0.60	0.198
2005-2011 Tier 2+	Line-haul and Passenger	4.65	0.14	0.069
	Switcher	6.86	0.27	0.095
2011-2014 Tier 3	Line-haul and Passenger	4.65	0.14	0.069
	Switcher	5.07	0.27	0.069
2015 Tier 4	Line-haul and Passenger	1.22	0.15	0.026
	Switcher	1.22	0.15	0.026

These factors are to be used for the project baseline emissions if the baseline locomotive is certified or required to be certified to the new (2008) federal locomotive remanufacture standards, and for the reduced emission locomotive if the project locomotive is remanufactured to the new standards or meets Tier 3 standards. Factors are based upon Regulatory Impact Analysis: Final U.S. EPA Locomotive Regulation (2008).
a - NOx and PM10 emission factors have been adjusted by a factor of 0.94 and 0.86, respectively, to account for use of California ultra-low sulfur diesel fuel.
b - ROG = HC * 1.053

The information in these tables has already been incorporated into the preceding emission factor tables. These tables are included for informational purposes.

Table D-25
Pollutant Fractions
NOx+NMHC Standards

Diesel Engines		Alternative Fuel Engines	
NOx	**NMHC**	**NOx**	**NMHC**
0.95	0.05	0.80	0.20

Table D-28
Fuel Correction Factors
Off-Road Diesel Engines

Model Year	NOx	PM10
Pre-Tier 1	0.930	0.720
Tier 1+	0.948	0.800

Example cost effectiveness calculations are show below.

General Cost-Effectiveness Calculations

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

A. Calculating the Annual Weighted Surplus Emission Reductions

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). The resulting annualized cost is used to complete formula C-2 to determine the cost-effectiveness of surplus emission reductions.

Formula C-2: Annualized Cost ($)

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

3. Calculating the Incremental Cost

Maximum eligible percent funding amounts define incremental cost, in many cases an applicant will provide an estimate of the cost of the reduced technology. The incremental cost is determined by multiplying the cost of the reduced technology by the maximum eligible percent funding amount (from applicable chapter), as described in formula C-3 below.

Formula C-3: Incremental Cost ($)

*Incremental Cost = Cost of Reduced Technology ($) * Maximum Eligible Percent Funding Amount*

Generally the cost of the baseline vehicle for a new purchase is assumed to be a certain percentage of the cost of a new vehicle meeting reduced emissions from the standard. The cost of the baseline technology for a repower is assumed to be a percentage of the new engine. For retrofits, there is no baseline technology cost; hence the entire cost of the retrofit may be eligible for funding in most cases, but not for on-road. Refer to the On-Road chapter for specific eligible retrofit cost.

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 diesel (particulate matter) PM have been identified as a toxic air contaminant and thus carry a greater weight in the calculation. However, emissions of combustion PM from gasoline, spark ignition engines have not been identified as a toxic air contaminant, therefore NOx, ROG, and PM emissions are given equal weight in the calculation.

Formula C-5: Annual Weighted Surplus Emission Reductions

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 six calculations:
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

Usage: The Carl Moyer Program allows the emissions reductions from a project to be calculated using the following activity factors on an annual basis:

(A) Hours of operation,
(B) Fuel consumption, or
(C) Miles traveled.

Specific activity factors allowed for each project category may differ and are identified in the source category chapters of the Carl Moyer Program Guidelines.

(A) Calculating Annual Emissions Based on Hours of Operation

When actual annual hours of equipment operation are the basis for determining emission reductions, the equipment activity level must be based on a properly functioning hour meter (See Chapter 2 and the relevant source category chapter for additional information on this topic). In addition, the horsepower rating of the engine and an engine load factors found in Appendix D must be used. A default load factor of 0.43 is used for those projects where no specific equipment load Baseline Technology. The method for calculating emission reductions based on hours of operation is described in formula C-6 below.

Formula C-6: Estimated Annual Emissions based on hours of Operation (tons/yr)

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (grams per brake horsepower-hour)(g/bhp-hr)) * Horsepower * Load Factor * Activity (hours(hrs)/yr) * Percent Operation in California (CA) * ton/907,200grams (g)*

The engine load factor is an indicator of the nominal amount of work done by the engine for a particular application. It is given as a fraction of the rated horsepower of the engine and varies with engine application. For projects in which the horsepower of the baseline technology and reduced technology are different by more than 25 percent, the load factor must be adjusted following formula C-7 below. It is important to understand the replacement load factor must never exceed 100 percent in cases where the reduced technology engine is significantly smaller than the baseline technology engine.

Formula C-7: Replacement Load Factor

*Replacement Load Factor = Load Factor baseline * hp baseline/hp reduced*

(B) 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 in Appendix D. 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*

Calculating Annual Emissions Based on Converted Standards: The unit conversion factor 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/907,200g*

List of 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):

Cost-Effectiveness ($/ton) = Annualized Cost ($/yr)

Annual Weighted Surplus Emission Reductions (tons/yr)

Formula C-2: Annualized Cost ($)

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

Formula C-3: Incremental Cost ($)

*Incremental Cost = Cost of Reduced Technology ($) * Maximum Eligible Percent*

Funding Amount

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-6: Estimated Annual Emissions based on hours of Operation (tons/yr)

Annual Emission Reductions =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * Horsepower * Load Factor * Activity (hrs/yr) * Percent Operation in CA * ton/907,200g*

Formula C-7: Replacement Load Factor

*Replacement Load Factor = Load Factor baseline * hp baseline/hp reduced*

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/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*

Formula C-13: Annual Surplus Emission Reductions by Pollutant (tons/yr) for Repowers and New Purchases

Annual Surplus Emission Reductions (by pollutant) =

Annual Emissions for the Baseline Technology – Annual Emissions for the Reduced Technology

Formula C-14: Annual Surplus Emission Reductions by Pollutant (tons/yr) for Retrofits

Annual Surplus Emission Reductions (by pollutant) =

*Annual Emissions for the Baseline Technology * Reduced Technology Verification Percent*

Formula C-15: Estimated Annual Emissions by Pollutant (tons/yr)

Annual Emission Reduction =

*Emission Factor or Converted Emission Standard (g/bhp-hr) * Annual Activity * Adjustment Factor(s) * Percent Operation in CA * ton/907,200g*

Formula C-16: Moyer Grant for Grantees receiving other Public Financial Incentive Funds

Maximum Moyer Grant Amount (if project is cost-effective) =

Incremental Cost (from formula C-2 or C-3) - Other Public Financial Incentive Funds

Formula C-17: Moyer Grant for Grantees receiving public funds from Air District

Moyer Grant Amount to Grantee =

Cost-effective Grant Amount (from formula C-1) – Air District Funds

Formula C-18: Maximum Grant Amount for projects exceeding Cost Effectiveness Limit

Maximum Grant Amount =

*(Cost-effectiveness limit * estimated annual emission reductions)/CRF*