

APPENDIX C

METHODOLOGY FOR DETERMINING COST EFFECTIVENESS

This appendix is an excerpt from the Board approved
2011 Carl Moyer Program Guidelines Part IV Appendixes

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 advanced hybrid school bus 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.

A. General Cost-Effectiveness Calculations

1. Calculating Cost-Effectiveness

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

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

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

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

2. Determining the Annualized Cost

Annualized cost is the amortization of the one-time incentive grant amount for the life of the project to yield an estimated annual cost. The annualized cost is calculated by multiplying the incremental cost by the capital recovery factor (CRF). 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 (\$)

$$\text{Annualized Cost} = \text{CRF} * \text{incremental cost (\$)}$$

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. 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:

- | 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 by the annual activity level and by other adjustment factors as specified for the calculation methodologies presented.

B. 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):

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

Formula C-2: Annualized Cost (\$)

$$\text{Annualized Cost} = \text{CRF} * \text{incremental cost (\$)}$$

Formula C-3: Incremental Cost (\$)

$$\text{Incremental Cost} = \text{Cost of Reduced Technology (\$)} * \text{Maximum Eligible Percent Funding Amount}$$

Formula C-5: Annual Weighted Surplus Emission Reductions

Weighted Emission Reductions =

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

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

Annual Emission Reductions =

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

Formula C-7: Replacement Load Factor

$$\text{Replacement Load Factor} = \text{Load Factor baseline} * \text{hp baseline/hp reduced}$$

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-12: Split Project Life

Total Annual Weighted Surplus Emission Reductions =

(Fraction project life / Total project life * Annual weighted surplus emissions from transaction 1) + Fraction project life / Total project life * Annual weighted surplus transaction from transaction 2)

Total Annual Weighted Surplus Emission Reductions = $(n1 / t * a1) + (n2 / t * a2)$

n1 = fraction project life from transaction 1

n2 = fraction project life from transaction 2

a1 = Annual weighted surplus emissions from transaction 1

a2 = Annual weighted surplus transaction from transaction 2

t = total project life

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

C. Important Tables for Cost Effectiveness Calculations

Table 1
Capital Recovery Factors (CRF) for Various Project Life
At Four Percent Discount Rate

Project Life	CRF
1*	1.040
2*	0.530
3	0.360
4	0.275
5	0.225
6	0.191
7	0.167
8	0.149
9	0.134
10	0.123
11	0.114
12	0.107
13	0.100
14	0.095
15	0.090
16	0.086
17	0.082
18	0.079
19	0.076
20	0.074

School bus demonstration project will assume to have a 20 year project life.

HEAVY-DUTY ON-ROAD PROJECTS

Table 2
Heavy Heavy-Duty Diesel Engines
Converted Emission Standards

EO Certification Level g/bhp-hr	g/bhp-hr ^(a)			g/mile ^(b)			g/gal ^{(c)(d)}		
	Diesel NO _x	Diesel ROG	Alternative Fuel NO _x	Diesel NO _x	Diesel ROG ^(e)	Alternative Fuel NO _x	Diesel NO _x	Diesel ROG ^(e)	Alternative Fuel NO _x
6.0 NO _x	5.58	0.29	4.80	16.74	0.86	14.40	103.23	5.33	88.80
5.0 NO _x	4.65	0.24	4.00	13.49	0.70	11.60	86.03	4.44	74.00
4.0 NO _x	3.72	0.19	3.20	10.79	0.56	9.28	68.82	3.55	59.20
2.5 NO _x +NMHC	2.21	0.11	2.00	6.41	0.33	5.80	40.86	2.11	37.00
1.8 NO _x +NMHC	1.59	0.08	1.44	4.61	0.24	4.18	29.42	1.52	26.64
1.5 NO _x +NMHC	1.33	0.07	1.20	3.84	0.20	3.48	24.52	1.27	22.20
1.20 NO _x +NMHC	1.06	0.05	0.96	3.07	0.16	2.78	19.61	1.01	17.76
0.84 NO _x +NMHC	0.74	0.04	0.67	2.15	0.11	1.95	13.73	0.71	12.43
0.20 NO _x	0.19	0.13	0.16	0.54	0.37	0.46	3.44	2.36	2.96
PM10	Diesel PM10		Alternative Fuel PM10	Diesel PM10		Alternative Fuel PM10	Diesel PM10		Alternative Fuel PM10
0.01	0.008		0.010	All Except Urban Bus			0.15		0.19
				0.023		0.029			
				Urban Bus					
0.10	0.08		0.10	All Except Urban Bus			1.33		1.85
				0.209		0.290			
				Urban Bus					
				0.320		0.400			

- a - Emission standards were converted where appropriate, using the NMHC and NO_x fraction default values and the ultra-low sulfur diesel fuel correction factors listed in Tables D-25 and D-26, respectively.
- b - Mileage based emissions factors were calculated using conversion factors from Table D-28.
- c - Fuel based emissions factors were calculated using fuel consumption rate factors from Table D-24.
- d - Fuel based factors are for engines less than 750 horsepower only.
- e - ROG = HC * 1.26639.

Table 3
Medium Heavy-Duty Diesel Engines 2007-2010
Converted Emission Standards

EO Certification Level g/bhp-hr	g/bhp-hr ^(a)			g/mile ^(b)			g/gal ^{(c)(d)}		
	Diesel NOx	Diesel ROG	Alternative Fuel NOx	Diesel NOx	Diesel ROG ^(e)	Alternative Fuel NOx	Diesel NOx	Diesel ROG ^(e)	Alternative Fuel NOx
6.0 NOx	5.58	0.29	4.80	10.60	0.52	8.64	103.23	5.33	88.80
5.0 NOx	4.65	0.24	4.00	8.37	0.43	7.20	86.03	4.44	74.00
4.0 NOx	3.72	0.19	3.20	6.70	0.35	5.76	68.82	3.55	59.20
2.5 NOx+NMHC	2.21	0.11	2.00	3.98	0.21	3.60	40.86	2.11	37.00
1.8 NOx+NMHC	1.59	0.08	1.44	2.86	0.15	2.59	29.42	1.52	26.64
1.5 NOx+NMHC	1.33	0.07	1.20	2.39	0.12	2.16	24.52	1.27	22.20
1.20 NOx+NMHC	1.06	0.05	0.96	1.91	0.10	1.73	19.61	1.01	17.76
0.84 NOx+NMHC	0.74	0.04	0.67	1.34	0.07	1.21	13.73	0.71	12.43
0.20 NOx	0.19	0.13	0.16	0.33	0.23	0.29	3.44	2.36	2.96
PM10	Diesel PM10		Alternative Fuel PM10	Diesel PM10		Alternative Fuel PM10	Diesel PM10		Alternative Fuel PM10
0.01	0.008		0.010	All Except Urban Bus			0.15		0.19
				0.014		0.018			
				Urban Bus					
0.10	0.08		0.10	All Except Urban Bus			1.33		1.85
				0.130		0.180			
				Urban Bus					
				0.320		0.400			

- a - 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.
- b - Mileage based emissions factors were calculated using conversion factors from Table D-28.
- c - Fuel based emissions factors were calculated using fuel consumption rate factors from Table D-24.
- d - Fuel based factors are for engines less than 750 horsepower only.
- e - ROG = HC * 1.26639

Table 4
Medium Heavy-Duty Alternative Fuel Engines
Converted Emission Standards

Model Year	g/bhp-hr		g/mile ^(a)		g/gal ^(b,c)	
	NO _x	PM10	NO _x	PM10	NO _x	PM10
1988 – 1989	6.0	0.60	11.40	1.140	111.00	11.10
1990	6.0	0.60	10.80	1.080	111.00	11.10
1991 – 1993	5.0	0.25	9.00	0.450	92.50	4.63
1994 – 1997	5.0	0.10	9.00	0.180	92.50	1.85
1998 – 2001	4.0	0.10	7.20	0.180	74.00	1.85
2002 – 2006	2.0	0.10	3.60	0.180	37.00	1.85
2007 – 2009	1.2	0.01	2.16	0.018	22.20	0.19
2010+	0.2	0.01	0.36	0.018	3.70	0.19

a - Mileage based emissions factors were calculated using conversion factors from Table D-28.

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.

Table 5
Heavy Heavy-Duty Alternative Fuel Engines
Converted Emission Standards

Model Year	g/bhp-hr		g/mile ^(a)		g/gal ^(b,c)	
	NO _x	PM10	NO _x	PM10	NO _x	PM10
1988 – 1989	6.0	0.60	18.60	1.860	111.00	11.10
1990	6.0	0.60	18.00	1.800	111.00	11.10
1991 – 1993	5.0	0.25	15.00	0.750	92.50	4.63
1994 – 1997	5.0	0.10	14.50	0.290	92.50	1.85
1998 – 2001	4.0	0.10	11.60	0.290	74.00	1.85
2002 – 2006	2.0	0.10	5.80	0.290	37.00	1.85
2007 – 2009	1.2	0.01	3.48	0.029	22.20	0.19
2010+	0.2	0.01	0.58	0.029	3.70	0.19

a - Mileage based emissions factors were calculated using conversion factors from Table D-28.

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.

Table 6
Diesel Medium Heavy-Duty Vehicles 14,001-33,000 pounds (lbs) Gross Vehicle
Weight Rating (GVWR)
Emission Factors (g/mile)^(a)

Model Year	NOx	ROG	PM10
Pre-1984	17.21	0.29	0.792
1984 – 1986	16.65	0.29	0.720
1987 – 1989	14.60	0.18	0.504
1990	14.60	0.18	0.504
1991 – 1993	12.18	0.16	0.288
1994 – 1997	10.70	0.10	0.216
1998 – 2002	9.77	0.08	0.144
2003+	5.39	0.08	0.216
2004 – 2006	5.12	0.08	0.216
2007 – 2009	2.79	0.05	0.024
2010+	0.51	0.02	0.024

a - Emission factors incorporate the ultra-low-sulfur diesel fuel correction factors in Table D-26.

Table 7
Diesel Heavy Heavy-Duty Vehicles 33,000+ lbs GVWR
Emission Factors (g/mile)^(a)

Model Year	NOx	ROG	PM10
Pre-1987	21.39	1.04	1.249
1987 – 1988	21.11	0.81	1.354
1989 – 1990	21.11	0.81	1.354
1991 – 1993	18.23	0.54	0.562
1994 – 1997	17.95	0.4	0.367
1998 – 2002	17.58	0.51	0.403
2003 – 2006	11.63	0.26	0.252
2007 – 2009	6.36	0.23	0.028
2010+	1.06	0.18	0.028

a - Emission factors incorporate the ultra-low-sulfur diesel fuel correction factors listed in Table D-26.