Eastern Research Group, Inc.

Analysis of Off-Road Emission Correction Factors

Final Report

Prepared for:

California Air Resources Board

Prepared by:

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May 10, 2013

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1.0 Introduction

As part of work by California Air Resources Board staff (ARB) to update emission inventories for off-road recreational vehicles, ERG was contracted to evaluate selected correction factors used to generate statewide emissions inventories by season. Correction factors are necessary to adjust baseline emissions to the range of meteorological conditions that occur in California over the course of a year; and also to allow accounting for storage of a portion of recreational vehicles in garages, where temperatures do not match ambient temperatures. The specific correction factors evaluated under this task were: a combined temperature and fuel RVP correction to evaporative hydrocarbon (HC) emissions (Task 1a); temperature and humidity corrections to exhaust HC, carbon monoxide (CO), and oxides of nitrogen (NOx) emissions (Task 1b); and corrections made to ambient temperature to estimate garage temperatures, and the impact of this garage correction on evaporative emissions (Task 2). Under each task, ERG was asked to evaluate ARB's current approach, and recommend alternatives where appropriate, with a focus on the development of simplified corrections that can be applied on a daily (vs. hourly) level. This report presents ERG's evaluation of ARB's current correction factor approach and recommended alternatives. Of particular note is the development of an alternative approach to estimating temperature & RVP corrections on evaporative HC emissions based on published vapor generation models and empirical data on fuel tank and hose permeation. This alternative approach was used to develop updated evaporative HC correction factors by Geographic Area of Interest (GAI) and season for garages.

2.0 Evaporative Temperature/RVP Corrections

To develop statewide emission inventories for off-road spark-ignited (SI) engines, ARB has used a statistical model to adjust evaporative diurnal and resting loss HC emissions as a function of temperature and RVP. This model was developed to correct from emissions at a baseline daily temperature diurnal of 65-105-65° F and fuel RVP of 7.0 psi. The model was developed by regressing hourly emission results from a series of evaporative diurnal tests conducted on two lawn mowers tested in the early 2000s, shown in Table 1. For ARB's inventory purposes, emissions over a 24-hour period are split into "diurnal" (defined as the period when temperature is increasing) and "resting loss" (defined as the remaining period of the day, when temperatures are stable or decreasing). The fitted models for diurnal and resting loss, shown in Table 2, assign coefficients for soak length (hours), starting temperature, delta temperature, RVP and interactive terms, with unique coefficients for diurnal and resting loss periods. We refer to this model as the "Mower model" throughout the report. As detailed in the following section, ERG evaluated the Mower model by comparing predicted corrections over different temperature/RVP conditions against corresponding data from independent datasets. ERG also developed an alternative model for estimating temperature/RVP corrections to aid in the evaluation of the Mower model.

Table 1. ARB mower data used to develop current Temperature/RVP correction

	Summertime (65-105F) 7.0 RVP	**Summertime (65-105F) 9.5 RVP**	**Average (50-90F) 9.5 RVP**	**Wintertime (48-69F) 7.0 RVP**
Equipment	**Diurnal (Grams per Day)**			
Mower 3	1.44			0.41
Mower 8	2.03	2.66	1.50	
	Resting Loss (Grams per Day)			
Mower 3	0.81			0.43
Mower 8	1.14	1.37	1.13	

Table 2. Statistical model & coefficients for current Temperature/RVP correction

ARB Temperature/RVP correction factor =
(A) hr + (B) RVP + (C) Temp + (D) dtemp + (E) temp*dtemp + (F) temp*hr + (G) temp*rvp + (H) dtemp*hr + (I) dtemp*rvp + intercept

	Diurnal	**Resting Loss**
Variable	Coefficients	Coefficients
A	-0.0832099	0.032988944
B	-0.007304156	0.041684179
C	-8.10117E-05	0.005296275
D	-0.025853192	0.06209003
E	0.000175569	-0.000459595
F	0.001980283	0.000596396
G	1.47497E-05	-0.000500966
H	0.001471629	0.000804361
I	0.001715214	-0.002281295
intercept	0.05201313	-0.40806693

2.1 Evaluation of Mower model predictions vs. Independent Data

In order to evaluate the predictive ability of the Mower model, predictions of temperature/RVP correction from baseline were compared against results from two independent evaporative emission datasets. The first was from ARB testing on two recreational vehicles of daily emissions over multiple temperature ranges and/or RVPs. The second was from EPA testing on multiple off-road fuel tanks over a forced heat build.

2.1.1 Evaluation vs. ARB Recreational Vehicle data

ARB data on two uncontrolled recreational vehicles, a 2006 Polaris Sportsmen 500 ATV (ATV3) and 2007 Honda CRF450X7 off-highway motorcycle (OHM4) tested at multiple temperature/RVP conditions, provided a good benchmark for evaluating the temperature/RVP adjustments predicted by the Mower model. ATV3 and OHM4 were tested for a 72-96° F diurnal on 7 RVP ("EPA Summer"), of 44-66° F on 9 RVP ("Winter"), 53-71° F on 7 RVP ("Annual Average") and 65-105° on 7 RVP ("ARB Summer"), the standard ARB certification test procedure and baseline from which Mower model corrections are based. Because ARB intends to apply temperature/RVP corrections on a daily basis, ERG evaluated the model against independent ATV/OHM data on both an hourly and daily basis. Having benchmark data under multiple conditions provides a good test for the robustness of the Mower model, particularly the ability of the model to correct for more typical summer conditions represented by the 72-96° F case. The benchmark total daily HC emissions from ATV3 and OHM4 are shown in Table 3.

Table 3. ARB recreational vehicle evaluation dataset

Vehicle	Baseline <u>ARB Summer</u> RVP: 7.0 Temp: 65-105° n=2	<u>EPA Summer</u> RVP: 7.0 Temp: 72-96° n=3	<u>Winter</u> RVP: 7.0 Temp: 44-66° n=1	<u>Annual Avg</u> RVP: 7.0 Temp: 53-71° n=2
ATV3 (grams HC/day)	8.27	5.73	1.81	2.25
Relative to Baseline	***1.00***	**0.69**	***0.22***	***0.27***
OHM4 (grams HC/day)	26.75	19.17	6.85	10.30
Relative to Baseline	***1.00***	***0.72***	***0.26***	***0.39***

Though the absolute emissions from ATV3 and OHM4 are quite different, emissions relative to the ARB Summer baseline are similar for the EPA Summer and Winter cases, while Annual Average emissions relative to the baseline differ more (0.27 vs. 0.39). The "relative to baseline" emissions were used as the benchmark for assessing the Mower model, as they are equivalent to the temperature/RVP correction the model is trying to estimate.

The Mower model was evaluated by how well it predicted the relative change in total daily diurnal plus resting loss emissions, as this is the reported total from the SHED and a more direct assessment of model performance for estimating daily emission inventories. To estimate changes in daily emissions from an hourly application of the Mower model, diurnal and resting loss coefficients from Table 2 were applied based on the temperature and RVP inputs, shown in Table 4. Diurnal coefficients were applied in hours with a positive delta temperature, and resting loss coefficients were applied in hours with negative delta temperature. Diurnal patterns for the winter and annual average were based on EMFAC and OFFROAD temperature profiles provided by ARB.

Table 4. Inputs used for ARB Mower model hourly predictions

Hour (Soak Length input for Model = 1 for each row)	EPA Summer RVP: 7.0 Initial T: 72° Delta Temp (°):	ARB Summer RVP: 7.0 Initial T: 65° Delta Temp:	Winter RVP: 7.0 Initial T: 44° Delta Temp:	Annual Avg RVP: 7.0 Initial T: 53° Delta Temp:
1	0.5	1.6	0.8	1.1
2	2.8	6	3.5	2.5
3	5.0	7.7	5.1	3.6
4	5.5	5.8	4.5	3.4
5	4.1	4.5	3.5	2.7
6	3.0	4	2.3	2.1
7	2.5	3.5	1.4	1.4
8	0.2	3.1	0.6	0.8
9	0.5	2.2	-0.6	0.4
10	-0.9	1.5	-2.2	-0.5
11	-1.8	0.1	-3.7	-1.8
12	-1.9	-0.8	-3.6	-2.7
13	-2.8	-3.1	-2.5	-3.0
14	-3.2	-5.8	-1.7	-2.5
15	-2.8	-6.5	-1.4	-1.7
16	-2.0	-4.4	-1.1	-1.2
17	-1.8	-3.6	-0.7	-1.0
18	-1.7	-3	-1.3	-0.8
19	-1.5	-2.5	-0.9	-0.7
20	-0.8	-3.3	-0.6	-0.7
21	-0.8	-2	-0.4	-0.5
22	-0.6	-1.8	-0.4	-0.5
23	-0.9	-1.7	-0.4	-0.3
24	-0.4	-1.5	-0.3	-0.1

For daily application of the Mower model, a single diurnal and resting loss value was calculated per day, using the diurnal and resting loss coefficients from Table 2. The inputs used for daily application of the model are shown in Table 5.

Table 5. Inputs used for ARB Mower model daily predictions

Diurnal				
Soak Length (Hours)	**ARB Summer RVP: 7.0 Initial T: 65° Delta Temp (°):**	**EPA Summer RVP: 7.0 Initial T: 72° Delta Temp:**	**Winter RVP: 7.0 Initial T: 44° Delta Temp:**	**Annual Avg RVP: 7.0 Initial T: 53° Delta Temp:**
11	40	-	-	-
9	-	24	22 (8)	18
Resting Loss				
Soak Length (Hours)	**Initial T: 105° Delta Temp (°):**	**Initial T: 96° Delta Temp:**	**Initial T: 66° Delta Temp:**	**Initial T: 71° Delta Temp:**
13	-40	-	-	-
15	-	-24	-22 (16)	-18

Results from the two approaches are shown in Table 6. The results of the model are shown as unitless, with the purpose of calculating the relative change between different diurnal profiles presented here. The result of the hourly model was calculated by summing model results for the diurnal and resting loss hours, and weighting these summed results 65/35 based on the diurnal/resting loss emissions weighting developed by ARB. The result of the daily model was calculated by weighting the calculated diurnal and resting loss results by this same weighting.

Table 6. Mower model predictions vs. ARB recreational vehicle data

Model Approach	Baseline ARB Summer RVP: 7.0	EPA Summer RVP: 7.0	Winter RVP: 7.0	Annual Avg RVP: 7.0
Hourly Application	1.15	1.07	0.17	0.43
Temp/RVP Correction	***1.00***	***0.93***	***0.15***	***0.37***
Daily Application	1.03	0.91	0.29	0.47
Temp/RVP Correction	***1.00***	***0.89***	***0.28***	***0.46***
ATV3&OHM4 Data Temp/RVP Correction*	***1.00***	***0.69-0.72***	***0.22-0.26***	***0.27-0.38***

* i.e. "relative to baseline" emissions from Table 3

The hourly application of the model is higher than the data for the EPA Summer case, lower than the data for the Winter case, and within range for the Annual Average case. The daily application of the model is higher than the data for all three cases. Model predictions are particularly high for the EPA Summer case, where hourly and daily applications of the model predicted corrections of 0.93 and 0.89, respectively, whereas for the data corrections from 0.69-0.72 were observed.

2.1.2 Evaluation vs. EPA fuel tank data

To further assess the Mower model, predictions were compared to a second independent dataset developed by EPA as part of validation for algorithms used in the NONROAD model.[1] This test program put 13 fuel tanks for a variety of applications into an evaporative test SHED and performed a forced build of the fuel temperature over roughly one hour, in an attempt to replicate a normal heat build over the course of the day. A quirk of the dataset is that each fuel tank ended up achieving a different fuel temperature profile, so unlike the ATV3/OHM4 data above, there weren't paired data on each tank. In addition, some of the fuel temperatures rose to extreme levels (over 130° F), beyond the intended range of the Mower model. To make use of the data for evaluation within the intended range, ERG narrowed down the data to look at test results over similar tank sizes (within 20 percent), only using temperature ranges with a maximum at or below 95° F. This left three fuel tank pairs, all from riding lawn mowers. Comparing across different tank sizes was considered reasonable because the Mower model was developed over two mowers with tank sizes about 25 percent different (0.30 vs. 0.38 gallons), and does not account for tank size in the model coefficients. Because the data were only for temperature rise conditions, only the diurnal component of the Mower model was evaluated. Mower model predictions were developed as daily corrections using the minimum and maximum fuel temperatures from the heat build.

Evaluation results for the three tank size pairs are shown in Table 7. Corrections were calculated as the ratio of lower temperature to higher temperature tests, to replicate the purpose of the Mower model corrections, shown in the "correction" column. The comparison of data vs. model is made based on this correction, as the Mower model is only predicting relative change in emissions; absolute results have no meaning.

Table 7. Mower model predictions vs. EPA fuel tank data

Tank size pair	Tank gallons	Fuel Temp Build (°F)		Data		Mower model predictions	
		min	max	Grams	Correction	Diurnal	Correction
1.4-1.7 gal	1.4	71.42	85.46	1.232	0.88	0.098	1.04
	1.7	67.1	86.54	1.394		0.094	
2.5-3.0 gal	2.5	80.6	95	3.225	0.23	0.142	0.58
	3	79.88	83.12	0.75		0.082	
6.5 gal	6.5	75.74	91.76	7.8	0.22	0.126	0.49
	6.5	68.9	75.02	1.69		0.062	

[1] U.S. EPA, "NONROAD Evaporative Emission Rates", EPA Report No. EPA-420-R-10-021, July 2010

As shown, for each of the three tank pairs, the Mower model correction overpredicts the correction from high to low temperature conditions of the data. Of particular note is the 1.4-1.7 gallon tank pair, where the Mower model predicts an increase in emissions (correction of 1.04) where the data decreased (correction of 0.88).

2.2 Alternative Model Development & Evaluation

To provide ARB another approach to estimate temperature and RVP corrections in evaporative emission inventory development, ERG compiled an alternative model for evaporative Temperature/RVP correction based on already published models and data. The goal was to develop a temperature/RVP correction model applicable to ARB's evaporative emission inventory calculations for recreational vehicles, and that could also be benchmarked against the independent data presented in the preceding section. ERG compiled this model based on established approaches reported in the literature and employed in U.S. EPA's NONROAD and MOVES models.

The underpinning of this approach is to break down evaporative emissions into distinct processes, in order to quantify the distinct response of each to changes in temperature and fuel RVP. As an example, EPA's MOVES model defines discrete evaporative processes as follows:

- Fuel permeation
- Vapor venting (which equals vapor generated in uncontrolled systems)
- Liquid fuel leaks
- Refueling spillage & vapor (outside the scope of this evaluation)

For nonroad sources, these processes also apply, with older fuel delivery technology and lack of vapor control producing more vapor from more points in the fuel delivery system. For example, most SI off-road equipment use carburetors, a technology largely phased out of the on-road fleet by the early 1990s. Permeation occurs through non-metal fuel tanks and hoses, and NONROAD models permeation distinctly from each. Liquid leaks can occur from cracked fuel lines and deterioration of connections. Diffusion is another source of emissions from some nonroad sources, if a fuel tank is openly vented to the atmosphere.

For this task, ERG focused on temperature/RVP effects on vapor generation and permeation, as the impact of temperature & RVP change on these processes is well established through prior studies. Vapor venting and permeation respond differently to changes in temperature and RVP, and the contribution of each to overall evaporative emissions will vary greatly depending on whether the equipment is sitting unused early in the day vs. late in the day, or is operating, and for how long; so it is important to assess the contribution of vapor generation and permeation separately in developing robust correction factors.

The three components of the Alternative model – vapor, tank permeation and hose permeation - are presented in Sections 2.2.1 & 2 below. A summary of all equations in the model, as well as a step-by-step example calculation, are in Appendix C.

2.2.1 Vapor Generation Model

Vapor generation - whether a vehicle is parked or operating - is dictated by vapor pressure in the fuel tank, a function of fuel RVP and temperature rise. Work to quantify the amount of vapor generated was undertaken by Wade in the 1960s, who established equations relating vapor generation to fuel temperature rise and several fuel properties, including RVP, distillation properties, density and molecular weight.[2] These equations have been used by U.S. EPA for earlier MOBILE versions as well as the NONROAD model. In the 1980s Reddy developed a simplified model for vapor generation based only on fuel temperature rise and RVP, and published model coefficients reflecting variations in altitude (sea level, Denver) and ethanol level (E0, E10).[3] The Reddy equations have been broadly used since, from automotive product development to evaporative inventory modeling, including in EPA's MOVES model. The Reddy equations are not used to predict total vapor vented into the atmosphere, if any vapor control is present; the amount that escapes into the atmosphere is more difficult to quantify in cases where control mechanisms such as pressurized fuel tanks or charcoal canisters are in place. However, for uncontrolled off-road equipment, the amount of vapor generated is a good surrogate for vapor emissions, since they are not equipped with charcoal canisters.

For this analysis, we used the Reddy equation for estimating grams of vapor generated on per gallon of vapor space, using coefficients for sea level and E10, as follows:

$$\textit{Vapor generated (g/gal vapor space)} = A\, e^{B(RVP)} \left(e^{CT_2} - e^{CT_1}\right)$$

Where RVP (psi), starting temperature (T_1, ◦F) and ending temperature (T_2, ◦F) are inputs, and A, B and C are the coefficients for E10 and sea level established by Reddy (A=0.00875, B = 0.2056, C=0.0430).

[2] Wade, D.T. "Factors Influencing Vehicle Evaporative Emissions", SAE Paper 670126

[3] Reddy, S.R. "Prediction of Fuel Vapor Generation From a Vehicle Fuel Tank as a Function of Fuel RVP and Temperature", SAE Paper 892089

Predicting emissions for the evaluation datasets required estimates of fuel tank size and fuel fill level. For the ARB recreational vehicle dataset (ATV3 & OHM4), an internet search for specs on these vehicles found fuel tank capacities of 4.1 and 2.3 gallons, respectively. The fuel tank sizes for the EPA fuel tank and ARB Mower datasets were already known. Fuel fill of 50 percent was assumed based on the test procedure from earlier ARB testing of small off-road equipment. To estimate total vapor generated (assumed to equal vapor emitted), the results from the Reddy equation above were multiplied by vapor space estimates, as follows:

*Vapor generated (grams) = Vapor (g/gallon vapor space) * Fuel Capacity (gal) * (1- Fill %)*

The resulting predictions of vapor generation are shown in Tables 9 through 11 as part of overall model predictions.

The vapor model was developed for vehicles without sealed tanks or pressure relief valves, but can be adapted for off-road equipment that is so equipped (e.g., pleasure craft). The amount of vapor restricted from venting to the atmosphere will depend on the setting of the pressure relief valve; for example, EPA estimates that this range varies from 0.5 – 4.0 psi on personal watercraft. Reddy and EPA both assessed the impact of a 1 psi pressure relief valve on vapor generation, with both concluding that a 1 psi valve would reduce vapor generation by about 0.7 grams per gallon vapor space. This would apply to different temperature and RVP conditions, as the relief valve is operating at the same threshold regardless of the conditions under which vapor was generated (through the relative reduction may be quite different). In order to develop a vapor generation model applicable to sealed systems with pressure relief valve in California, the recommended approach would be to determine the vapor reduction based on a fleet average pressure relief value setting using the Reddy methods, and subtract this from the uncontrolled vapor generation estimates derived above; or, assuming 1 psi valves, subtract 0.7 grams/gallon off of the uncontrolled vapor generation rate.

2.2.2 Permeation Model

The second aspect of the alternative model was permeation, the migration of vapor and fuel molecules through fuel tank and hose surfaces, escaping as vapor into the atmosphere. This process is happening all the time, and is a direct function of fuel temperature. Previous work for on-road sources have established that for non-metallic fuel tanks and hoses, standard for off-road equipment, permeation emissions at a given temperature will roughly double for an increase of

10◦ C (18◦ F).[4] Unlike vapor generation, which occurs only with increasing temperature, this effect occurs whether the temperature is increasing, decreasing or stable. Permeation is thus the dominant effect in "resting loss" emissions defined by ARB, and can be a significant component of diurnal emissions as well. This is particularly true on ethanol blend fuels; recent studies have established that the presence of ethanol at current blend levels greatly increase permeation emissions.[5] Under high temperature conditions on ethanol blend fuel, permeation can account for the majority of daily evaporative emissions, even for vehicles without vapor control.

U.S. EPA did considerable work to update permeation emissions from off-road tanks and hoses as part of a 2008 rule regulating off-road SI engines. This work was also the basis for updates to the NONROAD2008 model. The updates are well documented (see earlier cite 2), and provide a good basis for developing the alternative temperature correction model, so are used directly for this analysis.

The NONROAD tank and hose permeation models requires estimate of tank and hose surface area; as these are not readily available, relationships established for NONROAD between tank size and tank surface area were used, as well as NONROAD estimates of hose length and diameter by SCC and horsepower class. The NONROAD model also provided base permeation emission factors for E10, used to predict ARB recreational vehicle data: 10.7 g/m^2 /day for tanks, and 222 g/m^2 /day for hoses. For the EPA fuel tank and ARB Mower model data, base permeation emission factors for E0 were used: : 9.7 g/m^2 /day for tanks, and 122 g/m^2 /day for hoses. As discussed in EPA's NONROAD literature, temperature corrections for permeation in NONROAD are based on the rule of thumb that permeation emissions double with every increase of 10◦ C (18◦ F); the temperature correction equations are in Appendix C. The inputs used for the permeation model are shown in Table 8.

[4] Haskew, H. and McClement, D., "Fuel Permeation from Automotive Systems", Coordinating Research Council Project E-65 Final Report, September 2004
[5] Haskew, H. "Evaporative Emissions from In-Use Vehicles: Test Fleet Expansion (CRC E-77-2b)", Report for U.S. EPA, EPA Report No. EPA420-R-010-005, October 2010

Table 8. Permeation model inputs

Dataset	Equipment	Tank Size (gallons)	Estimated Tank Surface Area (m^2)	Hose Length from NONROAD (m)	Hose Diameter from NONROAD (m)	Estimated Hose Surface Area (m^2)
ARB Recreational Vehicle	**ATV3**	4.1	0.43	0.305	0.00635	0.0061
	OHM4	2.3	0.29	0.305	0.00635	0.0061
EPA Fuel Tank	**1.4-1.7 gal**	1.4 / 1.7	0.21 / 0.23	n/a	n/a	n/a
	2.5-3.0 gal	2.5 / 3.0	0.30 / 0.34	n/a	n/a	n/a
	6.5 gal	6.5	0.62	n/a	n/a	n/a
ARB Mower	**Mower 3**	0.38	0.10	0.1881	0.00635	0.0038
	Mower 8	0.30	0.09	0.1881	0.00635	0.0038

2.2.3 Evaluation of Alternative model vs. Independent Data

For the ARB Recreational Vehicle dataset, the resulting predictions of the vapor generation and permeation models for ATV3 and OHM4 are shown in Table 9.

Table 9. Alternative model predictions vs. ARB recreational vehicle data

Vehicle	Source	Baseline ARB Summer RVP: 7.0 Temp: 65-105°	EPA Summer RVP: 7.0 Temp: 72-96°	Winter RVP: 9.0 Temp: 44-66°	Annual Avg RVP: 7.0 Temp: 53-71°
ATV3 (4.1 gal tank)	**Data (g)**	8.27	5.73	1.81	2.25
	Temp/RVP Correction*	***1.00***	***0.69***	***0.22***	***0.27***
	Model (g)	14.55	10.24	3.52	3.82
	Permeation%	*61.0%*	*70.5%*	*66.1%*	*77.4%*
	Temp/RVP Correction	***1.00***	***0.70***	***0.24***	***0.26***
OHM4 (2.3 gal tank)	**Data (g)**	26.75	19.17	6.85	10.30
	Temp/RVP Correction*	***1.00***	***0.72***	***0.26***	***0.38***
	Model (g)	10.0	7.24	2.46	2.76
	Permeation%	*68.2%*	*76.6%*	*72.8%*	*82.4%*
	Temp/RVP Correction	***1.00***	***0.72***	***0.25***	***0.28***

* i.e. "relative to baseline" emissions from Table 1

Overall, the model tracks the relative change in emissions well versus the benchmark, for both vehicles. The one exception is the Annual Average case for OHM4, where the data result (correction of 0.38) is higher than the counterpart ATV3 correction (0.27) and the model prediction (0.28). Also included in Table 9 is the contribution of permeation to the total model predictions; permeation is estimated to contribute roughly 60 to 80 percent of total evaporative emissions under these conditions, depending on tank size, temperature range and RVP.

Alternative model results for the EPA Fuel Tank dataset are shown in Table 10. Predictions for the Alternative model are based on vapor and tank permeation models; unlike the Mower model, the diurnal emission predictions are in grams so can be compared directly to the measured results. However, for evaluation purposes the ratio from high temperature and low temperature is the prediction of interest, shown in the "correction" column.

Table 10. Alternative model predictions vs. EPA fuel tank data

Tank size pair	Tank gallons	Fuel Temp Build (°F)		Data		Alternative model predictions	
		min	max	HC (g)	Correction	HC (g)	Correction
1.4-1.7 gal	1.4	71.42	85.46	1.232	0.88	0.76	0.66
	1.7	67.1	86.54	1.394		1.16	
2.5-3.0 gal	2.5	80.6	95	3.225	0.23	1.99	0.25
	3.0	79.88	83.12	0.75		0.50	
6.5 gal	6.5	75.74	91.76	7.8	0.22	4.81	0.25
	6.5	68.9	75.02	1.69		1.20	

For the two larger tank size pairs, the model predicts the correction very well, but underestimates the correction for the 1.4-1.7 tank size range. Absolute emissions are consistently underpredicted by the model, across all three tank size pairs.

The ARB Mower model data provides an additional dataset to evaluate the Alternative model against. The comparison between Mower model and this dataset isn't presented above, because the Mower model was fit to these data – but it does serve as an independent dataset for Alternative model evaluation. The comparison is shown in Table 11.

Table 11. Alternative model predictions vs. ARB mower data

Mower / Temp & RVP Condition		Data		Alternative model predictions	
ARB Mower 8		**HC (g)**	**Correction**	**HC (g)**	**Correction**
65-105	7	3.18	**1.00**	2.41	**1.00**
65-105	9.5	4.03	**1.27**	2.72	**1.13**
50-90	9.5	2.63	**0.83**	1.51	**0.63**
ARB Mower 3		**HC (g)**	**Correction**	**HC (g)**	**Correction**
65-105	7	2.25	**1.00**	2.66	**1.00**
48-69	7	0.84	**0.37**	0.73	**0.27**

Here, the alternative model consistently underpredicts the corrections from baseline to higher RVP and/or lower temperature conditions, compared to the mower data.

2.2.4 Comparison of Mower and Alternative Model Results

The predictions of the Mower and Alternative models can be directly compared for the ARB Recreational Vehicle and EPA Fuel Tank datasets. For the ARB Recreational Vehicle datasets, Figures 1 and 2 summarize the overall comparison of temperature/RVP corrections from the data versus the Mower model and the Alternative model for ATV3 and OHM4. For this comparison, ERG's calculation of Mower model results based on daily application is shown. These comparison shows that the Alternative model generally does a better job than the Mower model relative to the data, particularly for the 72-96◦ case. The one case where the Mower model does better than the Alternative model is for the Annual Average case for OHM4.

Figure 1. Comparison of Mower & Alternative model predictions for ATV3: Temperature/RVP Corrections from 65-105 7 RVP

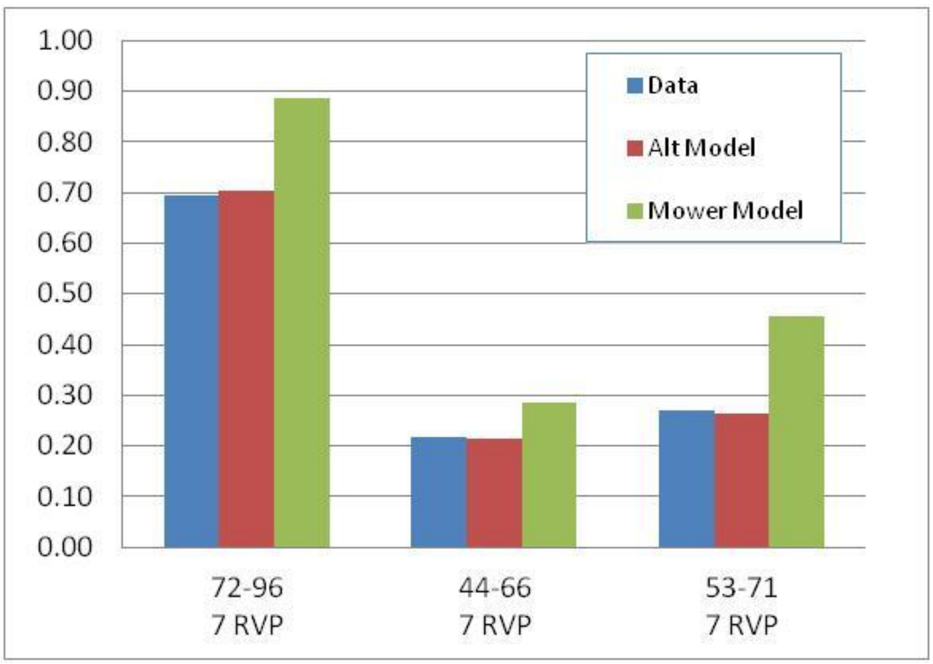
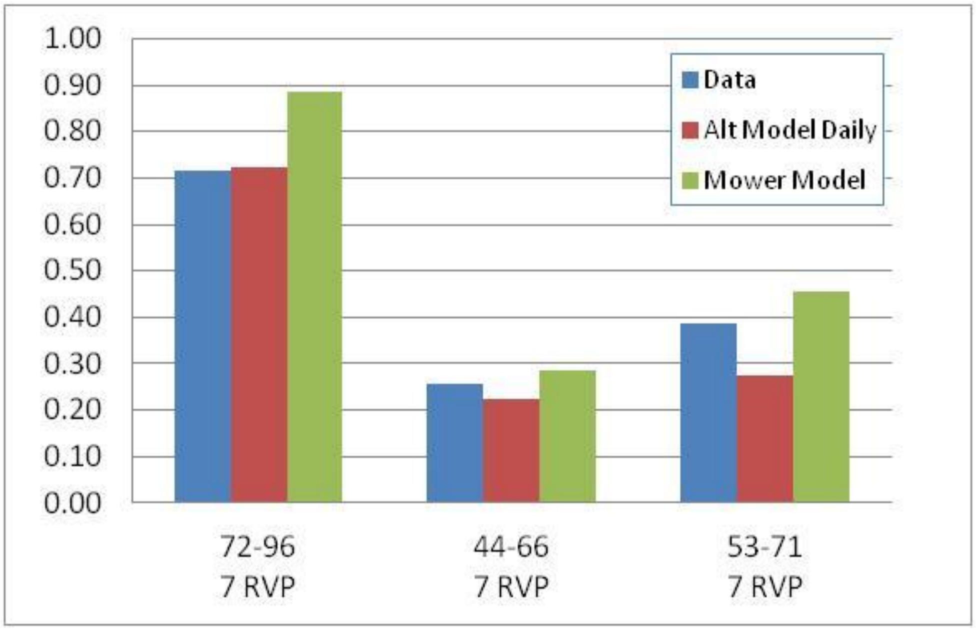
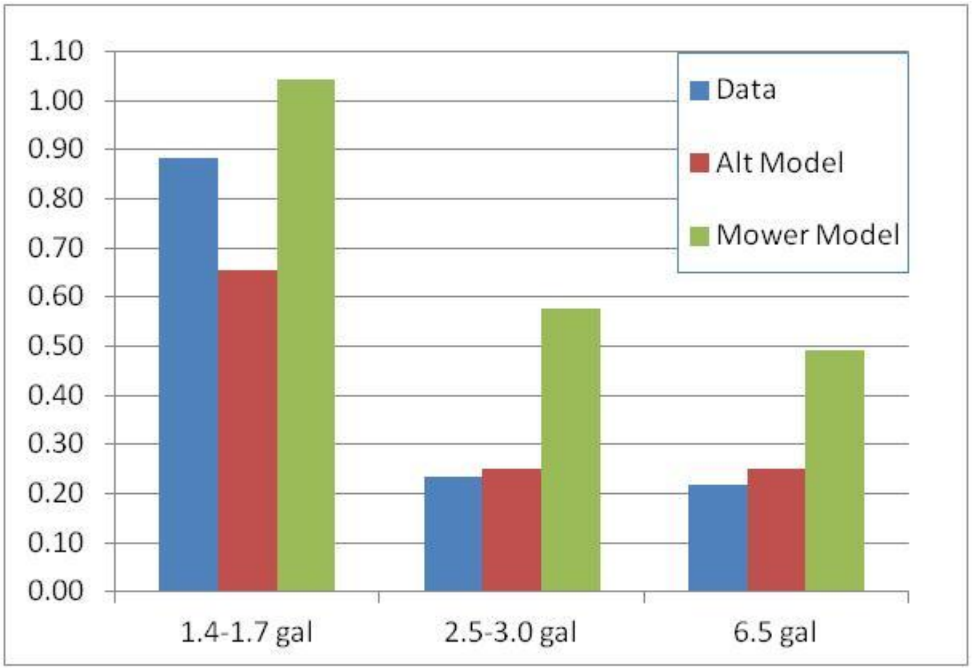


Figure 2. Comparison of Mower & Alternative model predictions for OHM4: Temperature/RVP Corrections from 65-105 7 RVP



For the EPA Fuel Tank data, Figure 3 summarizes the comparison of temperature/RVP corrections from the data versus the Mower model and the Alternative model over each of the three tank pairs analyzed. These comparison shows that the Alternative model does better than the Mower model; in particular, for the 1.4-1.7 gallon tank size pair, although the Alternative model underpredicts the data, it is directionally correct; the Mower model predicts an emission increase for this case, as discussed previously.

Figure 3. Comparison of Mower & Alternative model predictions for EPA Fuel Tank Data: Temperature/RVP Corrections from High→ Low Temperatures



2.2.5 Evaluation on Vehicles with Evaporative Controls

After model evaluation was complete for systems without evaporative control, ARB requested that ERG evaluate the Mower and Alternative models against data from vehicles with some evaporative control. ERG evaluated two later model year vehicles (2006/7) from the ARB recreational vehicle dataset equipped with fuel injection (rather than carburetors) and with passive charcoal canisters added; these vehicles were dubbed OHM7 and ATV2. Emissions from these vehicles were significantly lower than their uncontrolled counterparts, around 1 gram/day vs. roughly 10 grams/day averaged over all uncontrolled ATVs and OHMs. The correction from the baseline 65-105 ◦ F 7 RVP condition to the 72-96 ◦ F 7 RVP condition was calculated as 0.94 and 0.70, respectively.

To estimate Alternative model correction for these canister-equipped vehicles, vapor emissions were assumed to be zero, leaving only tank and hose permeation emissions. As demonstrated in the example calculation in Appendix C, for permeation the correction from 65-105 to 72-96 is 0.81; without vapor factored in, this correction would apply to both vehicles. The Mower model correction for the same temperature change is 0.91, also applicable to both vehicles. Both models therefore predict the correction within the broad range of the data over both vehicles. Because the absolute emissions from these vehicles are so low, future modeling with the Alternative model could be improved with more precise emissions data separating permeation vs. vapor (as was done for automobiles in recent CRC E-77 evaporative test programs), more detailed information on tank and hose materials and surface area, and canister capacity.

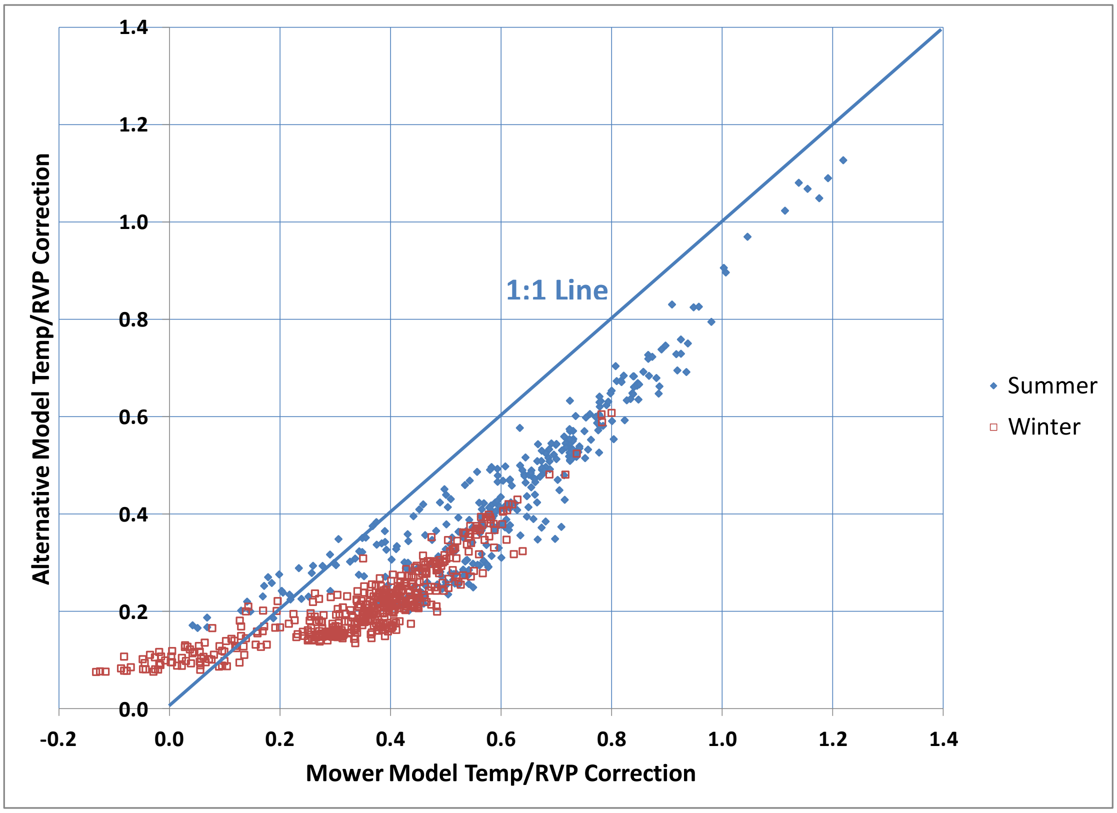
2.3 Evaporative Temperature/RVP Correction Conclusions & Recommendations

ERG recommends application of the Alternative model presented in the previous section. Evaluation of this model shows improved results over the Mower model, particularly when correcting to more typical summer time temperature conditions (e.g. 72-96◦ F). However, in applying the Alternative model, limitations of the model need to be considered. The model used for this analysis is most applicable to systems without pressure relief valves, though as discussed the model can be adjusted to account for these. The model relies on broad estimates for tank and hose surface areas which would require refinement when modeling lower emission vehicles. As shown in Appendix B, because the model is only addressing vapor and permeation losses, the model significantly underestimates absolute emissions for some vehicles, as additional sources of vapor (such as fuel leaks) are not accounted for.

2.4 Comparison of Mower & Alternative Models by County/Month

At ARB's request, ERG compared the temperature/RVP corrections from the Mower vs. Alternative model relative to a 65-105◦ 7 RVP baseline for every California county, by month. For the Mower model, the hours of diurnal and resting loss were derived directly from the data for each county/month case. A fleet average tank size of 3 gallons was used for the Alternative model. For both models, 7 RVP was assumed for May-September, and 9 RVP from October-April. The resulting comparison is shown in Figure 4, and shows that the corrections produced by the Mower model are generally higher than those produced by the Alternative model.

Figure 4. Comparison of Mower & Alternative model Temperature/RVP Corrections by County/Month



Following ARB's evaluation of these results, ARB decided to update the temperature/RVP corrections used for developing recreational vehicle evaporative emission inventories. ARB requested that ERG apply the Alternative model to develop correction factors for garage conditions, as discussed in Section 4 that could be applied to1990 and later calendar years. The methodology used to develop these corrections is detailed in Appendix A.

3.0 Exhaust Temperature & Humidity Corrections

Under this task, ERG assessed different approaches for developing daily off-road temperature and NOx humidity exhaust correction factors based on hourly approaches previously developed by ARB.

ARB's NOx humidity correction formula is as follows, where absolute humidity is in grains per pound of air:

$$\textit{Humidity Correction Factor} = 1-0.0038\ (\textit{Abs. Humidity} - 75)$$

ARB's exhaust temperature correction formula is as follows, where *a* is the coefficient from Table 12 depending on engine stroke and pollutant:

$$\textit{Temperature Correction Factor} = 10^{(T-75)a}$$

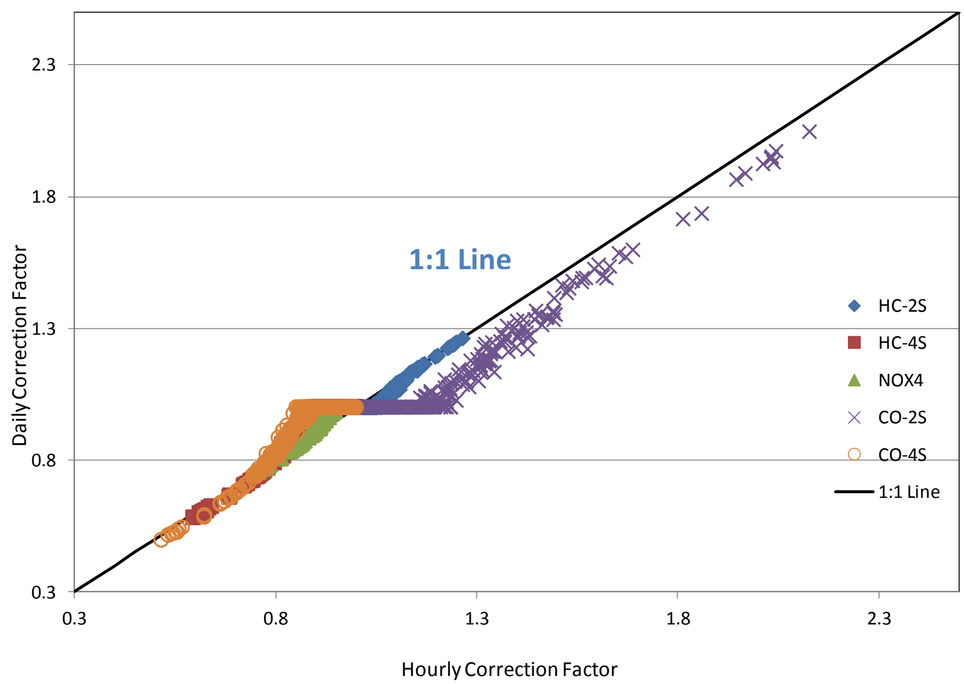
Table 12. Coefficients for Exhaust Temperature Correction

Pollutants	Low Temp (<75F)		High Temp(>75F)	
	2 Stroke	4 Stroke	2 Stroke	4 Stroke
CO	0	0	0.01494	-0.0146
HC	0	0	0.00484	-0.0113
NOx	0	0	0	-0.0059

ARB's provided the hourly temperature and humidity correction equations in spreadsheets, along with two approaches to estimating daily corrections; 1) applying hourly temperature to the correction factor equation and averaging the resulting hourly correction factors across all 24 hours of the day, and 2) applying the daily average temperature to the correction factor equation. For humidity corrections, ARB's analysis showed there is virtually no difference between these cases; because the NOx humidity correction is a linear correction, and hourly humidity doesn't vary that much over a day, applying a daily average humidity to the humidity correction equation is a reasonable approach for developing daily correction factors.

Developing a daily approach for temperature correction is less straightforward, because of the nonlinearities in the ARB temperature correction equations. Figure 5, from the spreadsheet ARB provided, shows the comparison of temperature correction factors for the average of the correction for each hour of the day, versus if only the daily average temperature is used. In general the hourly correction is of greater magnitude than the daily, positive (for 2-strokes) or negative (for 4-strokes). This trend is most clearly visible with CO for 2-strokes, shown in purple. This is because approach (2) dampens the nonlinear effects of the temperature correction coefficients. ERG's assessment is that while approach (1) is preferable to approach (2), it may still be underestimating temperature effect in the overall inventory, because it weights each hour equally in coming up with a daily average correction.

Figure 5. Exhaust Temperature Corrections, Average of 24 Hourly Corrections vs. Daily Average Temperature



A more precise way to estimate a daily correction would be to weight the correction based on activity, accounting for higher rates of recreational vehicle activity during daytime hours. A weighted daily average temperature correction will be higher than a straight average in cases where there is more activity during the day vs. night. The challenge, however, is that hourly activity data on recreational vehicles is not readily available; ERG polled technical documentation from the NONROAD model and reviewed previous work for other clients on off-road activity, and was not able to find any data on which to base hourly activity weightings for recreational vehicles. ERG therefore analyzed the sensitivity of a daily correction factor under the "upper bound" assumption that all recreational vehicle activity occurs between 9am-4pm, chosen based on a cursory review of the weekend operating hours of ATV courses (http://www.riderplanet-usa.com/atv/trails/california_list.htm). Figure 6 shows the comparison between hourly and daily approaches if only the hours of 9am-4pm are included in the hourly average. The trends are the same as in Figure 5, but much more pronounced; for example, for some cases the CO correction for 2-strokes is more than double the correction for the daily average temperature case (e.g., 80 percent increase vs. 30 percent). Figure 7 shows the comparison of peak hour-only averaged corrections vs. 24 hour corrections. The flatter slope of the correlation line indicates that the peak hour corrections are consistently more pronounced, positive or negative, than the 24-hour counterparts.

Figure 6. Exhaust Temperature Corrections, Average of Peak Hourly Corrections vs. Daily Average Temperature

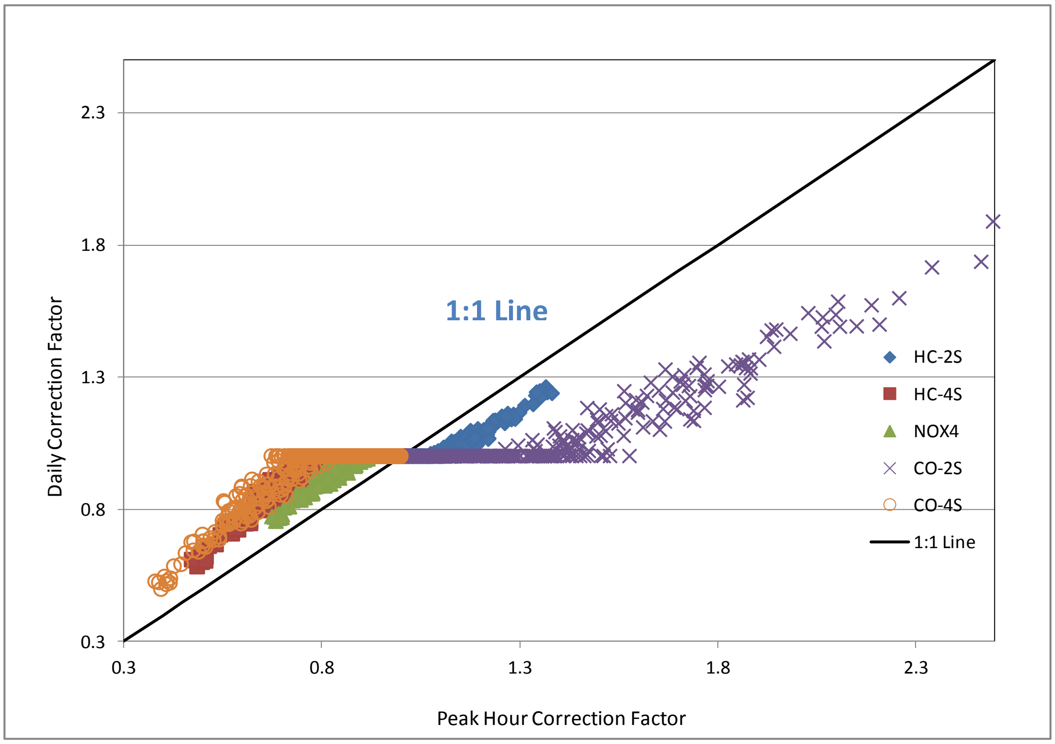
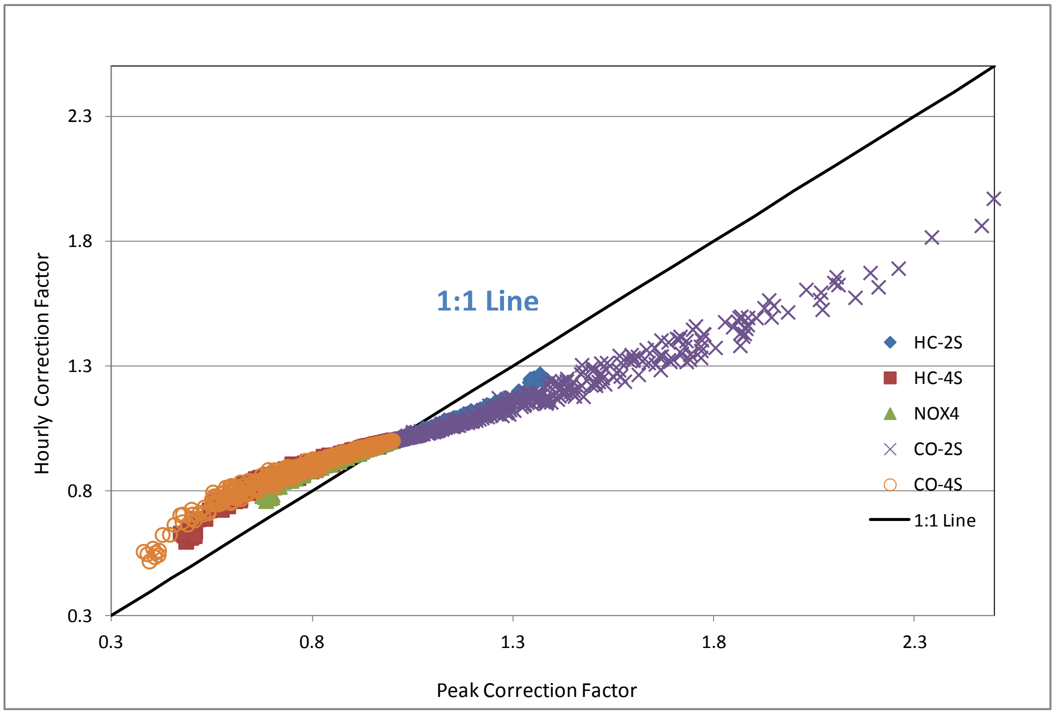


Figure 7. Exhaust Temperature Corrections, Average of Peak Hourly Corrections vs. Average of 24 Hourly Corrections



3.1 Exhaust & Humidity Correction Conclusions & Recommendations

Because of the difficulty in finding hourly activity allocation data for recreational vehicles, ERG doesn't recommend the peak-hour approach at this point; this was analyzed as a sensitivity case to show that it would be valuable to gather such data to aid future modeling efforts. ERG recommends that ARB use the 24-hour average approach, over the daily average temperature approach. Beyond this, a first step towards addressing activity weighting would be to develop a daily average based only the corrections from daytime hours, which would have a similar trend as the peak-hour relative to 24-hour (and daily), but not as pronounced. Because the trends are in both directions, increasing for 2-stroke (HC and CO) and decreasing for 4-stroke (HC, CO and NOx), the overall impact on the HC and CO inventories will be offsetting to some degree depending on 2-stroke / 4-stroke mix and relative contribution of each to the inventory.

4.0 Garage Temperature Corrections

ARB accounts for garage storage in constructing recreational vehicle emission inventories, as differences in temperature minimums and maximums in a garage vs. ambient will affect the mass of evaporative emissions generated for a given period. Under this task, ERG evaluated garage temperature correction factors provided by ARB in two ways; 1) a general "reasonableness" check on the algorithms used to estimate the garage temperatures relative to ambient temperatures, and 2) an analysis of the ARB garage correction factors for diurnal/resting loss based on the comparison of the Mower and Alternative models for evaporative temperature/RVP correction discussed in Section 2. Both evaluation methods are discussion below.

4.1 Reasonableness Check on Garage Temperature Correction

In general, the trend that the garage effect "dampens" the ambient diurnal reflects the expected trend. Assuming there is no heat gain from solar radiation, for example a garage under a shade tree the temperature inside a garage (with doors always closed) would have lower amplitude and be time-lagged with respect to the outside temperature. The maximum in-garage temperature would be lower than and would occur after the maximum ambient temperature. The minimum in-garage temperature would be higher than and would occur after the minimum ambient temperature. Also, the in-garage maximum minus minimum (delta temperature) would be smaller than the ambient maximum minus minimum.

If sun is beating down on the garage's roof or shining through windows, the in-garage temperatures will tend to increase with respect to the in-shade situation. If solar radiation is large enough, in-garage temperature can exceed ambient temperatures just as temperatures in a car parked in the sun can exceed ambient temperatures.

The first check of the proposed method would be to make sure that the maximum, minimum, and range expectations are satisfied. It appears that they are, as demonstrated by this example provided by ARB:

1. Ambient temperature = 65 to 82 F
2. Garage maximum temperature = 82 F x 0.97 = 79.5 F
3. Garage temperature difference = (82 -65 F) x 0.52 = 8.8 F
4. Garage minimum temperature = 79.5 F – 8.8 F = 70.7 F

5. Estimated garage temperature = 70.7 to 79.5 F

Step 2 guarantees that the in-garage maximum temperature is less than the maximum ambient temperature since the factor of 0.97 is less than 1. Step 3 guarantees that the in-garage diurnal range is less than the ambient diurnal range since the factor of 0.52 is less than 1. Together, Steps 2 and 3 guarantee that the in-garage minimum temperature is larger than the ambient minimum temperature since 0.52 + (1.00-0.97) is less than 1. These all reflect the expected trend for garage vs. ambient conditions.

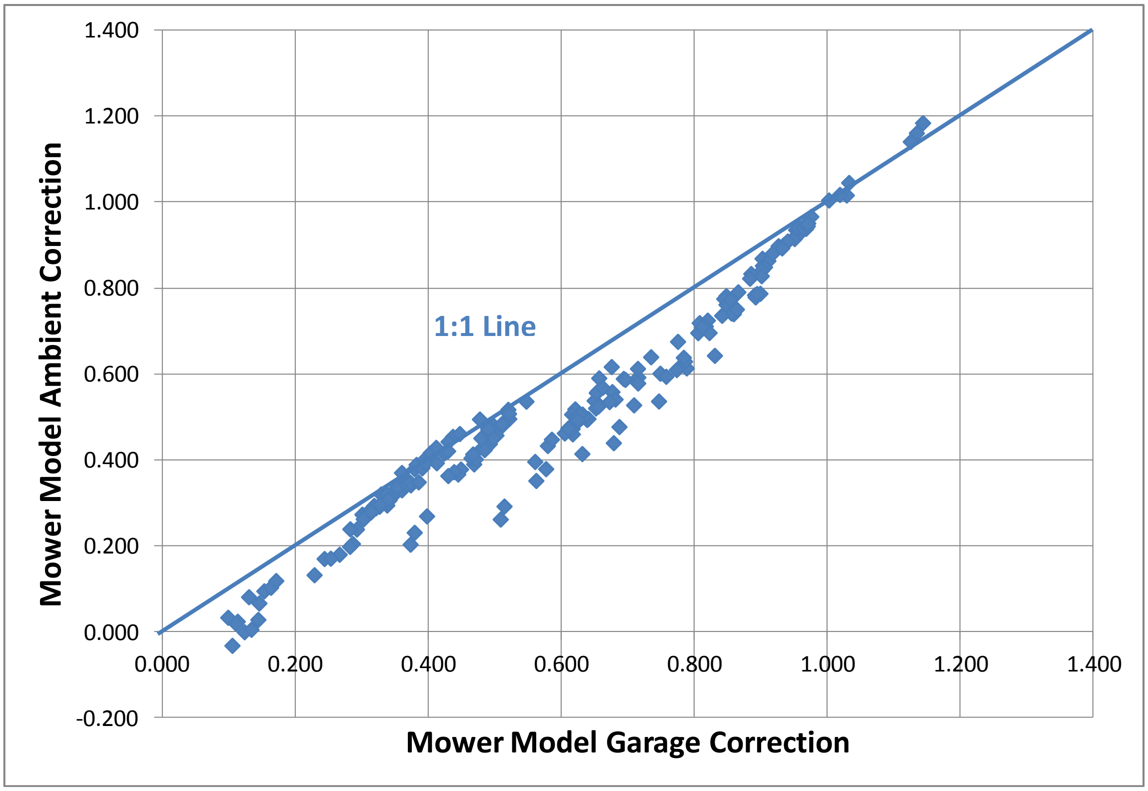
Though not evaluated under this task, further checks could examine extreme situations. For example, if the ambient temperature was constant, would the algorithm be reasonable? If the ambient temperature were constant at 82 F, the in-garage temperature would be calculated to be constant at 79.5 F. That is a little lower than the correct answer of 82 F, but it is not too far off. Additionally, the diurnal emissions for the calculated in-garage diurnal (79.5 F to 79.5 F) and the correct in-garage diurnal (82 F to 82 F) would be 0 grams in both cases.

A longer term approach could be to build some sort of heat transfer model such as the model used to calculate the diurnal temperatures in vehicle fuel tank as the results of ambient diurnal temperature changes. This would be a complex endeavor, however. There are many other factors (solar gain, garage door openings/closings, concrete vs. dirt floor, air infiltration, ceiling and wall insulation, windows vs. no windows) that could be considered, but for the purposes of diurnal emissions calculation the simpler approach taken by ARB is a reasonable approach.

4.2 Analysis of Temperature/RVP Corrections Applied to Garage Temperatures

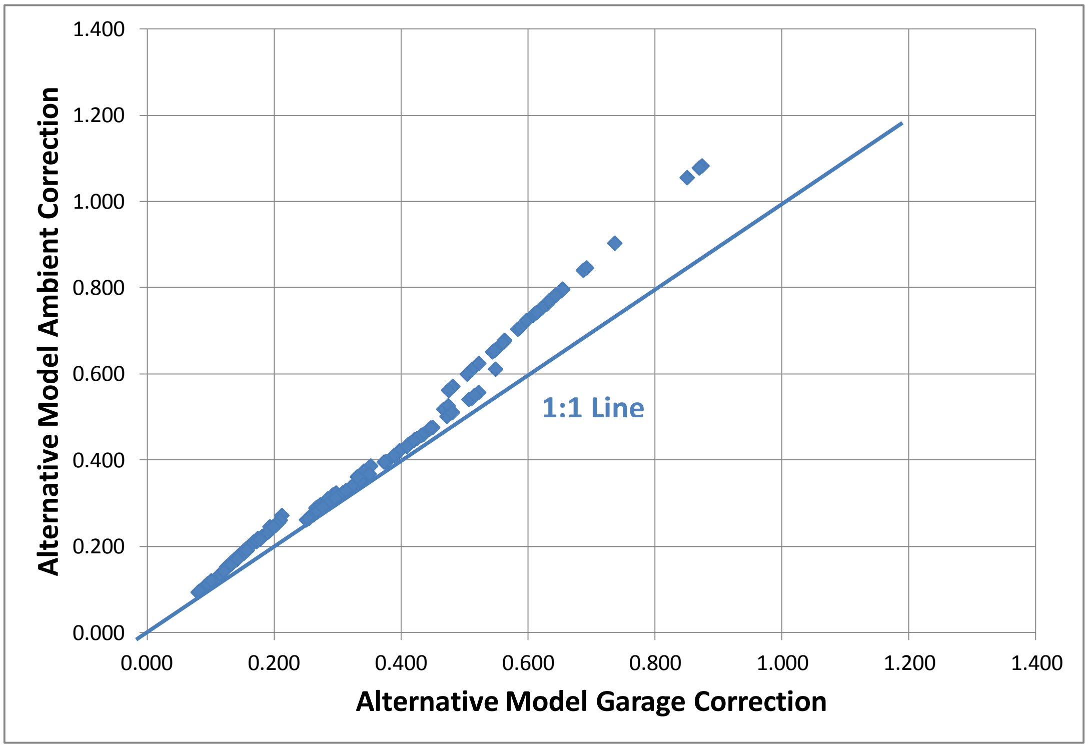
Based on ARB's garage temperature correction algorithm, ARB developed garage-corrected minimum and maximum temperatures by GAI and season, and estimated the evaporative temperature/RVP correction for the garage temperatures relative to a 65-105° baseline using the Mower model equation discussed under Section 2. Following from this work, ERG evaluated these garage temperature/RVP corrections against the Alternative model discussed in Section 2. The first step in this evaluation was to compare the temperature/RVP corrections produced by the Mower model using the ambient temperature min/max by GAI and season, with the corrections produced by the Mower model for the corresponding garage temperatures. This comparison is shown in Figure 8. As shown, ARB's garage corrections are generally higher than the ambient corrections, meaning that HC emissions would be projected to increase in the garage vs. outside; this is not an expected result given the dampening of the diurnal in a garage, discussed above. This is likely an unintended influence of the "initial temperature" term in the Mower model; because the garage has a higher initial temperature, the Mower model predicts a higher correction faction, which would result in higher emissions.

Figure 8. Mower model Temperature/RVP Corrections for Garage vs. Ambient



On a theoretical basis, however, we would expect that the lower temperature amplitude in a garage would lead to lower evaporative emissions compared to ambient temperatures. This is borne out by looking at garage vs. ambient corrections for the Alternative model, in Figure 9. Based on the evaluation of the Mower and Alternative models presented in Section 2, we believe that the Alternative model prediction of lower emissions in the garage vs. ambient is more consistent with the theoretical basis of evaporative emissions.

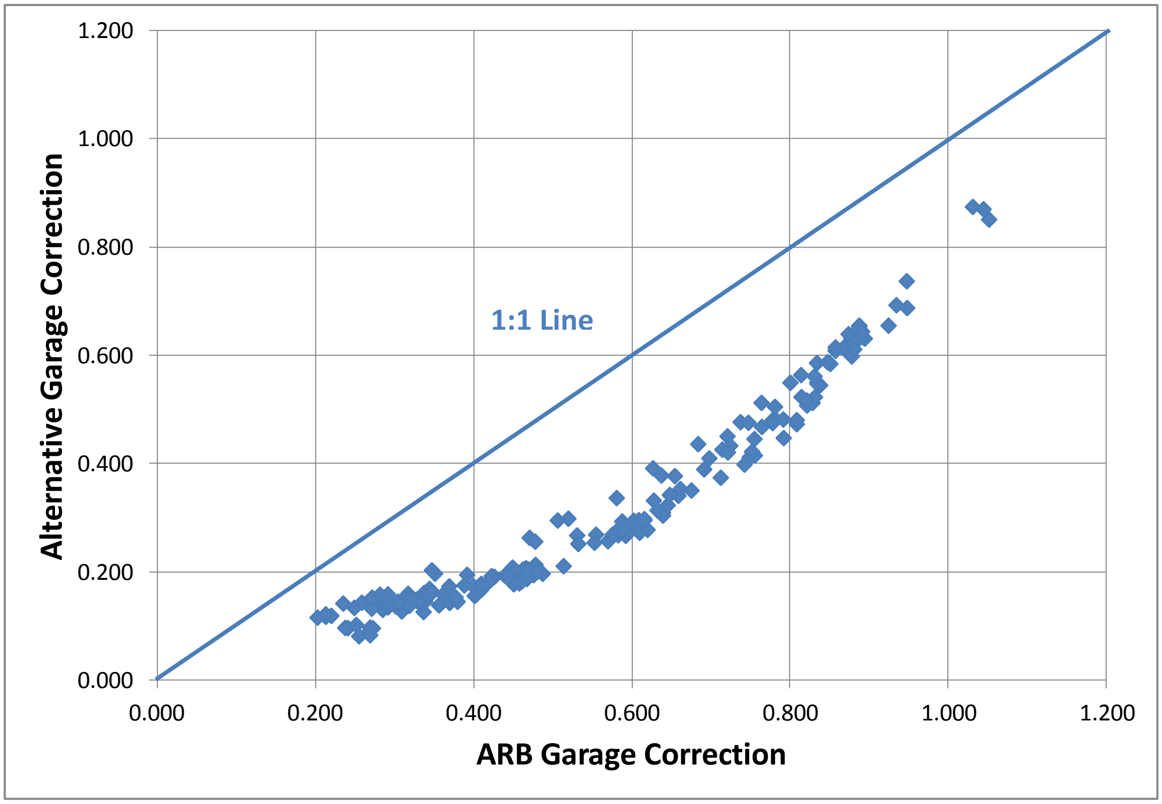
Figure 9. Alternative model Temperature/RVP Corrections for Garage vs. Ambient



4.3 Garage Temperature Correction Conclusions & Recommendations

Our check of the garage temperatures versus ambient suggests that the ARB approach for developing garage estimates is reasonable, but that the application of the Mower model for temperature corrections in the garage draws the erroneous conclusion that evaporative emissions will increase inside a garage. Taken in combination with the Mower model's overestimation of emissions for ambient conditions (Figure 4), the overestimation of garage emissions when using the Mower model-based corrections could be significant. To assess this combined effect, ERG plotted the garage temperature/RVP corrections using the Alternative model versus ARB's garage temperature corrections provided to ERG, by GAI and season; because ARB provided diurnal and resting loss corrections separately, ERG combined them using the 65/35 weighting ARB had developed previously. The result of this comparison is shown in Figure 10. As shown, the ARB garage corrections would result in much higher in-garage evaporative emissions compared to the Alternative model estimates, nearly double in some cases. As a result, ERG recommends the garage temperature/RVP corrections used for emission inventory development be updated to ones based on the Alternative model. While Figure 10 shows these corrections to daily emissions by GAI and season, application to the inventory will require corrections by the ARB emission processes categories of diurnal and resting loss, by GAI and season, across several calendar years. ERG has performed this calculation and delivered the results to ARB previously.[6] The process for calculating these correction factors is detailed in Appendix A.

Figure 10. Alternative model garage correction vs. ARB garage corrections



5.0 Acknowledgements

The authors gratefully acknowledge assistance from Sandeep Kishan of ERG, for general input and suggestions; Anita White of ERG, for report editing and formatting; and David Chou and Walter Wong of ARB for answering questions on ARB data and providing extensive review of model calculations and results.

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[6] Email correspondence from John Koupal, ERG to David Chou, ARB April 10th, 2013

Appendix A
Alternative Garage Corrections by Calendar Year, GAI and Season

ARB requested that ERG deliver garage temperature correction factors estimated by the Alternative model by Geographic Area of Interest (GAI) and season, for calendar years 1990 through 2050. ARB requested that these correction factors be estimated separately for diurnal and resting loss, for applicability to the current emission inventory approach. The resulting correction factors were delivered to ARB on 4/10/13; the method used to calculate them is described below. Appendix C contains the equations and an example calculation for the Alternative model.

The assumptions made in the development of the garage corrections are shown below:

Input	**Source**
Min temperature	Garage temperatures by GAI & season provided by ARB
Max temperature	Garage temperatures by GAI & season provided by ARB
RVP	RVPs by calendar year and season provided by ARB
Tank size	Estimated at 3.0 gallons per range from ARB Recreational Vehicle test program
Hose length & diameter	ATV assumptions from NONROAD model (Section 2, Table 8)

The RVP data provided by ARB varied from 1990 through 1995, but was constant from 1996 onward, so unique corrections were only needed for each year from 1990-1996, inclusive.

Using the equations and steps outlined in Appendix C, Alternative model corrections for the ARB processes of diurnal and resting loss were developed by allocating daily vapor and permeation emission predictions as follows:

- “Diurnal” = all vapor + 0.5 * permeation
- “Resting Loss” = 0.5* permeation

Corrections were then calculated as follows:

$$\textit{Diurnal Correction}_{\textit{GAI, Season, Calendar Year}}$$

$$= \textit{Diurnal Emissions}_{\textit{GAI, Season, Calendar Year}} \;/\; \textit{Diurnal Emissions}_{\textit{65-105, 7 RVP}}$$

$$\textit{Resting Loss Correction}_{\textit{GAI, Season, Calendar Year}}$$

$$= \textit{Resting Loss Emissions}_{\textit{GAI, Season, Calendar Year}} \;/\; \textit{Resting Loss Emissions}_{\textit{65-105, 7 RVP}}$$

Appendix B
Comparison of Alternative model gram/day predictions vs. ARB Recreational Vehicle Data

Figures B-1 and B-2 show the prediction of the Alternative model of the total daily evaporative HC emissions for all of the ATVs and OHMs tested by ARB, over the 72-96◦ 7 RVP condition. This comparison shows underprediction of the model on average, largely due to significant underprediction on a subset of vehicles; it is possible that fuel seepage or leaks are contributing to emission totals here, as well as carburetor losses.

Figure B-1. Daily Evap HC for ARB ATVs (grams/day)

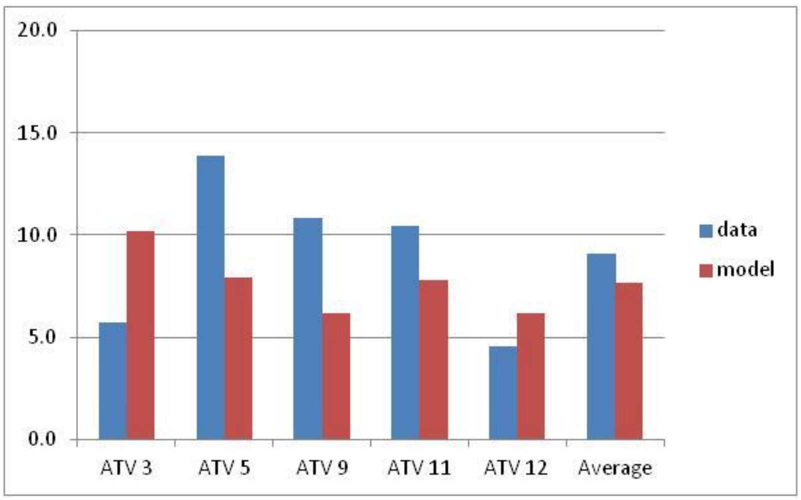
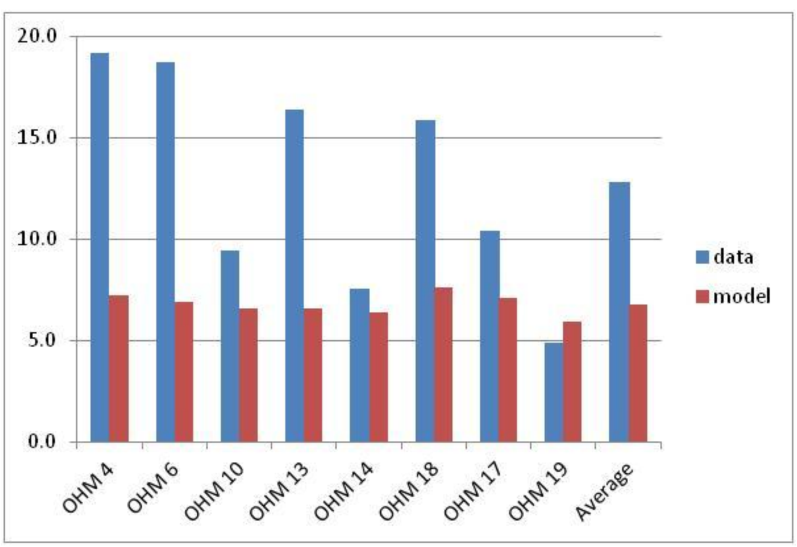


Figure B-2. Daily Evap HC for ARB OHMs (grams/day)



Appendix C
Alternative Model Equations & Example Calculation

Though the components of the Alternative model are presented in Section 2.2, the purpose of this section is to show a step-by-step example of how correction factors are calculated with the model. The example below shows how the correction factor for ATV3, from the ARB recreational vehicle dataset, was calculated.

Inputs:

	Baseline Scenario	***Correction Scenario***
Minimum Temperature	65	72
Maximum Temperature	105	96
RVP	7.0	7.0
Tank Size (gallons)	4.1	4.1

Vapor calculation:

Initial assumptions:

- Altitude = Sea level [Reddy equations provide coefficients for “Sea level” or “Denver”]
- Fuel = E10 [Reddy equations provide coefficients for E0 or E10]
- Tank fill = 50%

Step 1: Vapor generation rate (grams/gallon vapor space)

Reddy Equation: Vapor generated (g/gal vapor space) = $A\ e^{B(RVP)}\ (e^{CT_2} - e^{CT_1})$

This example, with Sea Level/E10 Coefficients:

Baseline Scenario = $0.00875e^{0.2056(7.0)}\ (e^{0.043(105)} - e^{0.043(65)})$ = **2.77 g/gal**

Correction Scenario = $0.00875e^{0.2056(7.0)}\ (e^{0.043(96)} - e^{0.043(72)})$ = **1.47 g/gal**

Step 2: Vapor emissions (g/gal * vapor space = grams/day)

Baseline Scenario = 2.77 g/gal * (4.1 gallons * 0.50) = **5.67 g/day**
Correction Scenario = 1.47 g/gal * (4.1 gallons * 0.50) = **3.02 g/day**

Tank permeation calculation:

Step 1: Tank surface area (m^2)

NONROAD equation: Surface area (m^2) = 0.15*SQRT((((Tank size+2)^2)/4)-1)

This example = 0.15*SQRT((((4.1+2)^2)/4)-1) = **0.43 m^2**

Step 2: Temperature correction

Daily temperature corrections were calculated by taking the average of calculated correction at the daily minimum and maximum temperatures. This was a simplification to allow daily application of the model.

NONROAD equation: Correction relative to 84 ◦F = $0.03788519e^{(0.03850818*T)}$

This example:

Baseline Scenario = AVG($0.03788519e^{(0.03850818*65)}$, $0.03788519e^{(0.03850818*105)}$) = **1.31**
Correction Scenario = AVG($0.03788519e^{(0.03850818*72)}$, $0.03788519e^{(0.03850818*96)}$) = **1.07**

Step 3: Tank permeation emissions (Surface area * Base EF * Temp correction = grams/day)

NONROAD Base Emission Factor (E10 @ 84 ◦F): 10.7 $g/m^2/day$

Baseline Scenario = 0.43 * 10.7 * 1.31 = **6.07 g/day**
Correction Scenario = 0.43 * 10.7 * 1.07 = **4.93 g/day**

<u>Hose permeation calculation:</u>

Step 1: Hose surface area (m^2)

NONROAD equation: Surface area (m^2) = π * Hose Length * Hose Diameter

NONROAD Hose Length for ATVs (SCC 2260001030): 0.305 m
NONROAD Hose Diameter for ATVs (SCC 2260001030): 0.00635 m

This example = π * 0.305 * 0.00635 = **0.00609 m^2**

Step 2: Temperature correction

Daily temperature corrections were calculated by taking the average of calculated correction at the daily minimum and maximum temperatures. This was a simplification to allow daily application of the model.

NONROAD equation: Correction relative to 73 ◦F = $0.06013899e^{(0.03850818*T)}$

This example:

Baseline Scenario = AVG($0.06013899e^{(0.03850818*65)}$, $0.06013899e^{(0.03850818*105)}$) = **2.08**
Correction Scenario = AVG($0.06013899e^{(0.03850818*72)}$, $0.06013899e^{(0.03850818*96)}$) = **1.69**

Step 3: Hose permeation emissions (Surface area * Base EF * Temp correction = grams/day)

NONROAD Base Emission Factor (E10 @ 73 ◦F): 222 $g/m^2/day$

Baseline Scenario = 0.00609 * 222 * 2.08 = **2.81 g/day**
Correction Scenario = 0.00609 * 222 * 1.69 = **2.29 g/day**

<u>Total emissions:</u>

	Baseline Scenario	***Correction Scenario***
Vapor (g/day)	5.67	3.02
Tank Permeation (g/day)	6.07	4.93
Hose Permeation (g/day)	2.81	2.29
Total predicted (g/day)	**14.55**	**10.24**
Correction from Baseline		***0.70***
Actual data (g/day)	**8.27**	**5.73**
Correction from Baseline		***0.69***

As shown in Appendix B, ATV3 is the only vehicle in the ARB recreational vehicle dataset that the Alternative model overpredicts gram/day emissions for.