Appendix K
Development of Evaporative Emissions Models

A. Evaporative THC Models

The bases for the development of the staff's evaporative emissions models are ARB's motor vehicle emissions model (EMFAC7G) and the U.S. EPA's running loss evaporative emission model contained in the federal reformulated gasoline regulations. EMFAC7G was used to develop a functional relationship between diurnal/resting loss and hot soak emissions and RVP, while the EPA running loss model was the basis for the development of the ARB running loss model.

1. Diurnal/Resting Loss and Hot Soak Models

The ARB's EMFAC7G model contains "adjustment" factors that allow the estimation of evaporative emissions as a function of RVP. The equations which form the basis of these adjustment factors can be found in The Air Resources Board's Methodology for Estimating Emissions from On-Road Motor Vehicles, Volume VI: Compilation of Equations Used in the EMFAC, Weight, and Burden Models, November 1996. The starting point in the development of the staff's evaporative emissions models was to run the EMFAC7G program for the year 2005 at various RVPs and record the estimated emissions. The results of these runs are shown in the table below.

Table 1
EMFAC7G Statewide Year 2005
Diurnal/Resting Loss and Hot Soak Emissions Estimates

RVP (psi)	Diurnal and Resting Loss		Hot Soak	
	Tons Per Day TOG	Ratio Relative to 6.9	Tons Per Day TOG	Ratio Relative to 6.9
6.5	58.24	0.9105	41.52	0.8208
6.8	62.48	0.9768	48.22	0.9532
6.9	63.96	1.0000	50.59	1.0000
7.0	65.48	1.0237	53.02	1.0481
7.5	73.62	1.1510	66.09	1.3064
8.0	82.78	1.2942	80.40	1.5894

Table 1 also shows the ratio of emissions at RVPs other than 6.9 to emissions at an RVP of 6.9. This statistic was calculated because it was the staff's objective to have a model which predicts the percent change in emissions as a function of RVP. After applying a logarithmic transformation, the ratio was then regressed against RVP (in the case of diurnal/resting losses) and RVP and RVP squared (in the case of hot soak

emissions). The results of these regressions (after converting from a ratio to a percent change) are shown below:

Diurnal/Resting Loss (% Change) = 100*exp(-1.6175913018 + 0.234433522*RVP) - 100
Hot Soak (% Change) = 100*exp(-5.57770591578 + (1.14227006*RVP) - (0.048392302*RVP^2) –100

These models have essentially a perfect fit (R-squared = 1.0) to the data due to the fact that the functional form of the regressions is essentially the same as the functional form of the equations that are used in EMFAC7G to calculate RVP adjustment factors. The above regressions are the staff's final evaporative emissions models for diurnal/resting loss and hot soak evaporative emissions.

2. Running Loss Emissions

EMFAC7G does not contain RVP adjustment factors and therefore does not have the capability of estimating evaporative running losses at different RVPs. Therefore, the staff decided to use the running loss model developed by the U.S EPA and contained in the federal reformulated gasoline regulations. This model is as follows:

Evaporative Running Loss (g/mi) = 0.017768*RVP^2 – 0.18746*RVP + 0.6146

The staff normalized the predictions made by the EPA model by dividing the model predictions by the prediction made at 6.9 RVP. This prediction was then converted to a predicted percent change relative to 6.9 RVP. The resultant model after this normalization and conversion is as follows:

Evaporative Running Losses (% Change) = 10.636*RVP^2 – 112.211*RVP + 267.87594

This is the staff's final model for estimating the change in running loss emissions as a function of RVP.

B. Evaporative Benzene Models

Evaporative benzene emissions are computed by multiplying two model predictions. The first model prediction is the predicted evaporative hydrocarbon emissions (in units of grams per mile). The second model prediction is the benzene fraction of the total hydrocarbons. This can be stated as follows:

Evap. Benzene (g/mi) = Evap THC (g/mi) * (Benzene/THC)

Individual models were developed for estimating evaporative THC emissions and the benzene fraction. The multiplication of the model predictions is done separately for each of the three evaporative emissions processes.

1. Evaporative THC (gram per mile) Models

Because the evaporative THC emissions models shown above in Sections A.1) and A.2) were in terms of the predicted percent change in emissions, instead of grams per mile, they cannot by used in the form presented above. However, it is easy to develop similar equations in terms of grams per mile by performing the same regressions on the grams per mile numbers instead of the ratios of the tons per day numbers. The average grams per mile emission estimates from EMFAC7G are show in the table below.

Table 2
EMFAC7G Average Evaporative Emissions (g/mi)

RVP	Diurnal/Resting	Hot Soak	Running[1]
6.5	0.06203	0.04422	0.09377
6.8	0.06654	0.05136	0.10313
6.9	0.06812	0.05388	0.10671
7.0	0.06973	0.05647	0.11051
7.5	0.07841	0.07039	0.13292
8.0	0.08816	0.08563	0.16101

1 - Running Loss estimates at RVPs other than 7.0 made using percent change predictions from the EPA running loss model

Performing the same regressions as discussed in Section A.1) and A.2) on the grams per mile numbers results in the following models.

Diurnal/Resting Loss THC Emisisons (g/mi) = exp(-4.304062385 + 0.234434005*RVP)
Hot Soak THC Emissions (g/mi) = exp(-8.498652909 + 1.142251184*RVP – 0.048390975*RVP^2)
Running Loss THC Emissions (g/mi) = 0.3925594957 – 0.1197399622*RVP + 0.0113496110*RVP^2

These are the final gram per mile evaporative hydrocarbon emission models that are used in the estimation of evaporative benzene emissions. It should be noted that these models could also be used to estimate the percent change in evaporative THC emissions as a function of RVP instead of the models shown in Sections A.1) and A.2), since they give identical (within roundoff error) percent changes. However, the percent change models shown in Sections A.1) and A.2) were developed and used to estimate percent changes in evaporative THC emissions because it was thought desirable to have models which predicted percent changes instead of grams per mile.

2. Evaporative Benzene Fraction Models

The evaporative benzene fraction models were developed from the data in the staff's data base which contained speciated evaporative emissions data. Regressions between emissions benzene fraction and fuel benzene content, fuel RVP, and fuel MTBE content were developed for each of the three evaporative benzene processes. RVP and MTBE content were included because some previous research has indicated that these

properties influence the benzene content of a gasoline vapor space. The functional form of the regressions for each of the processes was the following:

Benzene fraction = a*fuel benzene content*(1+b*RVP + c*MTBE content)

Where:
a, b, and c are constants which are estimated from the regression
BENZ is the fuel benzene content, in volume percent
RVP is the gasoline RVP, in psi, and
MTBE is the gasoline MTBE content, in volume percent

This functional form corresponds to the form used by the EPA in the federal reformulated gasoline regulations and gives the expected prediction of a zero benzene fraction for a zero percent benzene fuel. The results of the regressions are shown below.

Diurnal/Resting Benzene Fraction = 0.0294917804*BENZ – 0.0017567009*BENZ*RVP
Hot Soak Benzene Fraction = 0.0463141591*BENZ – 0.0027179513*BENZ*RVP - 0.0001435812*BENZ*fuel MTBE
Running Loss Benzene Fraction = 0.0648391842*BENZ – 0.005622979*BENZ*RVP

The term containing the fuel MTBE content is included in the Hot Soak model only because this term was found to have a very small coefficient in the other two models and not significant at a high level of statistical significance. The above equations are the final benzene fraction models.

C. Combination of Evaporative Benzene Model Predictions with Exhaust Toxics

The predictions from the evaporative benzene models are added to the potency-weighted predictions from the exhaust toxics model. However, some adjustments are made to the evaporative benzene model predictions before these additions are made. First, the evaporative benzene model predictions are multiplied by 1000 to convert from grams per mile to milligrams per mile. This is necessary because the exhaust toxics model predictions are in milligrams per mile. Second, the evaporative benzene emissions predictions are multiplied by the relative potency for benzene, which is 0.17.

Finally, the evaporative benzene model predictions have to be multiplied by a scaling factor constant before they can be added to the potency-weighted exhaust toxics model predictions. This is necessary because the evaporative benzene model and the exhaust toxics models are developed from different databases. The scaling factor puts the emissions predictions on a common scale, in this case putting the evaporative benzene predictions on the same scale as the exhaust toxics predictions. The evaporative benzene model is developed using the EMFAC7G model, while the exhaust toxics models are developed from the same database used in developing the exhaust THC and NOx models (albeit with fewer data points for the toxics). The cars in the database used to develop the exhaust models have lower emissions (on average) than those in the EMFAC7G model. There are a number of reasons for this, but the primary reason is that the cars in data base used to develop the exhaust toxics models are generally later model-year cars and cars with properly functioning emissions control systems, while the EMFAC7G model, in attempting to model the California vehicle fleet, includes older model-year vehicles and vehicles with malfunctioning emissions control systems. The scaling multiplier converts

the evaporative benzene predictions made in the EMFAC7G scale to the exhaust toxics model database scale.

The scaling factor multiplier that was used was the ratio of the average exhaust THC emissions level in the database used to develop the exhaust toxics models to the average THC emissions level in the EMFAC7G model. The average exhaust THC emissions level in the exhaust toxics model data base was 0.275 gram per mile, while the average exhaust THC emissions level in the EMFAC7G model was 0.609 gram per mile. The scaling factor multiplier is the ratio of these two numbers, which is 0.452. After being multiplied by 0.452, the evaporative benzene model predictions are added to the exhaust toxics model predictions. The combination of the evaporative benzene model predictions with the exhaust toxics model predictions can be summarized mathematically as follows:

Total Toxics = Exhaust Toxics + Evaporative Benzene, where :

$$\begin{aligned}\text{Exhaust Toxics} = {} & W_{\text{Tech 3}}*(PW_{\text{Benz}}*P_{\text{Benz Tech 3}} + PW_{\text{Buta}}*P_{\text{Buta Tech 3}} + PW_{\text{Form}}*P_{\text{Form Tech 3}} + PW_{\text{Acet}}*P_{\text{Acet Tech 3}}) \\ & + W_{\text{Tech 4}}*(PW_{\text{Benz}}*P_{\text{Benz Tech 4}} + PW_{\text{Buta}}*P_{\text{Buta Tech 4}} + PW_{\text{Form}}*P_{\text{Form Tech 4}} + PW_{\text{Acet}}*P_{\text{Acet Tech 4}}) \\ & + W_{\text{Tech 5}}*(PW_{\text{Benz}}*P_{\text{Benz Tech 5}} + PW_{\text{Buta}}*P_{\text{Buta Tech 5}} + PW_{\text{Form}}*P_{\text{Form Tech 5}} + PW_{\text{Acet}}*P_{\text{Acet Tech 5}})\end{aligned}$$

$$\begin{aligned}\text{Evaporative Benzene} = {} & 1000*PW_{\text{Benz}}*0.452*((P_{\text{THC Diur/Rest}}*F_{\text{Benz Diur/Rest}}) + (P_{\text{THC Hot Soak}}*F_{\text{Benz Hot Soak}}) + \\ & (P_{\text{THC Running}}*F_{\text{Benz Running}})),\ \text{where:}\end{aligned}$$

the W's are the Tech group weights for exhaust emissions,
the PW's are the Potency Weights,
the P's are the exhaust toxics and evap THC model predictions, and
the F's are the evap benzene fraction model predictions.