Speciation Profiles and Toxic Emission Factors for Nonroad Engines in MOVES3

United States Environmental Protection Agency

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Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

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1 Introduction

MOVES2014a was the first version of MOVES to include estimates of volatile organic compounds (VOCs) and toxics from nonroad equipment.[1] For the most part, the data and report here are unchanged from MOVES2014a[1], however, this report has been updated to reflect the toxics and speciation data updates made to MOVES2014b (as summarized in Section 1.3).

This document details the research and development behind MOVES2014b's estimates of speciation profiles and air toxic emissions for nonroad engines and equipment run on conventional gasoline without ethanol (E0) and gasoline blended with 10 percent ethanol (E10), as well as diesel fuel, compressed natural gas (CNG), and liquefied petroleum gas (LPG).

The research and development described in this document remain valid for MOVES3, although we updated the post-processing script for nonroad emissions for MOVES3.0.4 (see Appendix D.3).

MOVES uses the same datasets used to develop speciation profiles and toxic emission rates to develop estimates of organic gas emissions for a number of different aggregations. These aggregations vary based on measurement method, and presence or absence of methane, ethane, alcohols and aldehydes. The aggregations are defined as follows:

Total Hydrocarbons (THC): "THC is the measured hydrocarbon emissions using a Flame Ionization Detector (FID) calibrated with propane. The FID is assumed to respond to all hydrocarbons identically as it responds to propane in determining the concentration of carbon atoms in a gas sample. Most hydrocarbons respond nearly identically as propane with notable exceptions being oxygenated hydrocarbons such as alcohols and aldehydes commonly found in engine exhaust."[2] That is because THC measurements do not respond fully to carbon-oxygen bonds in oxygenated compounds, such as aldehydes, alcohols, and ketones.

Total Organic Gases (TOG): hydrocarbon emissions plus oxygenated hydrocarbons such as alcohols and aldehydes.[1] TOG is measured using gas and liquid chromatography methods.

Volatile Organic Compounds (VOC): TOG emissions minus those hydrocarbons that contribute little to ozone formation, such as methane, ethane, and acetone.[1].

Non-Methane Hydrocarbons (NMHC): NMHC = THC – CH_4 (methane).

Non-Methane Organic Gases (NMOG): NMOG = TOG – CH_4 (methane).

1.1 Air Toxics in MOVES

The air toxics included in MOVES are classified into four categories:

Volatile Organic Compounds (VOC): EPA defines VOC as any compound of carbon-- excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate--which participates in atmospheric photochemical reactions, except those designated by EPA as having negligible photochemical reactivity.[3]

Polycyclic aromatic hydrocarbons (PAHs): This category is defined as hydrocarbons containing fused aromatic rings. These compounds can be measured in the gaseous phase, particulate phase, or both, depending on properties of the compound, particle characteristics and conditions in the exhaust stream or the atmosphere. Currently, we use two separate sets of partitioning factors (one based on onroad diesel engine testing, and the other based on onroad gasoline testing) that represent the conditions under which the PAHs were measured.

Dioxins and furans: This category includes polychlorinated organic compounds which are persistent in the environment and considered bio accumulative in aquatic and terrestrial food chains.

Metals: This category includes metals or metal-containing compounds in elemental, gaseous and particulate phases.

Specific compounds in each category are listed in Table 1-1 through Table 1-4 and are identical to the compounds modeled for highway vehicles. Note that each compound is identified by its "pollutantID" in the MOVES database. Each compound is also identified by its Chemical Abstracts Service Registry number (CAS number).

Table 1-1.Hydrocarbons and Volatile Organic Compounds Included in MOVES

Pollutant	pollutantID	CAS Number
Benzene	20	71-43-2
Ethanol	21	64-17-5
1,3-Butadiene	24	106-99-0
Formaldehyde	25	50-00-0
Acetaldehyde	26	75-07-0
Acrolein	27	107-02-8
2,2,4-Trimethylpentane	40	540-84-1
Ethyl Benzene	41	100-41-4
Hexane	42	110-54-3
Propionaldehyde	43	123-38-6
Styrene	44	100-42-5
Toluene	45	108-88-3
Xylene(s)[a]	46	1330-20-7

Note:

[a] This species represents the sum of emissions from three isomers of xylene, i.e., *ortho*-, *meta*-, and *para*-xylene.

Table 1-2. Polycyclic Aromatic Hydrocarbons Included in MOVES

Pollutant	pollutantID		CAS Number
	(gaseous phase)	(particulate phase)	
Acenaphthene	170	70	83-32-9
Acenaphthylene	171	71	208-96-8
Anthracene	172	72	120-12-7
Benz(*a*)anthracene	173	73	56-55-3
Benzo(*a*)pyrene	174	74	50-32-8
Benzo(*b*)fluoranthene	175	75	205-99-2
Benzo(*g*,*h*,*i*)perylene	176	76	191-24-2
Benzo(*k*)fluoranthene	177	77	207-08-9
Chrysene	178	78	218-01-9
Dibenzo(*a*,*h*)anthracene	168	68	53-70-3
Fluoranthene	169	69	206-44-0
Fluorene	181	81	86-73-7
Indeno(1,2,3,*c*,*d*)pyrene	182	82	193-39-5
Naphthalene	185	23	91-20-3
Phenanthrene	183	83	85-01-8
Pyrene	184	84	129-00-0

Table 1-3. Dioxins and Furans Included in MOVES

Pollutant	pollutantID	CAS Number
2,3,7,8-Tetrachlorodibenzo-p-Dioxin	142	1746-01-6
1,2,3,7,8-Pentachlorodibenzo-p-Dioxin	135	40321-76-4
1,2,3,4,7,8-Hexachlorodibenzo-p-Dioxin	134	39227-28-6
1,2,3,6,7,8-Hexachlorodibenzo-p-Dioxin	141	57653-85-7
1,2,3,7,8,9-Hexachlorodibenzo-p-Dioxin	130	19408-74-3
1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	132	35822-46-9
Octachlorodibenzo-p-dioxin	131	3268-87-9
2,3,7,8-Tetrachlorodibenzofuran	136	51207-31-9
1,2,3,4,6,7,8-Heptachlorodibenzofuran	144	67562-39-4
1,2,3,4,7,8,9-Heptachlorodibenzofuran	137	55673-89-7
1,2,3,4,7,8-Hexachlorodibenzofuran	145	70648-26-9
1,2,3,6,7,8-Hexachlorodibenzofuran	140	57117-44-9
1,2,3,7,8,9-Hexachlorodibenzofuran	146	72918-21-9
1,2,3,7,8-Pentachlorodibenzofuran	139	57117-41-6
2,3,4,6,7,8-Hexachlorodibenzofuran	143	60851-34-5
2,3,4,7,8-Pentachlorodibenzofuran	138	57117-31-4
Octachlorodibenzofuran	133	39001-02-0

Table 1-4. Metals Included in MOVES

Pollutant	pollutantID	CAS Number
Mercury (elemental gaseous)	60	7439-97-6
Mercury (divalent gaseous)	61	7439-97-6
Mercury (particulate)	62	7439-97-6
Arsenic compounds	63	7440-38-2 (metal)
Chromium (Cr6+)	65	18540-29-9
Manganese compounds	66	7439-96-5 (metal)
Nickel compounds	67	7440-02-0 (metal)

1.2 Speciation

In addition to estimating emissions of pollutants that are discrete chemical compounds, such as carbon monoxide (CO) and sulfur dioxide (SO2), MOVES produces emission rates for aggregates of individual chemical compounds, including total hydrocarbons (THC), volatile organic compounds (VOC), total organic gases (TOG) and particulate matter (PM). Organic gas aggregations are described in the introduction, above. Particulate matter is operationally defined as the measured mass collected on a filter using EPA-defined sampling filter media, conditions, and practices. $PM_{2.5}$ refers to particulate matter emissions collected downstream of a cyclone that removes the particles with aerodynamic diameter greater than 2.5 microns, while PM_{10} refers to particulate matter emissions with aerodynamic diameter less than 10 microns.

The process of apportioning aggregate TOG and $PM_{2.5}$ into sets of separate components is called "speciation". For nonroad, toxics speciation is estimated in the nonroad portion of MOVES. However, detailed TOG speciation (including the calculation of chemical mechanism species[a]) and speciation of $PM_{2.5}$ are conducted as part of post-processing of MOVES nonroad results with EPA's Sparse Matrix Operator Kernel Emissions processor (SMOKE)[4] The nonroad emission output from MOVES can be distinguished by engine type, engine technology, engine size, fuel and fuel sub-type, and emission processes--the same factors used to categorize TOG and PM speciation profiles stored in EPA's database SPECIATE. Thus, post-processing scripts can map the MOVES nonroad output to the SPECIATE profiles without any loss of information. The assignment of nonroad TOG emissions to SPECIATE profiles is documented here in Table A4-13 in Appendix A. The assignment of PM profiles is documented in Appendix C. SMOKE uses these profiles to speciate both TOG and $PM_{2.5.}$ Further details on speciation for air quality modeling are described in Appendix D.

1.3 Data and Methods

Exhaust emissions data from two test programs conducted by Southwest Research Institute (SwRI), under contracts from EPA, were used to create VOC speciation profiles and gaseous toxic emission fractions for nonroad spark-ignition (SI) engines[5] and nonroad compression ignition (CI) engines.[6,7] The test programs and derivation of these speciation profiles are explained further in Appendix A and in the literature.[8] Data from the CI test programs were also used to develop PAH emission fractions. Data from the SI engine test program provided the basis for profiles of uncontrolled 2-stroke and 4-stroke engines operating on gasoline (E0) and gasoline containing 10 percent ethanol by volume (E10). Data from the CI engine test programs provided the basis for profiles of pre-Tier 1, Tier 1, and Tier 2 engines at various power levels.

In MOVES2014b, we created new engine technology classes to distinguish Tier 4 engines with different aftertreatment configurations, including use of diesel particulate filters (DPFs) and selective catalytic reduction (SCR) systems. In conjunction, we incorporated new speciation and toxic data from on-highway diesel engines equipped with diesel particulate filters and selective catalytic reduction systems from Phase 2 of the Advanced Collaborative Emissions Study

[a] To make the chemistry of air quality models computationally feasible, the thousands of actual chemical species are mapped to a relatively few "chemical mechanism" species.

(ACES)[20]. Moreover, nonroad diesel emission factors were corrected for hexavalent chromium. Details on these changes are provided in Section 3.

Where data on nonroad emissions were absent, nonroad emission factors were derived from onroad vehicles. Onroad emission factors were used as surrogates for nonroad gasoline engine emissions of PAHs, metals, and dioxins/furans. Furthermore, highway diesel engine emission factors were used as surrogates for VOCs, PAHs and metals from Tier 4 engines with DPF but no SCR and Tier 4 with both DPF and SCR. Dioxin/furan emission rates for large (≥56kW) Tier 4 diesel engines are also estimated from onroad surrogates. Finally, all air toxics from CNG and LPG nonroad engines are estimated from onroad surrogates. For detailed information on the data and derivation of emission factors for onroad vehicles, please refer to the Air Toxic Emissions from Onroad Vehicles in MOVES2014 (referred to in this document as the "onroad air toxics report").[9]

It is important to note that emissions factors for nonroad engines and equipment are based on composites of running and cold start emissions, and currently, there are not separate emission factors for idling, start, or hot-stabilized running emissions. In highway vehicles, emission factors vary substantially between these modes. It should also be mentioned that toxic fractions are mass-based (as opposed to using molar-ratios) and inputs used to estimate emissions of toxics do not vary by temperature. In addition, data from a limited number of equipment types were applied to other equipment types with the same engine technology type (i.e. 2-stroke SI, 4-stroke SI). For example, data collected on lawn and garden equipment with 4-stroke engines were applied to 4-stroke recreational vehicles. Differences in operating characteristics could affect the composition of the emissions.

2 Gasoline Exhaust

2.1 Organic Gas Aggregations and Air Toxic Emission Factors

A single nonroad spark-ignition test program[5] (further described in Appendix A) was used to develop exhaust emission factors for organic gases according to engine type (2-stroke or 4-stroke) and fuel subtype (E0 or E10). The choice of 2-stroke or 4-stroke technology and the choice of gasoline ethanol level are generally the most important factors influencing nonroad gasoline engine speciated emissions, and thus, all nonroad gasoline engines were assigned volatile organic compound (VOC) profiles according to stroke and fuel subtype. The presence of a three-way catalyst also influences emissions[10b]; however, as described in Appendix A, the limited data for catalyst-equipped engines from 2-strokes had many inconsistencies which rendered the data unusable.

In the MOVES model, individual VOC fractions are multiplied by total VOC emissions to obtain emission factors. Total VOC was derived from NMHC by first calculating NMOG according to 40 CFR §1066.635) [11] as defined in Equation 1.

[b] For MY 2011, 54 percent of the small 2-cycle SI nonroad engines in EPA's certification database are equipped with aftertreatment, with 28 percent of the small 4-cycle SI nonroad engines certified with aftertreatment. In MY 2015, 57 percent of the small 2-cycle SI nonroad engines include aftertreatment, with 23 percent of the small 4-cycle SI nonroad engines reporting aftertreatment. These numbers only reflect the percentage of engines certified for sale in the US, and may not reflect the percentage of engines sold with aftertreatment[10].

$$m_{NMOG} = m_{NMHC} + m_{oxygenates} - \rho_{NMHC} \cdot \sum_{i=1}^{N} \frac{m_{oxygenate_i}}{\rho_{oxygenate_i}} \cdot FID_{RF_i} \quad \textbf{Equation 1}$$

Where:
m_{NMHC} = the mass of NMHC in the exhaust
m_{NMOG} = the mass of NMOG in the exhaust
$m_{oxygenates}$ = the mass of formaldehyde and acetaldehyde (from Table A4-3)
ρ_{NMHC} = the effective C_1-equivalent density of NMHC, calculated using a C:H ratio of 1:2.64
$m_{oxygenate\ i}$ = the mass of oxygenated species *i* in the exhaust (from Table A4-3)
$\rho_{oxygenate\ i}$ = the C_1-equivalent density of oxygenated species *i*

From NMOG, TOG can be obtained by the addition of methane. VOCs are obtained from NMOG by the removal of ethane and acetone as defined in Equation 2.

$$VOC = NMOG - ethane - acetone \quad \textbf{Equation 2}$$

Table 2-1 lists aggregate species (or groups of chemical compounds defined operationally or for modeling purposes) including THC, NMHC, NMOG, TOG and VOC, and also includes ratios used to derive NMOG, VOC and methane from THC and NMHC. NMHC was derived from the THC and methane emissions, NMOG was derived from Equation 1, VOC from Equation 2, and TOG as the sum of NMOG + methane. NMOG/NMHC and VOC/NMHC factors derived from these values are also presented in Table 2-1.

Table 2-1. Organic Gas Aggregations Estimated from THC for Nonroad Gasoline Engines

Engine Technology	**2-stroke**	**2-stroke**	**4-stroke**	**4-stroke**
Fuel sub-type	**E0**	**E10**	**E0**	**E10**
Mass units[a]	***mg/mi***	***mg/mi***	***mg/hp-hr***	***mg/hp-hr***
THC	36,235	31,510	6,667	5,855
NMHC	35,491	30,875	5,622	4,981
NMOG	35,687	32,733	5,774	5,232
TOG	36,432	33,368	6,819	6,107
VOC	35,586	32,631	5,692	5,156
CH4	744	635	1,045	874
NMOG/NMHC	1.006	1.060	1.027	1.051
CH4/THC	0.021	0.020	0.157	0.149
VOC/NMHC	1.003	1.057	1.012	1.035

Note:
[a] 2-stroke engines were measured on a transient test cycle and 4-stroke engines were measured on a steady-state cycle, per Appendix A.

Emission factors for individual VOC are reported as the fraction of the individual species divided by total VOCs (Table 2-2). The remaining VOC species have been integrated into the term NONHAPTOG which is listed at the bottom of Table 2-2. NONHAPTOG is also referred to as residual total organic gas (TOG), and refers to the TOG minus the specific organic gas species

that MOVES estimates. More discussion of the use of NONHAPTOG is included in the onroad speciation report.[27]

Table 2-2. Nonroad Gasoline Toxic Fractions for VOC

Pollutant	E0 4 stroke	E0 2 stroke	E10 4 stroke	E10 2 stroke
1,3-Butadiene	0.01280	0.00214	0.01240	0.00272
2,2,4-Trimethylpentane	0.04610	0.08110	0.05720	0.13000
Acetaldehyde	0.00425	0.00103	0.00897	0.00336
Acrolein	0.00037	0.00031	0.00045	0.00044
Benzene	0.06940	0.01390	0.04590	0.01260
Ethanol	0.00172	0.00058	0.03030	0.07810
Ethyl Benzene	0.02200	0.03440	0.01670	0.02230
Formaldehyde	0.01980	0.00368	0.01760	0.00498
Hexane	0.00233	0.00772	0.00520	0.00715
m-& p-Xylene	0.04400	0.06440	0.05460	0.05390
o-Xylene	0.01460	0.02320	0.01530	0.01860
Propionaldehyde	0.00049	0.00051	0.00041	0.00052
Styrene	0.00976	0.00223	0.00715	0.00177
Toluene	0.08640	0.08640	0.07770	0.07770
NONHAPTOG	0.66600	0.67800	0.65000	0.58600

2.2 Polycyclic Aromatic Hydrocarbons

Emissions of PAH in the gaseous and particulate phases were estimated as fractions of total VOC and $PM_{2.5}$, respectively (Equation 3 and Equation 4). PAH emission factors for nonroad gasoline engines were adapted from onroad gasoline engine data (described in the onroad air toxics report[9]), due to unavailability of data for nonroad engines, assuming the same partitioning between gas and particle as onroad gasoline (Table 2-3). Since the nonroad portion of MOVES does not produce speciated $PM_{2.5}$ measurements (in particular, it does not estimate the carbon fraction of $PM_{2.5}$), the nonroad PAH emissions are estimated from total $PM_{2.5}$ emissions as opposed to the $OC_{2.5}$[c] used for onroad emissions. The onroad gasoline PAH emission factor is applied to both 2-stroke and 4-stroke gasoline engines and to both E0 and E10 fuel subtypes.

$$PAH\ gaseous\ emission\ fraction = \frac{PAH_i}{VOC_{total}} \times Gaseous\ Fraction_i \qquad \textbf{Equation 3}$$

$$PAH\ particulate\ emission\ fraction = \frac{PAH_i}{PM_{2.5}} \times Particulate\ Fraction_i \qquad \textbf{Equation 4}$$

Where:

[c] $OC_{2.5}$ refers to the organic carbon portion of $PM_{2.5}$ emissions

PAH_i (g) = mass of PAH species i (e.g. naphthalene)
VOC (g) = mass of volatile organic compounds
$PM_{2.5}$ (g) = particulate matter mass
Gaseous Fraction (unitless) = fraction of PAH_i measured in the gaseous phase (Table 2-3)
Particulate Fraction (unitless) = fraction of PAH_i measured in the particulate phase (Table 2-3)

Table 2-3. Toxic Fractions for PAH Compounds in Gaseous and Particulate Phases for Nonroad Gasoline Engines

Species	Gaseous Phase (PAH/VOC)	Particulate Phase (PAH/$PM_{2.5}$)
Naphthalene	2.07×10^{-3}	6.38×10^{-5}
Acenaphthylene	1.81×10^{-4}	2.09×10^{-5}
Acenaphthene	3.99×10^{-5}	0.0
Fluorene	8.08×10^{-5}	0.0
Anthracene	3.35×10^{-5}	2.21×10^{-5}
Phenanthrene	2.14×10^{-4}	7.80×10^{-5}
Fluoranthene	5.60×10^{-5}	7.81×10^{-5}
Pyrene	6.40×10^{-5}	8.47×10^{-5}
Benz(a)anthracene	5.40×10^{-6}	2.03×10^{-4}
Chrysene	6.05×10^{-6}	1.72×10^{-4}
Benzo(a)pyrene	2.94×10^{-7}	5.09×10^{-4}
Benzo(b)fluoranthene	4.01×10^{-6}	2.48×10^{-4}
Benzo(k)fluoranthene	4.01×10^{-6}	2.48×10^{-4}
Benzo(g,h,i)perylene	0.0	1.38×10^{-3}
Indeno(1,2,3,c,d)pyrene	0.0	5.17×10^{-4}
Dibenzo(a,h)anthracene	0.0	1.19×10^{-5}

2.3 Metals

Emission factors for chromium 6, manganese, nickel, elemental gas-phase mercury (Hg), reactive gas-phase Hg, particulate Hg, and arsenic were developed based on the onroad gasoline emission factors in MOVES[9] (due to the lack of nonroad emissions tests data for these compounds. Onroad emission factors in MOVES were used as surrogates and converted from grams-per-mile to grams-per-gallon using study-specific, miles per gallon (mpg) fuel economy estimates. A considerable source of uncertainty in this approach is that the onroad data were obtained from vehicles with catalysts, but are being applied to nonroad engines without catalyst controls.

Chromium 6 was estimated using data collected at U.S. EPA's National Vehicle Emissions Laboratory and analyzed at the Wisconsin State Laboratory of Hygiene at the University of Wisconsin-Madison. The study was conducted on a single vehicle, a 2008 Chevrolet Impala

flexible-fuel vehicle. They are the only available data with direct measurement of hexavalent chromium from a highway vehicle, gasoline or diesel. Development of a gasoline vehicle emission rate from these data is detailed in the onroad air toxics report. To obtain the nonroad gasoline emission factor for chromium 6, the onroad emission factor was converted to grams-per-gallon by using the Impala's fuel economy estimate of 18 miles per gallon.

Nonroad gasoline vehicle emission factors for mercury (all phases) were obtained from the onroad air toxics report. Nonroad grams-per-gallon emission factors were calculated from the onroad factors using a fuel economy estimate of 18 miles per gallon, based on average fuel economy estimates for gasoline vehicles used to develop the onroad estimates.[9]

Emission rates for manganese and nickel were developed from 99 vehicles sampled for chemical composition in the Kansas City test program.[12] For manganese and nickel, the mean rates were calculated as weighted averages of metal measured on Bag 2 of the LA92 test cycle. A fuel economy estimate of 20.43 mpg was calculated from vehicles in the Kansas City test program.

The emission rate for arsenic is from a Health Effects Institute research report.[13] In the absence of a study-specific fuel economy estimate for the vehicles used in the study, the 2000 fuel economy standard for gasoline vehicles (27.5 mpg) was used to reflect the fleet average fuel economy at the time when the majority of data were collected.

The resulting metal emission rates for nonroad gasoline engines are presented in Table 2-4. A single factor for each metal is applied to all nonroad gasoline engines and fuel sub-types (E0 and E10).

Table 2-4. Metal Emission Factors for Nonroad Gasoline Engines

Pollutant	Emission Factor (g/gal)
Chromium 6	2.20×10^{-7}
Manganese	2.72×10-5
Nickel	3.06×10-5
Elemental Gas-Phase Hg	1.80×10^{-6}
Reactive Gas-Phase Hg	1.70×10^{-7}
Particulate Hg	6.90×10^{-9}
Arsenic	6.33×10-5

2.4 Dioxins and Furans

Emission factors for 17 dioxins and furans were developed (See Table 2-5) based on onroad emission factors (detailed in the onroad air toxics report[9]) because of a lack of available data for nonroad engines. Onroad emission rates from MOVES were obtained from a tunnel **study[14] and** used in EPA's dioxin assessment.[15] These emission rates were converted from grams-per-mile to grams per gallon using a fuel economy of 23.5 miles per gallon from the tunnel study. Due to a lack of dioxin and furan test data differentiating 2-stroke and 4-stroke engines, the dioxin/furan emission factors in Table 2-5 will be applied to all nonroad gasoline engines. Each dioxin and furan rate is also applied across all fuel sub-types. MOVES uses the gram-per-gallon emission rate, but we also calculated a gram-per-gram-fuel emission rate by converting gallons to grams

of gasoline using the default fuel density (2,839 g/gallon) of highway conventional gasoline in MOVES2014. The fuel-based emission factor (grams-per-grams-fuel) is calculated as a reference that is used for estimating CNG and LPG emissions as described in Sections 4 and 5.

Table 2-5. Dioxin and Furan Emission Factors for Nonroad Gasoline Engines

Pollutant	Onroad Emission Rate (mg/mi)	Nonroad Emission Factor (g/gal)	Nonroad Emission Factor (g/g-gasoline)
2,3,7,8-Tetrachlorodibenzo-*p*-Dioxin (TCDD)	8.27×10^{-10}	1.94×10^{-11}	6.85×10^{-15}
1,2,3,7,8-Pentachlorodibenzo-*p*-Dioxin	3.70×10^{-10}	8.70×10^{-12}	3.06×10^{-15}
1,2,3,4,7,8-Hexachlorodibenzo-p-Dioxin	3.87×10^{-10}	9.09×10^{-12}	3.20×10^{-15}
1,2,3,6,7,8-Hexachlorodibenzo-p-Dioxin	7.92×10^{-10}	1.86×10^{-11}	6.56×10^{-15}
1,2,3,7,8,9-Hexachlorodibenzo-p-Dioxin	4.93×10^{-10}	1.16×10^{-11}	4.08×10^{-15}
1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	5.95×10^{-9}	1.40×10^{-10}	4.93×10^{-14}
Octachlorodibenzo-p-dioxin	4.70×10^{-8}	1.10×10^{-9}	3.90×10^{-13}
2,3,7,8-Tetrachlorodibenzofuran	2.76×10^{-9}	6.49×10^{-11}	2.28×10^{-14}
1,2,3,7,8-Pentachlorodibenzofuran	1.32×10^{-9}	3.10×10^{-11}	1.09×10^{-14}
2,3,4,7,8-Pentachlorodibenzofuran	9.68×10^{-10}	2.27×10^{-11}	8.00×10^{-15}
1,2,3,4,7,8-Hexachlorodibenzofuran	1.09×10^{-9}	2.56×10^{-11}	9.02×10^{-15}
1,2,3,6,7,8-Hexachlorodibenzofuran	1.16×10^{-9}	2.73×10^{-11}	9.60×10^{-15}
1,2,3,7,8,9-Hexachlorodibenzofuran	3.17×10^{-10}	7.45×10^{-12}	2.62×10^{-15}
2,3,4,6,7,8-Hexachlorodibenzofuran	1.36×10^{-9}	3.20×10^{-11}	1.13×10^{-14}
1,2,3,4,6,7,8-Heptachlorodibenzofuran	1.21×10^{-8}	2.84×10^{-10}	1.00×10^{-13}
1,2,3,4,7,8,9-Heptachlorodibenzofuran	3.87×10^{-10}	9.09×10^{-12}	3.20×10^{-15}
Octachlorodibenzofuran	1.37×10^{-8}	3.22×10^{-10}	1.13×10^{-13}

3 Diesel Exhaust

MOVES contains emission factors for nonroad diesel (fuelSubTypeID 23) and marine diesel (fuelSubTypeID 24). The emission factors presented in this section apply to both nonroad diesel and marine diesel engines, with some exceptions for marine diesel engines.[d]

3.1 Organic Gas Aggregations and Air Toxic Emission Factors

Diesel engines were assigned VOC exhaust emission factors according to engine control technology, as determined by the engine certification tier or phase, and engine size. Pre-Tier 1, Tier 1, and Tier 2 diesel engine VOC profiles were developed from EPA's nonroad CI test programs.[6,7] Because no speciated emissions data were available for Tier 3 engines, we applied the VOC profile developed for Tier 2 engines to Tier 3 engines.

The Tier 4 nonroad diesel standards require lower NMHC, NO_X, and PM emissions than Tier 2 and Tier 3, particularly for engines larger than 56 kW (75 hp).[16] The Tier 4 NMHC and NOx standards are unchanged from Tier 2 and Tier 3 for engines smaller than 19 kW (25 hp), and are moderately reduced from Tier 2 and Tier 3 for engines between 19 kW and 56 kW (25 to 75 hp). Tier 4 PM standards are substantially more stringent for all engine sizes.

In order to achieve the Tier 4 nonroad diesel standards, nonroad engine manufacturers have employed a variety of different aftertreatment emission control technologies, utilizing advanced technology such as diesel oxidation catalysts, diesel particulate filters, selective reduction catalysts, and ammonia slip catalysts.

Table 3-1 displays the use of different aftertreatment emission control strategies across engine families, by engine size, from the 2014 EPA certification database. The smallest Tier 4 nonroad engines (<19 kW, or 25 hp) do not utilize any aftertreatment devices. Many of the engines between 19 and 56 kw employ diesel oxidation catalysts, but do not have diesel particulate filters (DPFs), and none had selective catalytic reduction (SCR) systems. The majority of the engines above 75 kW have SCR systems, but there is little use of diesel particulate filters.

[d] The speciation and toxic factors for recreational marine diesel are unchanged from MOVES2014a. The speciation and toxic values for pre-Tier 1, Tier 1, Tier 2 & Tier 3 recreational marine diesel engines (BaseM, T1M, T2M, and T3M), are equivalent to the corresponding nonroad diesel values by tier presented in this report. For recreational marine engines with engineTechID 182 (T4M), the engines use the Tier 4 toxic and speciation values documented in the MOVES2014a nonroad speciation and toxic report[1]. Updating the recreational marine emission factors was not within the scope of the Tier 4 emission updates made for MOVES2014b.

Table 3-1. Aftertreatment Configurations of Selective Catalytic Reduction Systems and Diesel Particulate Filters for Nonroad Engine Families Certified to the Model Year 2014 Tier 4 Nonroad Engine Standards

Engine Size	No aftertreatment	DOC, no SCR, no DPF	SCR, no DPF	DPF, no SCR	DPF+SCR
kW<8	100%	0%	0%	0%	0%
8<=kW<19	100%	0%	0%	0%	0%
19<=kW<37	35%	33%	0%	33%	0%
37<=kW<56	16%	41%	0%	43%	0%
75<=kW<130	0%	0%	100%	0%	0%
130<kW<=560	0%	0%	61%	10%	29%
560<kW<=900	0%	75%	25%	0%	0%

Diesel particulate filters are highly effective at removing particulates, as well as oxidizing volatile organic compounds. From emissions measurements of onroad engines, we also know that the speciation profiles are significantly different between engines equipped with DPF, and engines equipped with both DPF and SCR.[19]

In MOVES2014b, we have defined additional engine technologies to distinguish Tier 4 engines equipped with different aftertreatment technologies that significantly impact the exhaust emissions. Definitions, population fractions, and emission rates by these new engine technologies are described in more detail the nonroad compression-ignition exhaust emission rate report[17]. Table 3-2 defines the engine technology, and the TOG speciation profiles we used to speciate exhaust emissions from those engines. The first two engine technology categories include Tier 4 engines without diesel particulate filters, including engines without any aftertreatment, engines with or without diesel oxidation catalyst (DOC), and engines with and without selective catalytic reduction systems. For this category, we apply the nonroad diesel engine speciation profile for Tier 2 developed from the EPA's nonroad CI test programs.[6,7]

Table 3-2. Tier 4 Engine Technologies and Associated TOG Speciation Profiles

Tier 4 Aftertreatment Classifications	Tier 4 Interim (I) and Final (F) Engine Tech IDs	Tier 4 Engine Technology Descriptions	TOG Speciation Profile
A	T4IA/T4FA	no DPF, no SCR	Tier 2 nonroad diesel engine (95333)
B	T4IA/T4FB	no DPF, SCR	Tier 2 nonroad diesel engine (95333)
C	T4IC/T4FC	DPF, no SCR	ACES Phase 1 (8775)
D	T4ID/T4FD	DPF+SCR	ACES Phase 2 (95335a)

We have defined an additional engine technology category for Tier 4 engines with DPF and no SCR, for which we apply the speciation profile developed from Phase 1 of the Advanced Collaborative Emissions Study (ACES).[18] ACES Phase 1 measured emissions from four on-highway heavy-duty 2007 engines that were equipped with diesel particulate filters (DPFs), but without selective catalytic reduction systems (SCR).

We have defined an additional engine technology for Tier 4 engines with both DPF and SCR. For this engine technology, we apply a speciation profile based on the ACES Phase 2 study

which contains measurements on three 2011 on-highway heavy-duty diesel engines equipped with both DPF and SCR.[19,20] The original profile based on ACES Phase 2, 95335, was corrected to subtract the mass of several alcohol species which was probably due to sample contamination. as discussed in the onroad speciation report[27]. The corrected profile was named 95335a.[e,21]

NMOG and VOC ratios for diesel engines were calculated using THC measurements, similar to the way we generated gasoline ratios (Section 2.1); this information is displayed in Table 3-3. NMOG was calculated using Equation 1, but the effective C_1-equivalent density of NMHC was calculated from emissions from combustion of a #2 diesel fuel, with a C:H molar ratio of 1:1.8. VOC and methane emission rates used to develop emission factors for the pre-Tier 1, Tier 1, and Tier 2 & 3 engine technologies listed in Table 3-3 were developed from the final TOG speciation profiles listed in Appendix A of this document. The CH_4/THC, NMOG/NMHC and VOC/NMHC rates for Tier 4: DPF, no SCR and Tier 4: DPF+SCR are taken from the ACES Phase 1 and 2 programs, as documented in the MOVES2014b Speciation of TOG and PM Emissions report.

VOC profiles were created by subtracting the values for methane, ethane, and acetone from TOG profiles in Appendix A. Emission factors are reported in fractions of individual species over total VOCs as shown in Table 3-4. The remaining VOC species have been integrated into the term NONHAPTOG, which is listed at the bottom of Table 3-4.

Table 3-3. Methane Emission Rates and Organic Gas Ratios Estimated from THC for Nonroad Diesel Engines

Engine technology:	Pre-Tier 1	Tier 1	Tiers 2 & 3	Tier 4: No DPF	Tier 4: DPF, no SCR	Tier 4: DPF+SCR
Fuel type	**Diesel**	**Diesel**	**Diesel**	**Diesel**	**Diesel**	**Diesel**
CH_4 [a]	3.567	4.722	7.960	7.960		
NMOG/NMHC	1.067	1.116	1.233	1.233	1.343	1.085
CH_4/THC	0.005	0.022	0.098	0.098	0.589	0
VOC/NMHC	1.062	1.110	1.233	1.233	1.285	0.965

Note:
[a] The units for methane emission rates are all mg/hp-hr.

[e] The removal of the alcohol species from profile 95355 was done in response to a comment made by one of the peer-reviewers of the draft report 'Speciation of Total Organic Gas and Particulate Matter Emissions from Onroad Vehicles in MOVES201X'. The comments from the peer-reviews are available on EPA's science inventory webpage[21].

Table 3-4. Toxic Fractions of VOC for Nonroad Diesel Vehicles by Engine Standard

	Toxic fraction					
Pollutant	**Pre-Tier 1**	**Tier 1**	**Tiers 2 & 3**	**Tier 4: no DPF**	**Tier 4: DPF, no SCR**	**Tier 4: DPF + SCR**
1,3-Butadiene	0.00186	0.00186	0.00186	0.00186	0.00080	0.0000
2,2,4-Trimethylpentane	0.00807	0.00712	0.00783	0.00783	0.00782	0.0045
Acetaldehyde	0.0746	0.0783	0.104	0.104	0.06934	0.0417
Acrolein	0.0302	0.0160	0.0187	0.0187	0.00999	0.0036
Benzene	0.0196	0.0225	0.0541	0.0541	0.01291	0.0000
Ethyl Benzene	0.00944	0.00384	0.00438	0.00438	0.00627	0.0117
Formaldehyde	0.207	0.223	0.292	0.292	0.21744	0.0266
Hexane	0.00230	0.00279	0.000	0.000	0.00541	0.0009
Xylenes	0.02256	0.01644	0.0116	0.0116	0.0380	0.0848
Propionaldehyde	0.0141	0.0386	0.0220	0.0220	0.00314	0.0029
Styrene	0.000	0.000	0.000	0.000	0.000	0.0000
Toluene	0.0122	0.0215	0.0378	0.0378	0.02999	0.0183
NONHAPTOG	0.598	0.568	0.446	0.446	0.59889	0.80568

3.2 Polycyclic Aromatic Hydrocarbons

Unlike gasoline, we had measurements of PAHs from nonroad diesel engines from EPA's nonroad CI test programs, but we did not have the PAH emissions measured separately from the gaseous and particulate phases. We partitioned the nonroad PAH emission factors into gaseous and particulate phases using the same set of partitioning factors used for pre-2007 highway diesel exhaust documented in the onroad air toxics report (Section 3). The data used to represent partitioning is the sampled diluted exhaust, which may not be representative of partitioning as seen in the atmosphere. However, because the PAH emissions in MOVES are based on the VOC and PM emission factors, we felt it was more important that the partitioning be consistent with the laboratory sampling conditions under which the VOC and PM emission factors were measured.

Emissions of PAH in the gaseous and particulate phases were estimated as fractions of total VOC and $PM_{2.5}$, respectively (Equation 3 and Equation 4). Toxic fractions were determined according to the same emission standard and horsepower distinctions discussed in the prior section. Toxic fractions for pre-Tier 1, Tier 1, Tier 2, Tier 3, and "Tier 4: no DPF", were calculated using the composite mass results from the EPA nonroad compression-ignition transient test program described in Appendix A.

In the absence of PAH data on nonroad engines with advanced controls ("Tier 4: DPF, no SCR", and "Tier 4 DPF + SCR")), we relied on speciated emissions data for onroad engines from Phase 1 and 2 of the ACES study, which tested vehicles equipped with only DPF (Phase 1)[18], and with both DPF and SCR (Phase 2).[19,20] The PAH toxic fractions for nonroad "Tier 4: no DPF, no SCR" engines were taken from the onroad conventional heavy-duty diesel engines (hot stabilized

running, profile 8995) detailed in Section 3 of the onroad air toxics report[9]. However, while onroad PAHs are calculated from $OC_{2.5,}$ MOVES does not estimate organic carbon for nonroad equipment. Thus, MOVES calculates nonroad PAH emissions as a fraction of total $PM_{2.5}$.

Gaseous results and particulate results were averaged separately according to the categories identified in Table A3-2 of Appendix A. The resulting PAH EFs are displayed in Table 3-5.

Table 3-5. PAH Emission Factors for Nonroad Diesel Engines

	Pre-Tier 1		Tier 1		Tier 2, Tier 3, & Tier 4: no DPF		Tier 4: DPF, no SCR		Tier 4: DPF + SCR	
Pollutant	***Gaseous***	***Particle***	***Gaseous***	***Particle***	***Gaseous***	***Particle***	***Gaseous***	***Particle***	***Gaseous***	***Particle***
Benz(a)anthracene	2.56×10^{-6}	4.51×10^{-6}	3.22×10^{-6}	3.24×10^{-6}	7.81×10^{-6}	7.76×10^{-6}	3.00×10^{-7}	8.00×10^{-7}	6.92×10^{-7}	1.94×10^{-5}
Benzo(a)pyrene	0.0	2.14×10^{-6}	0.0	2.13×10^{-6}	0.0	6.67×10^{-6}	0.0	3.30×10^{-6}	0.0	0.0
Benzo(b)fluoranthene	0.0	2.47×10^{-6}	0.0	2.60×10^{-6}	0.0	1.07×10^{-5}	0.0	1.40×10^{-6}	0.0	0.0
Benzo(k)fluoranthene	0.0	2.09×10^{-6}	0.0	2.03×10^{-6}	0.0	8.10×10^{-6}	0.0	1.40×10^{-6}	0.0	0.0
Chrysene	1.96×10^{-6}	7.89×10^{-6}	3.85×10^{-6}	6.26×10^{-6}	7.68×10^{-6}	1.31×10^{-5}	5.00×10^{-7}	2.50×10^{-6}	2.51×10^{-7}	5.32×10^{-6}
Dibenz(a,h)anthracene	0.0	1.89×10^{-6}	0.0	9.64×10^{-7}	0.0	9.52×10^{-7}	0.0	1.00×10^{-6}	0.0	0.0
Indeno(1,2,3-cd)pyrene	0.0	2.02×10^{-6}	0.0	1.53×10^{-6}	0.0	6.72×10^{-6}	0.0	5.00×10^{-7}	0.0	0.0
Benzo(ghi)perylene	6.20×10^{-7}	1.80×10^{-6}	1.22×10^{-6}	1.62×10^{-6}	5.70×10^{-6}	7.55×10^{-6}	2.00×10^{-7}	2.00×10^{-7}	0.0	0.0
Acenapthene	9.59×10^{-4}	0.0	3.79×10^{-4}	0.0	6.06×10^{-4}	0.0	5.26×10^{-5}	0.0	1.56×10^{-5}	0
Acenapthylene	4.64×10^{-4}	0.0	4.95×10^{-4}	0.0	1.24×10^{-3}	0.0	8.53×10^{-5}	0.0	1.49×10^{-5}	1.29×10^{-6}
Anthracene	8.74×10^{-5}	6.63×10^{-5}	4.63×10^{-5}	1.95×10^{-5}	8.81×10^{-5}	2.90×10^{-5}	3.04×10^{-5}	2.65×10^{-5}	6.47×10^{-6}	3.19×10^{-6}
Fluoranthene	2.27×10^{-5}	2.07×10^{-5}	5.22×10^{-5}	1.78×10^{-5}	1.45×10^{-4}	5.59×10^{-5}	4.57×10^{-5}	4.87×10^{-5}	6.41×10^{-6}	6.68×10^{-6}
Fluorene	1.15×10^{-3}	2.71×10^{-4}	5.00×10^{-4}	5.75×10^{-5}	7.90×10^{-4}	7.98×10^{-5}	1.96×10^{-4}	5.38×10^{-5}	3.35×10^{-5}	0
Napthalene	3.18×10^{-3}	0.0	2.73×10^{-3}	0.0	4.64×10^{-3}	0.0	1.63×10^{-2}	0.0	5.84×10^{-4}	1.35×10^{-5}
Phenanthrene	1.56×10^{-3}	6.79×10^{-4}	1.03×10^{-3}	2.03×10^{-4}	1.28×10^{-3}	2.37×10^{-4}	8.51×10^{-4}	4.29×10^{-4}	9.62×10^{-5}	2.61×10^{-5}
Pyrene	7.51×10^{-5}	8.28×10^{-5}	6.65×10^{-5}	3.20×10^{-5}	1.30×10^{-4}	6.15×10^{-5}	3.79×10^{-5}	4.67×10^{-5}	4.72×10^{-6}	4.67×10^{-6}

3.3 Metals

Emission factors for chromium 6 (also seen as chromium-6, chromium VI, Cr6+ and CrVI), manganese, nickel, elemental gas-phase mercury (Hg), reactive gas-phase Hg, particulate Hg, and arsenic were developed based on existing onroad emission factors in MOVES[9] due to the lack of nonroad emissions test data for these compounds. Onroad emission factors were converted from grams-per-mile to grams-per-gallon using study-specific, miles-per-gallon (mpg) fuel economy estimates. Studies used in developing onroad emission factors and study-specific fuel economy estimates are described below. When the study-specific fuel economy estimates were unavailable for some engine types, the average fuel economies were used instead. Where there was information to do so, diesel engine emission factors were determined by engine tier and power (as described in Section 3.1).

Chromium 6 emissions factors for nonroad diesel engines were developed from measurements on an onroad gasoline engine. The chromium 6 emission factors for nonroad engines certified to Tier 0 through Tier 3 and "Tier 4: No DPF" diesel engines were obtained by multiplying the nonroad gasoline engine emission rate (Table 2-4) by the ratio of total chromium in grams per gallon from pre-2007 highway diesel vehicle exhaust[22] to that in highway vehicle gasoline exhaust (**Equation 5**).[23] To convert the grams-per-mile highway vehicle emission rate to grams-per-gallon, an average (4.3 g/gal) was computed from the UDDS mile/gallon values from Tables 26 and 27 of the E55/59 report. [24]

For "Tier 4: DPF, no SCR" engines, the chromium 6 emission rate was obtained by multiplying the gasoline vehicle emission rate by the ratio of total chromium from 2007 – 2009 diesel and gasoline engines (**Equation 6**). The total chromium estimates came from the ACES Phase 1[18] and Kansas City test programs, respectively. A study-specific fuel economy of 6 mile-per-gallon was used from page 31 of the ACES Phase 1 report.[18]

For Tier 4: DPF+SCR, the chromium 6 emission rate was obtained from measurements from the ACES Phase 2 by multiplying the gasoline vehicle emission rate by the ratio of total chromium from 2010 and later diesel (ACES Phase 2)[20] (**Equation 7**). Since ACES Phase 2 provided no fuel economy estimates, we assumed the fuel economy of 6 miles per gallon estimated from ACES Phase 1.

Nonroad Diesel Without DPF Emission Factor (from pre-2007 highway diesel engine data).

$$\mathrm{EF} = 2.2\mathrm{x}10^{-7}\,\frac{\mathrm{g}}{\mathrm{gal}} \times \frac{6.8\mathrm{x}10^{-6}\,\frac{\mathrm{g}}{\mathrm{mi}} \times 4.3\,\frac{\mathrm{mi}}{\mathrm{gal}}}{4.07\mathrm{x}10^{-6}\,\frac{\mathrm{g}}{\mathrm{mi}} \times 20.43\,\frac{\mathrm{mi}}{\mathrm{gal}}} = \mathbf{7.78x10^{-8}\,\frac{g}{gal}} \qquad \textbf{Equation 5}$$

Where:
Nonroad chromium VI gasoline emission rate= 2.2 x 10^{-7} (g/gal)
Total chromium emission rate for pre-2007 diesel from the E55/59 program = 6.8x10^{-6} (g/mi)
Pre-2007 diesel fuel economy from the E55/59 program=4.3 (mi/gal)
Total chromium emission rate for gasoline vehicles =4.07x10^{-6} (g/mi)
Gasoline vehicle fuel economy from the Kansas City Program=20.43 (mi/gal)

Nonroad Diesel With DPF Emission Factor (from 2007-2009 highway diesel engine data).

$$EF = 2.2\text{x}10^{-7}\,\frac{\text{g}}{\text{gal}} \times \frac{2.01\text{x}10^{-6}\,\frac{\text{g}}{\text{mi}} \times 6.0\,\frac{\text{mi}}{\text{gal}}}{4.07\text{x}10^{-6}\,\frac{\text{g}}{\text{mi}} \times 20.43\,\frac{\text{mi}}{\text{gal}}} = \mathbf{3.19x10^{-8}}\ \ \frac{\mathbf{g}}{\mathbf{gal}} \qquad \textbf{Equation 6}$$

Where:
Nonroad chromium VI gasoline emission rate= 2.2 x 10^{-7} (g/gal)
Total chromium emission rate for 2007-2009 diesel from the ACES Phase 1 program = $2.01\text{x}10^{-6}$ (g/mi)
2007-2009 diesel fuel economy from the ACES Phase 1 program=6(mi/gal)
Total chromium emission rate for gasoline vehicles =$4.07\text{x}10^{-6}$ (g/mi)
Gasoline vehicle fuel economy from the Kansas City Program=20.43 (mi/gal)

Nonroad Diesel With DPF and SCR Emission Factor (from 2010+ highway diesel engine data).

$$EF = 2.2x10^{-7}\,\frac{g}{gal} \times \frac{7.33x10^{-7}\,\frac{g}{mi} \times 6.0\,\frac{mi}{gal}}{4.07x10^{-6}\,\frac{g}{mi} \times 20.43\,\frac{mi}{gal}} = \mathbf{1.16x10^{-8}}\,\frac{\boldsymbol{g}}{\boldsymbol{gal}} \qquad \textbf{Equation 7}$$

Where:
Nonroad chromium VI gasoline emission rate= 2.2 x 10^{-7} (g/gal)
Total chromium emission rate for 2010 diesel from the ACES Phase 2 program = $7.33\text{x}10^{-7}$ (g/mi)
Pre-2007 diesel fuel economy from the ACES Phase 1 program=6 (mi/gal)
Total chromium emission rate for gasoline vehicles =$4.07\text{x}10^{-6}$ (g/mi)
Gasoline vehicle fuel economy from the Kansas City Program=20.43 (mi/gal)

Mercury (all phases) emission factors were calculated from two Ford F-250 diesel vehicles as documented in Appendix B of the onroad air toxics report. The fuel economy estimate for these vehicles was 19 miles per gallon.

Emission factors for arsenic were developed from onroad data reported in tunnel studies.[13] Because the average fuel economy for these vehicles was not reported in those studies, the average heavy-duty diesel fuel economy of 7 miles-per-gallon for model year 2007 was used since most of the data was collected in 2000.

Emission factors for manganese and nickel for Tier 0 – Tier 3 and "Tier 4: No DPF" diesel engines were developed from the CRC E-55/59[24] test program, using the same reported fuel economy (4.3 mi/gal) used in **Equation 5**. For "Tier 4: DPF, no SCR" nonroad diesel engines, emission factors were developed from ACES Phase 1.[9,18] A study-specific fuel economy of 6 mile-per-gallon was used from page 31 of the ACES Phase 1 report.[18] For "Tier 4: DPF+SCR", we used the emission factors from ACES Phase 2.[19,20] Since ACES Phase 2 provided no fuel economy estimates, we assumed the fuel economy of 6 miles per gallon.

Table 3-6. Metal Emission Factors for Nonroad Diesel Engines

Engine Tier & Power	Pollutant	Emission Factor (g/gal)
Tier 0 – Tier 3, Tier 4: no DPF	Chromium 6	7.78×10^{-8}
	Manganese	3.46×10^{-5}
	Nickel	6.05×10^{-5}
	Elemental Gas-Phase Hg	1.20×10^{-7}
	Reactive Gas-Phase Hg	6.20×10^{-8}
	Particulate Hg	3.20×10^{-8}
	Arsenic	1.61×10^{-5}
Tier 4: DPF, no SCR	Chromium 6	3.19×10^{-8}
	Manganese	4.09×10^{-6}
	Nickel	4.15×10^{-6}
	Elemental Gas-Phase Hg	1.20×10^{-7}
	Reactive Gas-Phase Hg	6.20×10^{-8}
	Particulate Hg	3.20×10^{-8}
	Arsenic	1.61×10^{-5}
Tier 4: DPF+SCR	Chromium 6	$1.16\text{x}10^{-8}$
	Manganese	1.2×10^{-6}
	Nickel	1.58×10^{-6}
	Elemental Gas-Phase Hg	1.20×10^{-7}
	Reactive Gas-Phase Hg	6.20×10^{-8}
	Particulate Hg	3.20×10^{-8}
	Arsenic	1.61×10^{-5}

3.4 Dioxins and Furans

Emission factors for 17 dioxins and furans were developed based on onroad emission factors because of a lack of available data for nonroad engines. Onroad emission rates in MOVES were used as surrogates and converted from grams-per-mile to grams-per-gallon (Table 3-7).

To represent emissions of dioxins and furans from onroad pre-2007 heavy-duty diesel engines, the emissions rates for 17 related compounds or congeners were calculated from the results of an EPA diesel dioxin/furan study of legacy onroad engines.[25] The data used to calculate the emission rates for 2007-2009 onroad engines were obtained from the EPA diesel dioxin study using a MY 2008 onroad diesel engine with a catalyzed diesel particulate filter (DPF). The 2010+ later emission rates used the same MY 2008 diesel engine, and diesel particulate filter (DPF), but also included a selective catalytic reduction (SCR) emission control system.[26] More information on the development of the onroad diesel emission rates and the studies used can be found in the onroad air toxics report.[9]

In applying the onroad dioxin and furan rates to nonroad diesel engines, we grouped the engines differently than for other pollutants. This is because dioxins and furans are formed in the exhaust after combustion and may not be affected by after-treatment control technologies in the same way as other air toxics. In particular, we expect less sophisticated engine combustion technologies on Tier 0, Tier 1, Tier 2 and the smaller Tier 3 and Tier 4 diesel engines, and thus, higher dioxin and furan emissions on a per gallon basis. For all Tier 0, Tier 1, Tier 2 and the Tier

3 and Tier 4 engines diesel engines less than 56 kW we used an average of emission factors from three legacy onroad engines.[25] The rated-power of 56 kW (75 hp) was used as the dividing line between smaller and larger engines because NMHC-specific Tier 4 standards only apply to 56 kW-and-larger engines. Tier 3 ≥ 56kW engines are considered to have similar dioxin/furan emissions as Tier 4 engines ≥ 56kW based on observations of onroad engines.[26] Thus, for Tier 3 and Tier 4 diesel engines ≥ 56kW, we used the emission factor representing model year 2010 on-highway engine (including DPF+SCR).

Table 3-7. Dioxin and Furan Emission Factors (g/gallon) for Nonroad Diesel Engines

Pollutant ID	CAS Number	Pollutant	Tier 0 – Tier 2 (all hp categories), Tier 3 and Tier 4 (<56 kW)[1]	Diesel ≥ 56 kW Tiers 3 and 4[2]
142	17466016	2,3,7,8-Tetrachlorodibenzo-*p*-Dioxin (TCDD)	4.04×10^{-12}	ND[3]
135	40321764	1,2,3,7,8-Pentachlorodibenzo-*p*-Dioxin	ND	ND
134	39227286	1,2,3,4,7,8-Hexachlorodibenzo-p-Dioxin	ND	ND
141	57653857	1,2,3,6,7,8-Hexachlorodibenzo-p-Dioxin	1.88×10^{-12}	ND
130	19408743	1,2,3,7,8,9-Hexachlorodibenzo-p-Dioxin	8.68×10^{-12}	ND
132	35822469	1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	7.59×10^{-11}	1.90×10^{-11}
131	3268879	Octachlorodibenzo-p-dioxin	2.93×10^{-10}	1.27×10^{-10}
136	51207319	2,3,7,8-Tetrachlorodibenzofuran	1.18×10^{-10}	9.24×10^{-13}
139	57117416	1,2,3,7,8-Pentachlorodibenzofuran	2.52×10^{-11}	1.95×10^{-12}
138	57117314	2,3,4,7,8-Pentachlorodibenzofuran	4.03×10^{-11}	5.86×10^{-12}
145	70648269	1,2,3,4,7,8-Hexachlorodibenzofuran	1.46×10^{-11}	4.00×10^{-12}
140	57117449	1,2,3,6,7,8-Hexachlorodibenzofuran	7.71×10^{-12}	4.41×10^{-12}
146	60851345	1,2,3,7,8,9-Hexachlorodibenzofuran	5.51×10^{-12}	3.27×10^{-12}
143	72918219	2,3,4,6,7,8-Hexachlorodibenzofuran	ND	ND
144	67562394	1,2,3,4,6,7,8-Heptachlorodibenzofuran	3.93×10^{-11}	1.80×10^{-11}
137	55673897	1,2,3,4,7,8,9-Heptachlorodibenzofuran	ND	1.06×10^{-12}
133	39001020	Octachlorodibenzofuran	3.37×10^{-11}	3.15×10^{-11}

Notes:
[1] Used an average of the onroad pre-2007 legacy engines, converted pg/L to g/gal.
[2] Used the emission factors from representing an onroad 2010 engine, converted pg/L to g/gal.
3 ND = non-detect, fractions set to zero. Detection limits ranged from 2 to 18 pg/L, depending on the compound.

4 Compressed Natural Gas Exhaust

4.1 Organic Gas Aggregations and Air Toxic Emission Factors

In the absence of data on nonroad engines, VOC exhaust emission factors for compressed natural gas equipment are replicated from onroad exhaust CNG transit buses in the onroad air toxics report[9]. Toxic fractions are based on uncontrolled (pre-2002) transit buses (Table 4-1), since CNG nonroad engines are typically uncontrolled. However, since transit buses are quite different from CNG nonroad engines, the quality of this surrogate is unclear.

Table 4-1. Toxic Fractions of VOC for Nonroad CNG Engines

Pollutant	Toxic fraction
1,3 Butadiene	0.000234
Benzene	0.00135
Toluene	0.000691
Ethylbenzene	0.0000841
Xylenes	0.000823
Formaldehyde	0.517
Acetaldehyde	0.0305
Acrolein	0.00235
Propionaldehyde	0.0153

The derivation of the exhaust NMOG/NMHC and VOC/NMHC ratios used for CNG nonroad engines (Table 4-2) is documented in the Onroad speciation report[27] and comes from CNG transit bus emissions with no control technologies.

Table 4-2. NMOG/NMHC and VOC/NMHC Ratios estimated from CNG Transit Bus Exhaust

Measured values (mg/mile)	
THC	8,660.0
Methane	7,670.0
Ethane	217.0
Acetone	4.7
Formaldehyde	860.0
Acetaldehyde	50.7
Calculated values (mg/mile)	
NMHC	990
NMOG	1,881
VOC	1,664
Ratios	
NMOG/NMHC	1.90
VOC/NMHC	1.68

4.2 Polycyclic Aromatic Hydrocarbons

In the absence of data, PAH toxic fractions for CNG engines are estimated in a manner similar to how PAH toxic fractions for gasoline engines were derived, using Equation 3 and Equation 4. The PAH toxic fractions for CNG engines developed from onroad CNG transit buses (see onroad air toxics report[9]) are displayed in Table 4-3.

Table 4-3. PAH Emission Factors for CNG Engines

	Gaseous Phase (PAH/VOC)	**Particulate Phase (PAH/$PM_{2.5}$)**
Naphthalene	9.554×10^{-6}	1.144×10^{-5}
Acenaphthylene	4.230×10^{-6}	ND[1]
Acenaphthene	1.243×10^{-6}	9.027×10^{-6}
Fluorene	2.986×10^{-6}	1.580×10^{-5}
Anthracene	1.164×10^{-6}	1.315×10^{-6}
Phenanthrene	8.356×10^{-6}	1.062×10^{-5}
Fluoranthene	1.936×10^{-6}	1.507×10^{-5}
Pyrene	3.743×10^{-6}	2.891×10^{-5}
Benz(a)anthracene	1.682×10^{-7}	5.155×10^{-6}
Chrysene	2.441×10^{-7}	1.083×10^{-5}
Benzo(a)pyrene	ND	ND
Benzo(b)fluoranthene	ND	ND
Benzo(k)fluoranthene	ND	ND
Indeno(1,2,3-cd)pyrene	ND	ND
Benzo(g,h,i)perylene	ND	2.633×10^{-6}
Dibenz(a,h)anthracene	ND	ND

Note:
[1] ND = not detected, fractions set to 0.

4.3 Metals

Emission factors for chromium 6, manganese, nickel, elemental gas-phase mercury (Hg), reactive gas-phase Hg, particulate Hg, and arsenic were developed based on the same data used for the onroad CNG emission factors in MOVES (see onroad air toxics report[9]) due to the lack of nonroad emissions test data for these compounds. For Chromium 6 and nickel, the CNG onroad emission factors originate from measurements made by Okamoto et al. (2006)[28] on a CNG transit bus operating on the Central Business District (CBD) driving cycle. We used

Equation 8 to calculate fuel-based chromium 6 and nickel emission factors for nonroad equipment.

$$
\begin{aligned}
&Nonroad\ CNG\ emission\ factor\ (\frac{g}{gal}) \\
&= Emission\ rate_{(\frac{g}{mi})} \times \frac{1}{Energy\ rate_{(\frac{KJ}{mi})}} \times\ Energy\ Content_{(\frac{KJ}{g})} \\
&\quad \times Fuel\ Density_{(\frac{g}{gal})} \\
&= Emission\ rate_{(\frac{g}{mi})} \times \frac{1}{45137.4_{(\frac{KJ}{mi})}} \times 48.632_{(\frac{KJ}{g})} \times 2.767_{(\frac{g}{gallon})}
\end{aligned}
$$

Equation 8

Where:
Average energy rate measured for a model year 2000 CNG transit bus operating on the CBD driving cycle reported in the MOVES HD emissions rate report[29]= 45,137.4 (KJ/mile)
Default CNG energy content in MOVE = 48.632 (KJ/g)
Fuel density of CNG at ambient temperature and pressure (uncompressed)=2.767 (g/gallon)

The resulting emission rates calculated using Table 4-4 are presented in Table 4-4.

Table 4-4 Chromium 6+ and Nickel Emission Factors for Nonroad CNG Engines

Pollutant	CNG Transit Bus Emission Rate (g/mi)	CNG Emission Rate (g/g-fuel)	CNG Nonroad Emission Rate (g/gal)
CR6+	2.20×10^{-7}	2.37×10^{-10}	6.56×10^{-10}
Nickel	3.06×10^{-5}	3.30×10^{-8}	9.14×10^{-8}

We derived the elemental gas-phase mercury (Hg), reactive gas-phase Hg, particulate Hg, and arsenic emission rates for CNG nonroad equipment from the nonroad gasoline emission rates. We assume that the grams-per-grams-fuel burned emission rates are the same for gasoline and CNG fuels. We first converted the grams-per-gallon gasoline emission rates from Table 4-4 to grams-per-grams gasoline using the energy density of conventional onroad gasoline in MOVES (2,839 g/gal). We then converted the grams-per-grams-gasoline emission rates to grams-per-gallon-CNG using
Equation **9**.

$$
\begin{aligned}
&Nonroad\ CNG\ emission\ factor_{(\frac{g}{gal})} \\
&= Gasoline\ emission\ rate_{(\frac{g}{g-fuel})} \times CNG\ Fuel\ Density_{(\frac{g-fuel}{gal})} \\
&= Gasoline\ emission\ rate_{(\frac{g}{gallon})} \times \left(\frac{1\ gallon}{2{,}839\ g}\right) \times 2.767_{(\frac{g-fuel}{gallon})}
\end{aligned}
$$

Equation 9

Where:
Gasoline emission rate (g/gallon) = Elemental gas-phase mercury (Hg), reactive gas-phase Hg, particulate Hg, and arsenic emission rates in Table 2-4 (g/gallon)
Energy density of conventional gasoline = 2,839 g/gal
Fuel density of CNG at ambient temperature and pressure (uncompressed)=2.767 (g/gallon)

The resulting emission rates calculated using Equation 9 are presented in Table 4-5.

Table 4-5 Manganese, Mercury, and Arsenic Metal Emission Factors for Nonroad CNG Engines

Pollutant	Gasoline Emission Rate (g/gal)	Emission Rate (g/g-gasoline)	CNG Emission Rate (g/gal)
Manganese	2.72×10^{-5}	9.57×10^{-9}	2.65×10^{-8}
Elemental Gas-Phase Hg	1.80×10^{-6}	6.34×10^{-10}	1.75×10^{-9}
Reactive Gas-Phase Hg	1.70×10^{-7}	5.99×10^{-11}	1.66×10^{-10}
Particulate Hg	6.90×10^{-9}	2.43×10^{-12}	6.73×10^{-12}
Arsenic	6.33×10^{-5}	2.23×10^{-8}	6.16×10^{-8}

4.4 Dioxins and Furans

Emission factors for 17 dioxins and furans were developed based on emission factors from onroad gasoline engines[9] because of a lack of available data for nonroad CNG engines (Table 4-5). Because PAHs are emitted from CNG engines, and formation of dioxins and furans can be driven by the presence of these compounds combined with the availability of chlorine,[30] it is reasonable to expect CNG engines emit dioxins. Therefore, we concluded it was better to use surrogate data rather than assume emissions are zero. Onroad emission rates from MOVES were used as surrogates, and we assume that the fuel-specific (g/kg-fuel) emission rates are the same for gasoline and CNG fuels.

MOVES estimates CNG nonroad dioxin emissions from CNG fuel-usage expressed in gallons at ambient pressure and volume (2.767 g/gallon). We converted the grams-per-gram-fuel to grams-per-gallon-CNG using Equation 10. The gasoline fuel-based emission rates and resulting CNG grams-per-gallon emission factors are shown in Table 4-6.

$$Nonroad\ CNG\ emission\ factor_{(\frac{g}{gal})} = Gasoline\ emission\ rate_{(\frac{g}{g-fuel})} \times CNG\ Fuel\ Density(2.767)_{(\frac{g-fuel}{gal})} \quad \textbf{Equation 10}$$

Where:
Gasoline emission rate (g/g-fuel) = Stored in Table 4-6.
Fuel density of CNG at ambient temperature and pressure (uncompressed)=2.767 (g/gallon)

Table 4-6. Dioxin and Furan Emission Factors for Nonroad CNG Engines

Pollutant	Emission Factor (g/g-fuel)	CNG (g/gallon)
2,3,7,8-Tetrachlorodibenzo-*p*-Dioxin (TCDD)	6.85×10^{-15}	1.89×10^{-14}
1,2,3,7,8-Pentachlorodibenzo-*p*-Dioxin	3.06×10^{-15}	8.47×10^{-15}
1,2,3,4,7,8-Hexachlorodibenzo-p-Dioxin	3.20×10^{-15}	8.86×10^{-16}
1,2,3,6,7,8-Hexachlorodibenzo-p-Dioxin	6.56×10^{-15}	1.81×10^{-14}
1,2,3,7,8,9-Hexachlorodibenzo-p-Dioxin	4.08×10^{-15}	1.13×10^{-14}
1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	4.93×10^{-14}	1.36×10^{-13}
Octachlorodibenzo-p-dioxin	3.90×10^{-13}	1.08×10^{-12}
2,3,7,8-Tetrachlorodibenzofuran	2.28×10^{-14}	6.32×10^{-14}
1,2,3,7,8-Pentachlorodibenzofuran	1.09×10^{-14}	3.02×10^{-14}
2,3,4,7,8-Pentachlorodibenzofuran	8.00×10^{-15}	2.21×10^{-14}
1,2,3,4,7,8-Hexachlorodibenzofuran	9.02×10^{-15}	2.50×10^{-14}
1,2,3,6,7,8-Hexachlorodibenzofuran	9.60×10^{-15}	2.66×10^{-14}
1,2,3,7,8,9-Hexachlorodibenzofuran	2.62×10^{-15}	7.26×10^{-15}
2,3,4,6,7,8-Hexachlorodibenzofuran	1.13×10^{-14}	3.11×10^{-14}
1,2,3,4,6,7,8-Heptachlorodibenzofuran	1.00×10^{-13}	2.77×10^{-13}
1,2,3,4,7,8,9-Heptachlorodibenzofuran	3.20×10^{-15}	8.86×10^{-15}
Octachlorodibenzofuran	1.13×10^{-13}	3.14×10^{-13}

5 Liquefied Petroleum Gas

5.1 Organic Gas Aggregations and Air Toxic Emission Factors

In the absence of nonroad LPG VOC data, the onroad VOC speciation profile 8860 was used to develop exhaust VOC toxic fractions for nonroad LPG engines (Table 5-1).[31,32] This profile is based on the average of three light-duty onroad LPG vehicles equipped with three-way catalysts, tested in 2003. It should be noted since this profile is based on data from catalyst-equipped onroad vehicles, it may not be representative of the nonroad equipment.

Table 5-1. VOC Toxic Fractions for Nonroad LPG Engines

Pollutant	Fraction
1,3-butadiene	0.000357
Acetaldehyde	0.004466
Acetylene	0.001189
Acrolein	0.004924
Ethane	0.05549
Ethylene	0.038902
Formaldehyde	0.024523
Methane	0.176432
N-butane	0.001402
Propane	0.658555
Propylene	0.017313
Unknown	0.016448

The VOC ratios calculated from the 8860 speciation profile following a method similar to that used for nonroad gasoline engines are presented in
Table 5-2. In absence of a THC or NMHC measurement, we calculated NMHC by reversing the equation in 40 CFR §1066.635 as shown in
Equation **11**.

$$m_{NMHC} = m_{NMOG} - m_{oxygenates} + \rho_{NMHC} \cdot \sum_{i=1}^{N} \frac{m_{oxygenate_i}}{\rho_{oxygenate_i}} \cdot FID_{RF_i} \qquad \textbf{Equation 11}$$

Where:
m_{NMHC} = the mass of NMHC
m_{NMOG} = the mass of NMOG in the exhaust
$m_{\text{oxygenates}}$ = the mass of formaldehyde and acetaldehyde (Table 5-1)
ρ_{NMHC} = the effective C_1-equivalent density of NMHC, calculated using a C:H ratio of 1:2.64
$m_{\text{oxygenate } i}$ = the mass of oxygenated species *i* in the exhaust as indicated in Table 5-1
$\rho_{\text{oxygenate } i}$ = the C_1-equivalent density of oxygenated species *i*

Table 5-2. Organic Gas Aggregations Estimated from THC for Nonroad LPG Engines

Aggregation	THC Ratio
NMOG/NMHC	1.035
CH_4/THC	0.181
VOC/NMHC	0.965
VOC/THC	0.790
TOG/THC	1.028

5.2 Polycyclic Aromatic Hydrocarbons

The toxic fractions used for PAHs from nonroad LPG engines are the same as those for nonroad CNG engines (Table 4-3).

5.3 Metals

For metals, we used the same fuel-specific emission factors for LPG as for CNG. For use in MOVES, we calculate gram-per-gallon-LPG emission factors using the default MOVES LPG fuel density (1,923 g/gallon), as shown in Equation 12.
Table 5-3 presents g/g-fuel emission rates and resulting g/gal emission factors.

$$Nonroad\ LPG\ emission\ factor_{(\frac{g}{gal})} = CNG\ emission\ factor_{(\frac{g}{g-fuel})} \times LPG\ fuel\ density_{(\frac{g}{gallon})}$$

Equation 12

Where:
CNG fuel-based emission factor (g/g-fuel) = Stored in Table 5-3.
MOVES default fuel density of LPG=1,923 (g/gallon)

Table 5-3 Metal Emission Factors for Nonroad LPG Engines

Pollutant	Emission Factor (g/g-fuel)	LPG Nonroad Emission Factor (g/gal)
CR6+	2.37×10^{-10}	4.56×10^{-7}
Nickel	3.30×10^{-8}	6.35×10^{-5}
Manganese	9.57×10^{-9}	1.84×10^{-5}
Elemental Gas-Phase Hg	6.34×10^{-10}	1.22×10^{-6}
Reactive Gas-Phase Hg	5.99×10^{-11}	1.15×10^{-7}
Particulate Hg	2.43×10^{-12}	4.67×10^{-9}
Arsenic	2.23×10^{-8}	4.28×10^{-5}

5.4 Dioxins and Furans

As for nonroad CNG engines, we used the gasoline fuel-specific emission factors for dioxins and furans. We converted the factors from units of gram-per-gram-fuel to gram-per-gallon-LNG using the default LPG fuel density in MOVES (1,923 g/gallon) as shown in Equation 13. The resulting dioxin and furan emission factors are shown in Table 5-4.

$$Nonroad\ LPG\ emission\ factor_{(\frac{g}{gal})} = Gasoline\ emission\ factor_{(\frac{g}{g-fuel})} \times LPG\ fuel\ density_{(\frac{g}{gallon})}$$ **Equation 13**

Where:

Gasoline emission rate (g/g-fuel) = Stored in Table 4-6 and Table 5-4.
MOVES default fuel density of LPG=1,923 (g/gallon)

Table 5-4. Dioxin and Furan Emission Factors for Nonroad LPG Engines

Pollutant	Emission Factor (g/g-fuel)	LPG Emission Factor (g/gallon)
2,3,7,8-Tetrachlorodibenzo-*p*-Dioxin (TCDD)	6.85×10^{-15}	1.32×10^{-11}
1,2,3,7,8-Pentachlorodibenzo-*p*-Dioxin	3.06×10^{-15}	5.89×10^{-12}
1,2,3,4,7,8-Hexachlorodibenzo-p-Dioxin	3.20×10^{-15}	6.16×10^{-12}
1,2,3,6,7,8-Hexachlorodibenzo-p-Dioxin	6.56×10^{-15}	1.26×10^{-11}
1,2,3,7,8,9-Hexachlorodibenzo-p-Dioxin	4.08×10^{-15}	7.85×10^{-12}
1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	4.93×10^{-14}	9.47×10^{-11}
Octachlorodibenzo-p-dioxin	3.90×10^{-13}	7.47×10^{-10}
2,3,7,8-Tetrachlorodibenzofuran	2.28×10^{-14}	4.39×10^{-11}
1,2,3,7,8-Pentachlorodibenzofuran	1.09×10^{-14}	2.10×10^{-11}
2,3,4,7,8-Pentachlorodibenzofuran	8.00×10^{-15}	1.54×10^{-11}
1,2,3,4,7,8-Hexachlorodibenzofuran	9.02×10^{-15}	1.74×10^{-11}
1,2,3,6,7,8-Hexachlorodibenzofuran	9.60×10^{-15}	1.85×10^{-11}
1,2,3,7,8,9-Hexachlorodibenzofuran	2.62×10^{-15}	5.05×10^{-12}
2,3,4,6,7,8-Hexachlorodibenzofuran	1.13×10^{-14}	2.16×10^{-11}
1,2,3,4,6,7,8-Heptachlorodibenzofuran	1.00×10^{-13}	1.93×10^{-10}
1,2,3,4,7,8,9-Heptachlorodibenzofuran	3.20×10^{-15}	6.16×10^{-12}
Octachlorodibenzofuran	1.13×10^{-13}	2.18×10^{-10}

6 Evaporative Emissions

Emissions of toxics from the evaporation of unburned fuel are estimated as fractions of total evaporative VOC. Currently, MOVES only estimates evaporative VOC emissions from nonroad engines powered by gasoline (including gasoline-ethanol blends). Thus, air toxics from evaporative emission processes are only estimated from nonroad gasoline engines in MOVES. We anticipate incorporating evaporative emissions for LPG, CNG (e.g. refueling natural gas leaks), and diesel engines (e.g. spillage emissions) in future versions of MOVES. Although only the gasoline VOC speciation values and associated toxic fractions for evaporative processes are currently used in MOVES, this section documents the HC speciation factors and toxic ratios that are stored in the MOVES database for evaporative emissions from all nonroad engines, including diesel, CNG, and LPG fueled engines.

6.1 Gasoline Engines

6.1.1 Vapor Venting and Refueling Emission Processes

Vapor venting processes in the nonroad portion of MOVES include diurnal fuel, hot soak, and running loss. Refueling emission processes in the nonroad portion of MOVES include spillage loss and displacement vapor loss. In absence of detailed data for nonroad engines, toxic fractions for these evaporative VOC emission processes were taken from onroad vehicles. Simple fractions for air toxics in evaporative non-permeation emissions were obtained from profiles developed for EPA by Environ Corporation, using data from the Auto/Oil program conducted in the early 1990's.[33,34] These toxic fractions are listed below in Table 6-1.

Table 6-1. Toxic Fractions for Evaporative VOC Emissions, for Vapor-venting and Refueling processes

Pollutant	Ethanol Level	
	0.0% (E0)	10% (E10)
Ethanol	0.00000	0.11896
2,2,4-Trimethylpentane	0.01984	0.03354
Ethyl Benzene	0.02521	0.01721
N-Hexane	0.02217	0.02536
Toluene	0.09643	0.14336
Xylene	0.07999	0.06423
Benzene	0.03318	0.03187

6.1.2 Permeation

Permeation processes in the nonroad portion of MOVES include tank and hose permeation. In absence of detailed permeation data for nonroad engines, toxic fractions representing permeation emissions were taken from onroad vehicles. The study characterizing permeation emissions was conducted by Southwest Research Institute for EPA and the Coordinating Research Council in the CRC E-77-2b test program.[35] It is important to note that tank and hose permeation were not differentiated in the onroad portion of MOVES and the supporting studies. Thus, data on separate tank and hose permeation processes is unavailable and a single value is used in

MOVES. The toxic fractions representing permeation emissions are listed below in Table 6-2. Each of the toxic fractions listed in Table 6-2 are applied across all nonroad gasoline engine types.

Table 6-2. Toxic Fractions Representing Permeation Emissions as Components of Total VOC Emissions

Pollutant	Ethanol Level	
	0.0% (E0)	10% (E10)
Ethanol	0.000	0.202
2,2,4-Trimethylpentane	0.036	0.024
Ethyl Benzene	0.003	0.001
N-Hexane	0.050	0.065
Toluene	0.110	0.101
Xylene	0.016	0.011
Benzene	0.025	0.023

6.2 Diesel Engines

As stated earlier, MOVES does not estimate evaporative or refueling emissions from diesel nonroad engines. Currently, the CH_4/THC values are zero for these processes, and the NMOG/NMHC and VOC/NMHC values are set to one. The toxic ratios are also set equal to zero currently as placeholder values.

6.3 CNG and LPG Engines

As stated earlier, MOVES does not estimate evaporative or refueling emissions from CNG or LPG emissions. However, the MOVES database contains CH_4/THC, NMOG/NMHC, and VOC/NMHC values based on data analysis of CNG and LPG fuels.

We estimated organic gas aggregation values for evaporative and refueling emissions based on speciated measurements of CNG fuel reported by Kato et al. (2005).[36] Table 6-3 includes the speciated measurements from two CNG fuel samples measured by Kato et al. (2005) used for fueling CNG transit buses operating in Los Angeles, California. From the two fuel samples, we calculated an average weight percent of methane, ethane, and propane, normalized to the total hydrocarbon emissions. From these values, we calculated CH_4/THC, NMOG/NMHC, and VOC/NMHC values as shown in Table 6-4.

Table 6-3. Speciation of CNG Fuel Reported by Kato et al. (2005)[36]

Species	mole %, Test 1	mole %, Test 2	Average mole %	g/mol	Average weight %, normalized to THC
Methane	94.33%	86.93%	90.63%	16.04	86.32%
Ethane	2.43%	6.40%	4.42%	30.07	7.88%
C3-propane	0.83%	3.60%	2.22%	44.1	5.80%
CO2 + N2	2.14%	2.39%	2.27%		
Oxygen	0.07%	0.12%	0.10%		

Table 6-4. Estimated Organic Gas Aggregations Used for Evaporative and Refueling CNG Emissions Calculated from Table 6-3

Pollutant Ratio	Calculation	Value
CH_4/THC	CH_4/(CH_4 + ethane + C3-propane)	0.863
NMOG/NMHC	(C3-propane + ethane)/(C3-propane + ethane)	1.0
VOC/NMHC	C3-propane/(C3-propane + ethane)	0.424

Organic gas aggregations for evaporative and refueling emissions from LPG-fueled nonroad equipment were estimated from the speciation profile ('LPG from Super Energy Propane & Westex Conversion' #2444).[31] The weight percent of the organic species are provided in Table 6-5.

Table 6-5. Organic Speciation of LPG Fuel Reported by SPECIATE Profile 2444[31], and the Estimated Organic Gas Aggregations Used for Evaporative and Refueling LPG Emissions

Species	Weight Percent
Propane	91.91%
Ethane	7.31%
Isobutane	0.42%
Propylene (1-Propene)	0.25%
N-butane	0.11%
Organic Aggregation	**Ratio**
CH4/THC	0.000
NMOG/NMHC	1.000
VOC/NMHC	0.927

As for diesel, the toxic ratios are currently set to zero as placeholder values.

7 Crankcase Exhaust Emissions

Unlike onroad, MOVES does not estimate CO, NO_X, and PM crankcase emissions from nonroad engines. However, MOVES does produce organic gas aggregations (e.g., VOC) and air toxics (e.g., benzene) that are based on the THC crankcase emissions.

MOVES models THC crankcase emissions from nonroad equipment using ratios to tailpipe exhaust using the ratios shown in Table 7-1. The crankcase/exhaust THC ratios are documented in the NONROAD spark-ignition[37] and compression-ignition[17] exhaust and crankcase emission factor reports.

By model year 2004, all nonroad gasoline, LPG, and CNG engines are modeled to have no crankcase emissions, due to pre-control engines adopting closed crankcases and the implementation of the Phase 1 nonroad gasoline standards (which require closed crankcases on all spark-ignition engines under 25 hp and all recreational equipment). Tier 4 compression-ignition engines are modeled to have no crankcase emissions, because Tier 4 engines are assumed to either have closed crankcase emission systems, or the crankcase emission systems are included in the tailpipe exhaust emission rates.[17]

Table 7-1. Crankcase/Exhaust THC Ratios Used in MOVES for Nonroad Equipment

Fuel	Nonroad engines	Crankcase/Exhaust THC Ratio
Gasoline	2-stroke	0
	4-stroke gasoline recreational marine	0
	Baseline (Pre-control) lawn and garden 4-stroke gasoline < 25 HP	0.083
	Other Baseline (Pre-control) 4-stroke	0.393
	Pre-control 4-stroke recreational equipment equipped with closed crankcases	0
	Phase 1 or later 4-stroke engines	0
LPG and CNG	Baseline (Pre-control) LPG and CNG	0.33
	Phase 1 or later LPG and CNG	0
Diesel	Compression-ignition Tier 3 and prior engines	0.02
	Compression-ignition Tier 4 engines (including Tier 4 transitional)	0

7.1 Organic Gas Aggregations and Air Toxic Emission Factors

MOVES models crankcase CH_4, NMHC, NMOG, VOC, and TOG using the corresponding ratios for tailpipe exhaust. From crankcase VOC emissions, MOVES estimates all of the VOC toxics listed in Table 1-1, using the corresponding toxic/VOC ratios used for modeling toxics from the tailpipe exhaust.

7.2 Polycyclic Aromatic Hydrocarbons

Similar to the VOC toxics, the gaseous phase PAH toxics are modeled from the crankcase VOC emission, using the same PAH factors used for tailpipe exhaust.

Particle phase PAHs (based off of $PM_{2.5}$) are not modeled for crankcase emissions as the nonroad portion of the model does not currently model crankcase PM.

7.3 Metal and Dioxin Emissions

MOVES does not produce crankcase emission rates for metals, dioxins or furans from nonroad or onroad engines. Because crankcase emissions are small in comparison to exhaust emissions, we assume that these emissions are negligible.

Appendix A Development of Exhaust TOG and VOC Speciation Profiles for Spark-Ignition and Compression-Ignition Nonroad Engines.

A.1 Introduction

Exhaust emissions from nonroad engines or equipment vary based on engine/equipment type, control technology, fuel, and operating conditions. Characterizing the magnitude and chemical composition of these emissions is necessary for inventory and air quality modeling. To model the impact of air pollutant emissions, speciation profiles are used to distribute individual chemical compounds in total organic gas (TOG) emissions into emission estimates for individual species. However, speciation data for nonroad engines is limited, especially for engines with emission controls running on gasoline/ethanol blends and more recent diesel technologies.

In this document, we present the results of an extensive review and analysis of available speciation data for TOG. Our review concluded that the best available data sets for nonroad engines that had different levels of emission controls and were running on representative fuels were from two test programs conducted by Southwest Research Institute (SwRI), under contracts from EPA. Exhaust emissions data from these programs were used to create TOG speciation profiles for nonroad spark-ignition (SI) engines[5] and nonroad compression ignition (CI) engines.[6,7] Data from the SI engine test program provided the basis for profiles of uncontrolled 2-stroke and 4-stroke engines operating on gasoline (E0) and gasoline containing 10 percent ethanol by volume (E10). Data from the CI engine test programs using low and high sulfur diesel fuel provided the basis for profiles of pre-Tier 1, Tier 1, and Tier 2 engines with varying power levels. Profiles were developed for use in air quality modeling runs such as those done with the Community Multi-scale Air Quality (CMAQ) model and were submitted to EPA's database for TOG and particulate matter (PM) speciation profiles. This database, called SPECIATE, maintains the record of each profile including its referenced source, testing methods, a subjective rating of the quality of the data, and other detailed data that allow researchers to decide which profile is most suitable for model input.

A.2 Methods

A.2.1 Exhaust Emissions Data

A.2.3.1 Engines

Engines in the SI test program include those in Table A2-1. Seven small off-road engines (SOREs) were used to create E0 and E10 4-stroke uncatalyzed profiles. The profiles were applied to all off-road 4-stroke engines regardless of size. These engines include two mowers, two riding mowers, two generators and a blower (three non-handheld Class I, three non-handheld Class II, one handheld). Data on recreational vehicles from the SI test program, including two all-terrain vehicles (ATVs) and two nonroad motor cycles (NRMCs), were used to create E0 and E10 2-stroke uncatalyzed profiles. It should be noted that the 4-stroke blower and 2-stroke

ATVs and NRMC are not representative of most engines for those equipment types. Engines in the CI test programs are listed in Table A2-2 and include a forklift truck, construction engines/equipment, and an agricultural tractor.

Table A2-1. Spark-Ignition Test Engines and Equipment

Type		SORE	SORE	SORE	SORE	SORE	SORE	SORE
Equipment	Make	MTD	Honda	MTD 638RL	Snapper	Briggs & Stratton	Honda	Makita
	Model Year	2006	2007	2007	2007	2004	2006	2007
	Model	11A-084F229	HRC 2163HXA	Yard machine 13A1762F229	S150X	Elite Series 6200 30386	EB11000	BHX2500
	Type	22" Mower	Mower	Riding Mower	Riding Mower	Generator	Generator	Blower
Engine	Make	Briggs & Stratton	Honda	Techumseh	Kawasaki	Briggs & Stratton	Honda	Makita
	Model	10T502158	GXV160	OV 358 EA	FH641V-ES25-R	1015499427	GX620KI	EHO25
	2-stroke or 4-stroke	4	4	4	4	4	4	4
	Three-way Catalyst	No	No	No	No	No	No	No

Type		NRMC	NRMC	ATV	ATV
Engine	Make	Honda	Kawasaki	Yamaha	Polaris
	Model	CR125	KX250	Blaster	Trailblazer
	Model Year	2007	2002	2006	2005
	2-stroke or 4-stroke	2	2	2	2
	Three-way Catalyst	No	No	No	No
	Oil Lubrication	Pre-mixed	Pre-mixed	Injected	Injected

Table A2-2. Compression-Ignition Test Engines

Intended Application	Manufacturer	Model	Model Year	Tier	hp	rpm
forklift truck	Kubota	V2203E	1999	1	50	2800
construction equipment	Cummins	QSL9	1999	1	330	2000
rubber-tired loader	Caterpillar	3408	1999	1	480	1800
motor grader	Deere	6068T	1996	0	160	2200
Excavator	Cummins	M11C	1997	1	270	1700
agricultural tractor	Caterpillar	3196	2001	2	420	2100
telescoping boom excavator	Cummins	ISB190	2001	1	194	2300

A.2.3.2 Fuels

Test fuels for the SI test program included federal certification fuels (CERT1 and CERT2), fuels used in a concurrent California Air Resources Board (ARB) program which are similar to California Phase III fuel without ethanol (ARB E0), fuel being used for the California ARB program with ten percent ethanol (ARB E10-7), a modified ARB E10 fuel with 10-psi RVP (designated as ARB E10-10), and an EPA gasoline blend of E10. A brief description of the fuels is provided in Table A2-3 and the test properties of these fuels is included in Table A2-4.

Table A2-3. Fuel Used for SI Engine Testing

Fuels	Fuel description
CERT1	Federal Certification, non-oxygenated
CERT2	Federal Certification, non-oxygenated
ARB E0	Non-oxygenated gasoline
ARB E10-7	10% ethanol, RVP 7 psi
ARB E10-10	10% ethanol, RVP 10 psi by adding butane to ARB E10-7
EPA-E10	10% ethanol, RVP 9 psi

Table A2-4. SI Test Fuel Properties

	E0	E10					
Test fuel	ARB E0	CERT1	CERT2	ARB E10-7a	ARB E10-7b	ARB E10-10	EPA-E10
Ethanol (Wt%)	<0.2	<0.1	NP	9.65	9.98	9.69	9.39
RVP (psi)	7.15	8.98	9.2	6.96	6.76	9.79	8.99
T50 (deg F)	228	224	223	214	213	207	211
T90 (deg F)	304	309	318	315	314	313	319
Aromatics (Vol%)	31.78	31.5	27.9	22.08	24.92	22.66	24.7
Benzene (Wt%)	0.31	0.7*	NR	0.97	0.72*	0.70*	0.68
Sulfur Content (ppm)	<10	2.3	3.2	<10	2.8	4.6	21.9

Note:
NP = Not performed for this non-oxygenated fuel

NR = Not reported

* Benzene content reported as volume percent

Fuels used in the CI test programs were an emissions certification test grade Type-2D diesel fuel and a high-sulfur Nonroad-2D diesel fuel. The Type-2D fuel had a sulfur level of 390 ppm and the Nonroad-2D had a sulfur level of 2570 ppm. Additional fuel properties are described in Table A2-5. The high-sulfur diesel fuel was in compliance with EPA fuel sulfur regulations at the time of the test program. The Type-2D diesel fuel sulfur level complies with EPA diesel fuel sulfur standards (500 ppm) for nonroad engines as of 2007. Nonroad diesel fuel sulfur levels have been further tightened by the Tier 4 Nonroad Diesel Rule to 15 ppm starting in 2010 and fully phased in by 2015.

Table A2-5. CI Test Fuel Properties

Test fuel	Type-2D	Nonroad-2D
Sulfur, ppm	390	2570
Cetane Number	48.0	46.1
T50 (deg F)	505	511
T90 (deg F)	618	613
Total Aromatics (Vol%)	32.15	31.9
Saturates (Vol%)	66.05	67.45
Specific Gravity	0.8444	0.8507
API Gravity	36.1	34.8

A.2.3.3 Sample Collection and Analysis, Spark-Ignition Engines

Exhaust emission testing for the small SI engines was performed using modal test cycles applicable to the type of equipment. One complete emission test was performed with each test fuel using dilute exhaust test methodologies. Steady-state modal emissions tests were performed on the small SI engines. More detail on the steady-state operation modes used on these engines can be found in Table 18 of the SI test report.[5] All non-handheld engines were tested with the governor in control of load, and speed was controlled by the dynamometer according to 40CFR Part 1065.510 protocols. Handheld engine load and speed were controlled by the engine operator and dynamometer, respectively.

Testing for the ATVs and NRMCs was conducted using a Superflow CycleDyn Motorcycle and ATC eddy-current (chassis) dynamometer modified for vehicle-plus-driver weights as low as 153 kg (337 lbs.). Each ATV and NRMC was tested using the Urban Dynamometer Drive Schedule (UDDS) drive cycle from 40 CFR, Part 86, Appendix I. The test cycle consists of two test intervals of the UDDS, each 1370 s long (7.5 miles). The first test interval begins with a single cold-start UDDS. The two test intervals were separated by stopping the test vehicle for 10 minutes. Composite emission rates were calculated using weighting factors of 0.43 and 0.57 for the first (cold-start and running) and second phases (hot-start and running), respectively.

Regulated emissions were measured along with aldehydes, alcohols, ammonia, nitrous oxide, and speciated hydrocarbons. Exhaust samples were analyzed for the presence of more than 200 different exhaust species. Proportional dilute exhaust gas samples were collected in bags for the analysis of hydrocarbons. Four gas chromatography with flame ionization detector (GC-FID) procedures, using a method similar to the Phase II Auto-Oil method,[F] were used to identify and quantify C2-C4 species, C5-C12 species, benzene and toluene, and alcohols. The collection of alcohols was accomplished by bubbling a fraction of the sample through glass impingers. Aldehyde and ketone samples were collected on cartridges packed with silica gel impregnated with 2,4-dinitrophenylhydrazine (DHPH) and were extracted with acetonitrile. A high

[F] Coordinating Research Council (1997). Auto/Oil Air Quality Improvement Research Program Final Report

performance liquid chromatography (HPLC) procedure was used to analyze aldehydes and ketones. More details on the test procedures can be found in the SI test report, Appendix A.

A.2.3.4 Sample Collection and Analysis, Compression-Ignition Engines

The transient duty cycles used in testing each of these seven engines were the U.S. on-highway heavy-duty Federal Test Procedure (FTP) and the backhoe loader nonroad duty cycle (BHL). Engine emissions were sampled under transient operating conditions for each engine using a test cell control strategy developed for commanding dynamometer and throttle control for each engine over the FTP cycle. The on-highway FTP cycle ran 20 minutes, and the BHL cycle ran 16 minutes. All results were from single tests.

Steady-state engine tests were based on an 8-mode ISO Type-C1 weighting scheme. Calibration and sampling methods of the steady-state C1 test adhered to test procedures in CFR, Part 89, and generally satisfied ISO 8178-1 guidelines.

Prior to emissions testing, engines were run over a preparatory test cycle, followed by a 20-minute engine-off soak period. After engine soak, each transient emission test was run from a hot-start, utilizing procedures and sampling processes given in CFR 40, Part 86, Subpart N. Another 20-minute engine-off soak period separated any duplicate runs of a test cycle.

Measurements of unregulated emissions consisted of carbonyls, ammonia, N_2O, sulfate, and several C_1-C_{12} hydrocarbons. Proportional bag samples of dilute exhaust were analyzed via GC-FID to speciate hydrocarbons from C_1 through C_{12} using a method similar to the Phase II Auto-Oil method.[G] For carbonyls, an array of impingers was used during each emission test to capture gaseous samples of dilute exhaust for later analyses. Formaldehyde and acetaldehyde were measured using a DNPH (2,4-dinitrophenyl solution) technique, as outlined in CFR Title 40, Part 86. A liquid chromatograph was used to quantify additional aldehydes and ketones captured by the impingers in a DNPH solution.

A.2.2 Assignment of SPECIATE Identification Numbers for TOG Speciation Profiles

For use in the SPECIATE database and air quality modeling, each speciated compound must be assigned a unique identification number. SPECIATE identification numbers were matched to compounds in the TOG exhaust emission profiles using CAS numbers. For compounds that did not have a one-to-one match with a SPECIATE identification number, the most similar listed compound was used. Table A2-6 lists the SPECIATE substitutions used in developing the nonroad profiles.

[G] E.R. Fanick (2005). Diesel Exhaust Standard – Phase II: CRC Project No. AVFL-10b. Final Report.

Table A2-6. SPECIATE surrogates used for nonroad profiles

Original Chemical Analysis	SPECIATE Substitution
Dimethylbenzaldehyde	2,5-Dimethylbenzaldehyde
Tert-1-but-2-methylbenzene	1-Methyl-2-tert-butylbenzene
3,4-Dimethylcumene	1,3-Dimethyl-4-isopropylbenzene
Methylpropylbenzene	(1-Methylpropyl)benzene
Cis-1-methyl-2-ethylcyclopentane	Cis-1-ethyl-2-methylcyclopentane
Trans-1-methyl-2-ethylcyclopentane	Tran-1-ethyl-2-methylcyclopentane
3-Ethyl-cis-2-pentene	3-Ethyl-2-pentene
Cyclopentadiene	1,3-Cyclopentadiene
2,2-Dimethylpropane	Neopentane
2-Methylpropene	Isobutylene
2-Methylbutane	Isopentane

For some species that co-elute, the chromatography peak area was split equally between the two compounds by the contractor. For other species, the contractor noted co-elution but only reported one of the co-eluted compounds and assigned all mass to that species. In such cases, the mass was subsequently split equally between the co-eluted compounds and the unreported species were added to the chemical list. The following were indicated as co-eluted species:

2,2-dimethylpentane and methylcyclopentane
3-methyl-3-ethyl-pentane and 3,4-dimethylhexane
Cis-1,4-dimethylcyclohexane and trans-1,3-dimethylcyclohexane
Propylcyclopentane and 2,6-dimethylheptane
2,5-dimethylheptane and 3,5-dimethylheptane
Decane and isobutylbenzene
n-butylbenzene and 1-methyl-4-n-propylbenzene
Isobutyraldehyde and methyl ethyl ketone

Unknown hydrocarbons were reported by the lab according to carbon number as unidentified C5, C6, C7, C8, and C9-C12+. Reported designations were maintained in assigning species identification numbers instead of combining unknowns into one specie identification number.

A.2.3 Speciation Profile Development

A.2.3.1 SI Engine Profiles

Four profiles were developed from the SI engine test program, one for each of the following engine/fuel combinations shown in Table 3-1:
4-stroke uncatalyzed engines running on E0
4-stroke uncatalyzed engines running on E10
2-stroke uncatalyzed engines running on E0
2-stroke uncatalyzed engines running on E10

A speciation profile comprised of weight percents for every compound was created for each individual test by dividing each compound's mass by the total mass of the all species. These individual test profiles were averaged within their respective engine/fuel categories to obtain a

composite profile representing that particular engine/fuel combination. The number of tests for each composite profile are indicated in Table A3-1 (note that CERT1 and CERT2 test fuels are E0 fuels). Two tests, not shown in Table A3-1, were excluded from the 4-stroke E0 profile: the B&S walk behind mower test (1-E10-759) was missing seven low weight paraffins and olefins, and the Honda walk behind mower test (2-E0-776) was missing all alcohol data. We evaluated data to identify potential outliers, defined as outside the range of 3.5 standard deviations. No SI data met this criterion.

Table A3-1. Engine/Fuel Combinations Used for SI Engine Speciation Profile Development

	Engines	Tests	Fuels
4 stroke uncatalyzed, E0	SOREs	7	ARB E0
	SOREs	1	CERT2
4 stroke uncatalyzed, E10	SOREs	6	ARB E10-7
	SOREs	1	EPA-E10
2 stroke uncatalyzed, E0	ATV-Blaster	1	CERT1
	ATV-Polaris	1	CERT1
	NRMC-CR125	1	CERT1
	NRMC-Kawasaki	1	CERT1
2 stroke uncatalyzed, E10	ATV-Blaster	1	ARB E10-10
		1	ARB E10-10
		1	ARB E10-7
	ATV-Polaris	1	ARB E10-7
		1	ARB E10-10
	NRMC-CR125	1	ARB E10-7
		1	ARB E10-10
	NRMC-Kawasaki	1	ARB E10-7
		1	ARB E10-10

Although no outliers meeting the criteria described above were identified, several adjustments were made to individual compounds following a thorough quality assurance assessment of the composite profiles. First, due to the nature of the fuels used in the SI emissions testing, toluene was highly variable across both 2-stoke and 4-stroke uncatalyzed profiles (ranging from 0.05 percent to 12.48 percent). As a result, we replaced the nonroad composite profile toluene values with values from pre-Tier 2 onroad vehicle profiles (from profiles 8750a and 8751a).[31] Specifically, toluene was adjusted to 8.64 percent for the E0 profiles and 7.77 percent for the E10 profiles. Second, the 1,3-butadiene values in the 4-stroke uncatalyzed E0 profiles were replaced with the composite E10 value because the E0 values were low for olefins. Third, 2,3-dimethylhexane in one of the 4-stroke E10 tests (the Makita blower) was zeroed out due to its abnormally high value (1408 mg/hp-hr, 7.6 percent) and erroneously strong influence (1 percent) on the composite profile. Finally, in the 2-stroke non-catalyst E0 profile, one test (the CR125) had an abnormally high fraction of 3-methylpentane (10.8 percent in the hot-start bag), causing the composite profile fraction to be subsequently high (2.5 percent). The composite profile was

adjusted by replacing the high 3-methylpentane value in the hot-start CR125 test with the average value from the other 2-stroke E0 tests.

The profiles for each engine/fuel combination were recalculated following the adjustments outlined above, and the resulting profiles are listed in Table A4-3.

We note that there were emissions test data from 2-stroke catalyst engines, however we were unable to use these tests to create speciation profiles due to many inconsistencies and high values in the data. For example, cyclohexane E10 values were eight times higher than E0 values, 2,2,4-trimethylpentane decreased from E0 to E10 opposite the uncatalyzed profiles), and values of hexane, 3-methylheptane and 3-methyl-cis-2-pentene were abnormally high in the E10 profiles. Without additional test programs on catalyzed 2-stroke engines to validate these variable measurements, we decided to exclude these tests from our analysis.

A.2.3.2 CI Engine Profiles

Three profiles were developed from the CI engine test program by the following emission control categories:
Pre-Tier 1 uncontrolled engines
Tier 1 controlled engines
Tier 2 controlled engines

While both CI engine steady state and transient operation tests are presented in this report, only the transient data were used for NONROAD-MOVES because transient tests better represent real world conditions. In addition, we have a greater number of transient tests, allowing for greater confidence in the data. We initially looked at the breakpoint of 50 horsepower (37 kW) to differentiate low and high horsepower engines because the Tier 1 emission standards for 11 to 50 Hp engines are less stringent (NMHC + NOx g/hp-hr) than +50 hp engines. However, differences in horsepower between profiles were insignificant and thus all Tier 1 engines were grouped together.

As with the SI engine profiles, a speciation profile was first created for each individual test by dividing each compound's mass by the total mass of the all species for that test. These profiles were averaged within their respective emission control/power categories to obtain a composite profile representing that particular control/power combination under steady state and transient operating conditions. The number of tests for each CI engine profile are indicated in Table 3-2. As discussed in Section A2.1.2, tests for each engine were performed on both a high sulfur fuel and a low sulfur fuel. To increase the robustness of the composite profiles, we doubled the number of samples by including tests on both fuel types after our analysis found that speciated compounds had similar weight percent values between high and low sulfur fuel tests (Table 3-3). After incorporating both high and low sulfur fuels, a standard deviation test was performed to identify potential outliers. All measurements outside the range of 3.5 standard deviations were evaluated as potential outliers. Outliers were addressed as described below.

Table A3-2. Engine Combinations Used for CI Engine Speciation Profile Development

	Transient Total Tests	Rated Power (Hp, kW)	Model Year	Engines
Pre-Tier 1	6	160hp 119kW	1996	Deere 6068T motor grader
Tier 1	36	270hp 201kW	1997	Cummins M11C excavator
		194hp 145kW	2001	Cummins ISB190 telescoping boom excavator
		330hp 261kW	1999	Cummins QSL9 construction equipment
		480hp 358kW	1999	Caterpillar 3408 rubber-tired loader
		50hp 37kW	1999	Kubota V2203E forklift truck
Tier 2	6	420hp 313kW	2001	Caterpillar 3196 agriculture tractor

Table A3-3. Regression comparing low and high sulfur diesel fuels

	R^2	Slope	95% confidence interval	
Pre-Tier 1	0.98	0.98	0.95	1.00
Tier 1	0.99	0.99	0.97	1.01
Tier 2	0.91	1.03	0.96	1.09

Following a quality assurance assessment of the initial transient profiles, several adjustments were made to individual compounds. Unusual variability was observed in the 1,3-butadiene tests across all profiles, so all weight percents were replaced with the current NONROAD CI engine exhaust weight percent of 0.18616 percent. The acetone mass in one Caterpillar 3196 high-sulfur fuel test (E12DBHL1) and one Kubota V2203E low-sulfur fuel test (KP2DFTP1) failed the standard deviation checks and were subsequently zeroed out (41.9 mg/hp-hr for the Caterpillar 3196 while all other similar tests were 0.0 mg/hp-hr; 28.1 mg/hp-hr for the Kubota V2203E while all other similar tests were 0-0.7 mg/hp-hr). One Caterpillar 3196 test (E12DFTP1) had an abnormally high propane value which was also zeroed out (19.54 percent where other tests were 0.00 percent). Finally, a different Caterpillar 3196 test (E12DBHL1) had an unrealistically high acetylene value (10.82 percent where the other tests averaged to 1.15 percent); thus we did not use this high value in developing the profile.

The profiles for each emission control/power combination were recalculated following the adjustments outlined above, and the resulting profiles are listed in Table A4-9.

A.3 Results

Chemical comparisons between currently used onroad profiles and the profiles developed in this report are also detailed in the literature.[8] The final composite SI speciation profiles are presented in Tables A4-1, A4-2, and A4-3. Table A4-1 shows percentages of compounds grouped by class. Table A4-2 shows percentages for 10 compounds of interest. Table A4-3 shows the

complete profiles with all compounds and includes CAS and SPECIATE ID numbers. In a similar fashion, the composite CI speciation profiles are presented in Tables A4-4 through A4-9. Composite SI and CI VOC emission factors are presented in Tables A4-10 through A4-12. The assignment of nonroad emissions to SPECIATE profiles is documented in Table A4-13.

Table A4-1. Composite SI TOG Profile Percentages by Compound Class

Compound	E0 % 4 stroke, noncatalyst	E0 % 2 stroke, noncatalyst	E10 % 4 stroke, noncatalyst	E10 % 2 stroke, noncatalyst
Paraffins	33.90	50.88	31.85	47.31
Aromatics	27.32	31.46	24.75	26.72
Olefins	33.76	11.79	35.76	12.98
Aldehyde/Ketones	3.25	0.85	3.06	1.21
Oxygenates	0.47	0.15	2.76	7.76
Unknowns	1.30	4.86	1.81	4.03

Table A4-2. Composite SI TOG Profile Percentages of Selected Compounds

Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
Methane	15.89	1.70	15.40	1.74
Ethylene	8.94	1.79	10.11	1.94
Propylene	5.29	1.14	5.29	1.26
2,2,4-Trimethylpentane	3.76	7.94	4.70	12.72
2-Methylbutane	2.22	10.25	1.46	6.14
Toluene	8.64	8.64	7.77	7.77
m-& p-Xylene	3.58	6.30	4.49	5.27
o-Xylene	1.20	2.27	1.26	1.82
Ethylbenzene	1.79	3.37	1.37	2.18
2,3-Dimethylpentane	1.87	0.62	1.42	0.00

Table A4-3. Composite SI Organic Gas Exhaust Speciation Profiles Displayed as Weight Percentages of TOG

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
1	135-98-8	(1-methylpropyl)benzene	0.00E+00	3.33×10^{-3}	4.43×10^{-2}	3.23×10^{-3}
9	4259-00-1	1,1,2-TRIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	3073-66-3	1,1,3-TRIMETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	4516-69-2	1,1,3-TRIMETHYLCYCLOPENTANE	2.30E-02	0.00E+00	2.54E-02	0.00E+00
19	590-66-9	1,1-DIMETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	1638-26-2	1,1-DIMETHYLCYCLOPENTANE	3.20E-03	8.70E-03	3.16E-03	2.92E-03

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
21	16747-50-5	1,1-Methylethylcyclopentane	5.91E-04	1.86E-02	1.55E-03	1.90E-02
36	135-01-3	1,2 DIETHYLBENZENE	2.73E-02	8.83E-02	0.00E+00	7.61E-02
22	488-23-3	1,2,3,4-TETRAMETHYLBENZENE	1.50E-03	6.99E-02	4.05E-02	6.97E-02
23	527-53-7	1,2,3,5-TETRAMETHYLBENZENE	8.65E-02	1.29E-02	4.89E-02	1.16E-02
25	526-73-8	1,2,3-TRIMETHYLBENZENE	2.24E-01	2.09E-02	1.63E-01	6.39E-02
28	95-93-2	1,2,4,5-TETRAMETHYLBENZENE	1.44E-02	1.26E-01	8.82E-03	1.41E-01
29	877-44-1	1,2,4-TRIETHYLBENZENE	6.84E-04	2.32E-02	0.00E+00	2.02E-02
30	95-63-6	1,2,4-TRIMETHYLBENZENE	1.39E+00	2.10E+00	1.29E+00	2.00E+00
37	933-98-2	1,2-dimethyl-3-ethylbenzene	0.00E+00	5.66E-03	0.00E+00	4.09E-03
39	934-80-5	1,2-DIMETHYL-4-ETHYLBENZENE	1.25E-01	3.58E-02	9.44E-02	2.75E-02
42	463-49-0	1,2-PROPADIENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	102-25-0	1,3,5-TRIETHYLBENZENE	0.00E+00	2.42E-02	0.00E+00	1.84E-02
44	108-67-8	1,3,5-TRIMETHYLBENZENE	4.33E-01	7.52E-01	5.71E-01	7.21E-01
55	934-74-7	1,3,-DIMETHYL-5-ETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	106-99-0	1,3-BUTADIENE	1.02E+00	2.08E-01	1.02E+00	2.65E-01
51	141-93-5	1,3-DIETHYLBENZENE	6.40E-02	1.73E-01	6.40E-02	1.69E-01
52	2870-04-4	1,3-DIMETHYL-2-ETHYLBENZENE	6.25E-02	1.74E-02	2.50E-02	1.38E-02
53	874-41-9	1,3-DIMETHYL-4-ETHYLBENZENE	3.43E-02	7.90E-02	9.26E-02	7.72E-03
54	4706-89-2	1,3-dimethyl-4-isopropylbenzene	2.54E-02	0.00E+00	5.91E-02	0.00E+00
59	105-05-5	1,4-DIETHYLBENZENE	1.98E-02	4.10E-01	0.00E+00	3.91E-01
60	1758-88-9	1,4-DIMETHYL-2-ETHYLBENZENE	5.71E-02	2.50E-01	6.49E-02	2.40E-01
64	106-98-9	1-BUTENE	3.61E-01	1.17E-01	4.34E-01	1.27E-01
65	107-00-6	1-butyne	0.00E+00	0.00E+00	0.00E+00	0.00E+00
357	15890-40-1	1-CIS,2-TRANS,3-TRIMETHYLCYCLOPENTANE	3.53E-02	1.44E-01	5.17E-02	1.56E-01
996	872-05-9	1-DECENE	0.00E+00	1.52E-02	7.69E-02	1.36E-02
75	637-92-3	1-ethyltertbutylether	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	592-76-7	1-HEPTENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	592-41-6	1-HEXENE	3.34E-02	9.29E-02	9.76E-02	1.08E-01
80	611-14-3	1-METHYL-2-ETHYLBENZENE	3.35E-01	6.14E-01	3.36E-01	4.93E-01
81	527-84-4	1-METHYL-2-ISOPROPYLBENZENE	1.77E-01	6.51E-02	2.66E-01	5.08E-02
84	1074-17-5	1-METHYL-2-N-PROPYLBENZENE	3.82E-02	3.65E-02	9.27E-02	2.82E-02
89	620-14-4	1-METHYL-3-ETHYLBENZENE	1.01E+00	1.81E+00	9.11E-01	1.53E+00
90	535-77-3	1-METHYL-3-ISOPROPYLBENZENE	2.83E-01	3.94E-02	2.22E-01	2.65E-02
92	1074-43-7	1-METHYL-3-N-PROPYLBENZENE	1.27E-01	2.20E-01	2.32E-01	1.84E-01
94	622-96-8	1-METHYL-4-ETHYLBENZENE	4.16E-01	7.70E-01	2.98E-01	6.37E-01

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
97	99-87-6	1-METHYL-4-ISOPROPYLBENZENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	1074-55-1	1-METHYL-4-N-PROPYLBENZENE	1.15E-01	4.37E-02	5.86E-02	2.33E-02
103	693-89-0	1-METHYLCYCLOPENTENE	1.42E-02	1.11E-01	6.36E-02	1.66E-01
106	124-11-8	1-NONENE	1.09E-01	1.74E-01	2.41E-02	6.89E-02
107	111-66-0	1-OCTENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
108	109-67-1	1-pentene	0.00E+00	1.71E-01	0.00E+00	2.23E-01
607	71-23-8	1-Propanol	9.58E-02	0.00E+00	5.96E-02	0.00E+00
730	15890-40-1	1-TRANS-2-CIS-3-TRIMETHYLCYCLOPENTANE	7.23E-03	6.32E-02	1.77E-02	7.80E-02
1540	2815-58-9	1-TRANS-2-CIS-4-TRIMETHYLCYCLOPENTANE	0.00E+00	7.46E-02	0.00E+00	6.90E-02
112	464-06-2	2,2,3-TRIMETHYLBUTANE	2.46E-02	5.81E-02	4.54E-02	6.84E-02
113	564-02-3	2,2,3-TRIMETHYLPENTANE	4.21E-01	9.40E-01	2.99E-01	1.05E+00
117	16747-26-5	2,2,4-trimethylhexane	4.45E-03	2.56E-02	0.00E+00	1.93E-02
118	540-84-1	2,2,4-TRIMETHYLPENTANE	3.76E+00	7.94E+00	4.70E+00	1.27E+01
121	3522-94-9	2,2,5-TRIMETHYLHEXANE	3.08E-01	5.77E-01	5.06E-02	4.09E-02
122	75-83-2	2,2-DIMETHYLBUTANE	2.94E-02	9.06E-02	4.12E-02	6.98E-02
123	1071-26-7	2,2-DIMETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
124	590-73-8	2,2-DIMETHYLHEXANE	4.50E-03	9.91E-02	7.65E-03	8.83E-02
125	15869-87-1	2,2-DIMETHYLOCTANE	5.59E-02	9.31E-02	2.81E-02	5.55E-02
126	590-35-2	2,2-DIMETHYLPENTANE	6.08E-02	4.21E-01	2.16E-01	6.11E-01
127	463-82-1	2,2-DIMETHYLPROPANE (NEOPENTANE)	0.00E+00	8.52E-02	0.00E+00	7.04E-02
128	560-21-4	2,3,3-TRIMETHYLPENTANE	6.05E-01	1.45E+00	1.08E-01	2.08E-01
129	921-47-1	2,3,4-TRIMETHYLHEXANE	0.00E+00	1.98E-02	0.00E+00	2.04E-02
130	565-75-3	2,3,4-TRIMETHYLPENTANE	9.31E-01	2.40E+00	2.17E-01	6.65E-01
132	1069-53-0	2,3,5-TRIMETHYLHEXANE	4.82E-02	9.10E-02	1.16E-02	3.74E-02
135	10574-37-5	2,3-DIMETHYL-2-PENTENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
136	79-29-8	2,3-DIMETHYLBUTANE	3.88E-01	7.34E-01	1.95E-01	5.40E-01
137	3074-71-3	2,3-DIMETHYLHEPTANE	0.00E+00	1.81E-02	0.00E+00	2.45E-02
138	584-94-1	2,3-DIMETHYLHEXANE	1.38E-01	0.00E+00	1.14E-02	1.29E-01
140	565-59-3	2,3-DIMETHYLPENTANE	1.87E+00	6.24E-01	1.42E+00	1.47E-03
141	107-39-1	2,4,4-TRIMETHYL-1-PENTENE	7.17E-03	8.99E-02	6.60E-02	1.07E-01
142	107-40-4	2,4,4-TRIMETHYL-2-PENTENE	0.00E+00	1.17E-02	5.20E-02	1.84E-02
143	16747-30-1	2,4,4-TRIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
148	2213-23-2	2,4-DIMETHYLHEPTANE	4.42E-02	7.87E-02	2.31E-02	5.99E-02
149	589-43-5	2,4-DIMETHYLHEXANE	4.78E-01	1.29E+00	3.50E-01	1.14E+00
151	4032-94-4	2,4-DIMETHYLOCTANE	7.68E-03	5.93E-02	3.31E-02	6.70E-02
152	108-08-7	2,4-DIMETHYLPENTANE	1.09E+00	1.41E+00	3.29E-01	9.47E-01
155	2216-30-0	2,5-DIMETHYLHEPTANE	5.39E-02	8.94E-02	3.22E-02	6.76E-02
156	592-13-2	2,5-dimethylhexane	0.00E+00	2.37E-03	0.00E+00	0.00E+00
160	1072-05-5	2,6-DIMETHYLHEPTANE	0.00E+00	4.45E-03	0.00E+00	6.71E-03
170	503-17-3	2-butyne	0.00E+00	0.00E+00	0.00E+00	0.00E+00
511	78-79-5	2-METHYL-1,3-BUTADIENE	1.89E-01	1.09E-01	2.62E-01	1.43E-01
181	563-46-2	2-methyl-1-butene	0.00E+00	2.91E-01	0.00E+00	4.42E-01

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
2185	6094-02-6	2-METHYL-1-HEXENE	0.00E+00	2.66E-02	4.24E-03	2.97E-02
184	763-29-1	2-METHYL-1-PENTENE	3.34E-02	1.04E-01	9.76E-02	1.28E-01
185	513-35-9	2-METHYL-2-BUTENE	2.01E-01	5.86E-01	2.40E-01	7.56E-01
186	2738-19-4	2-methyl-2-hexene	0.00E+00	1.06E-01	1.32E-02	1.32E-01
187	625-27-4	2-METHYL-2-PENTENE	3.68E-02	1.31E-01	7.13E-02	1.84E-01
508	78-78-4	2-METHYLBUTANE (ISOPENTANE)	2.22E+00	1.02E+01	1.46E+00	6.14E+00
2568	03968-85-2	2-METHYLBUTYLBENZENE (sec AMYLBENZENE)	1.18E-02	1.55E-01	0.00E+00	1.54E-01
193	592-27-8	2-METHYLHEPTANE	2.17E-01	7.75E-01	2.07E-01	5.49E-01
194	591-76-4	2-METHYLHEXANE	0.00E+00	2.60E+00	0.00E+00	5.02E+00
198	3221-61-2	2-METHYLOCTANE	1.83E-01	6.15E-01	1.63E-01	4.70E-01
199	107-83-5	2-METHYLPENTANE	3.31E-01	1.73E+00	7.82E-01	2.32E+00
491	75-28-5	2-METHYLPROPANE (ISOBUTANE)	1.40E-01	2.24E-01	3.15E-02	1.58E-02
497	115-11-7	2-METHYLPROPENE (ISOBUTYLENE)	2.66E+00	7.48E-01	3.07E+00	1.02E+00
513	67-63-0	2-Propanol	1.42E-02	1.67E-02	4.77E-03	0.00E+00
203	558-37-2	3,3-DIMETHYL-1-BUTENE	1.80E-02	9.77E-03	3.83E-02	9.95E-03
205	4032-86-4	3,3-DIMETHYLHEPTANE	0.00E+00	3.17E-02	0.00E+00	3.74E-02
206	563-16-6	3,3-DIMETHYLHEXANE	2.53E-02	8.53E-02	4.40E-02	8.09E-02
208	562-49-2	3,3-DIMETHYLPENTANE	2.60E-02	9.62E-02	7.03E-03	4.08E-02
209	7385-78-6	3,4-DIMETHYL-1-PENTENE	8.31E-03	1.69E-02	1.29E-02	2.13E-02
211	922-28-1	3,4-DIMETHYLHEPTANE	0.00E+00	4.27E-02	0.00E+00	2.90E-02
212	583-48-2	3,4-DIMETHYLHEXANE	3.85E-02	8.67E-02	9.33E-03	7.15E-02
215	926-82-9	3,5-DIMETHYLHEPTANE	5.39E-02	8.94E-02	3.22E-02	6.76E-02
221	816-79-5	3-ethyl-2-pentene	0.00E+00	1.00E-02	0.00E+00	1.21E-02
226	619-99-8	3-ETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
229	617-78-7	3-ETHYLPENTANE	2.65E-02	2.14E-01	1.01E-01	3.27E-01
230	563-45-1	3-METHYL-1-BUTENE	4.18E-02	1.98E-01	7.99E-02	1.27E-01
231	3404-61-3	3-methyl-1-hexene	0.00E+00	1.91E-02	0.00E+00	1.98E-02
232	760-20-3	3-METHYL-1-PENTENE	3.09E-02	8.00E-02	4.21E-02	8.82E-02
233	1067-08-9	3-Methyl-3-ethyl-pentane	3.85E-02	8.67E-02	9.33E-03	7.15E-02
236	922-62-3	3-METHYL-CIS-2-PENTENE	3.20E-02	1.56E-01	6.75E-02	2.35E-01
242	1120-62-3	3-METHYLCYCLOPENTENE	3.41E-03	3.00E-03	1.85E-02	3.33E-03
244	589-81-1	3-METHYLHEPTANE	2.69E-01	1.20E+00	2.31E-01	7.25E-01
245	589-34-4	3-METHYLHEXANE	1.89E-01	1.57E+00	4.07E-01	1.35E+00
247	2216-33-3	3-METHYLOCTANE	1.14E-01	4.35E-01	9.49E-02	3.11E-01
248	96-14-0	3-METHYLPENTANE	2.01E-01	1.07E+00	5.36E-01	1.55E+00
239	616-12-6	3-METHYL-TRANS-2-PENTENE	3.70E-02	1.97E-01	9.19E-02	2.74E-01
240	3899-36-3	3-methyl-trans-3-hexene	0.00E+00	0.00E+00	0.00E+00	0.00E+00
253	1068-19-5	4,4-DIMETHYLHEPTANE	4.23E-03	9.56E-02	9.31E-03	7.20E-02
1471	2216-32-2	4-ETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
258	691-37-2	4-METHYL-1-PENTENE	0.00E+00	1.20E-03	0.00E+00	1.95E-02
260	691-38-3	4-METHYL-CIS-2-PENTENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
264	589-53-7	4-METHYLHEPTANE	5.92E-02	7.29E-01	3.44E-02	1.76E-01

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
267	2216-34-4	4-methyloctane	0.00E+00	0.00E+00	0.00E+00	0.00E+00
262	674-76-0	4-METHYL-TRANS-2-PENTENE	5.18E-03	6.54E-02	0.00E+00	8.16E-02
279	75-07-0	Acetaldehyde	3.49E-01	1.01E-01	7.40E-01	3.28E-01
281	67-64-1	Acetone	2.48E-01	3.92E-02	2.04E-01	4.86E-02
282	74-86-2	ACETYLENE	1.35E+01	3.10E+00	1.30E+01	2.69E+00
283	107-02-8	Acrolein	3.05E-02	3.04E-02	3.71E-02	4.33E-02
301	100-52-7	Benzaldehyde	4.26E-01	1.06E-01	2.13E-01	6.51E-02
302	71-43-2	BENZENE	5.64E+00	1.36E+00	3.77E+00	1.23E+00
592	106-97-8	BUTANE	6.22E-01	1.69E+00	5.01E-01	1.17E+00
351	2207-01-4	CIS-1,2-DIMETHYLCYCLOHEXANE	3.55E-02	1.10E-01	3.63E-02	9.95E-02
360	1192-18-3	CIS-1,2-DIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
352	638-04-0	Cis-1,3-dimethylcyclohexane	0.00E+00	0.00E+00	0.00E+00	0.00E+00
353	2532-58-3	CIS-1,3-DIMETHYLCYCLOPENTANE	2.13E-02	6.81E-02	8.82E-02	1.91E-02
354	624-29-3	Cis-1,4-Dimethylcyclohexane	1.14E-03	2.59E-02	7.12E-03	2.71E-02
362	930-89-2	Cis-1-ethyl-2-methylcyclopentane	9.97E-03	8.48E-02	1.65E-02	6.56E-02
364	2613-66-3	CIS-1-METHYL-3-ETHYLCYCLOPENTANE	1.78E-02	4.71E-02	4.03E-02	5.83E-02
367	590-18-1	CIS-2-BUTENE	1.79E-01	7.69E-02	1.95E-01	1.04E-01
368	6443-92-1	CIS-2-HEPTENE	1.62E-02	5.13E-02	2.19E-02	5.69E-02
369	7688-21-3	CIS-2-HEXENE	2.40E-02	7.63E-02	2.06E-02	9.53E-02
370	7642-04-8	CIS-2-OCTENE	0.00E+00	7.55E-02	0.00E+00	1.26E-02
371	627-20-3	CIS-2-PENTENE	1.01E-01	2.15E-01	1.43E-01	2.81E-01
2616	7642-10-6	CIS-3-HEPTENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
372	7642-09-3	CIS-3-HEXENE	5.50E-03	9.20E-02	2.78E-02	1.16E-01
373	20237-46-1	CIS-3-NONENE	0.00E+00	6.70E-03	0.00E+00	6.23E-03
382	4170-30-3	Crotonaldehyde	3.01E-02	1.91E-02	2.45E-02	2.35E-02
385	110-82-7	CYCLOHEXANE	5.26E-02	5.26E-02	5.31E-01	7.58E-02
388	110-83-8	CYCLOHEXENE	1.19E-01	2.77E-02	4.58E-02	3.71E-02
48	542-92-7	CYCLOPENTADIENE	3.47E-01	1.17E-01	3.92E-01	1.21E-01
390	287-92-3	CYCLOPENTANE	3.65E-02	7.45E-02	5.60E-02	1.04E-01
391	142-29-0	CYCLOPENTENE	2.94E-02	9.05E-02	7.18E-02	1.27E-01
598	124-18-5	DECANE	5.43E-02	7.60E-02	3.90E-02	5.86E-02
2735	108-20-3	DI-ISOPROPYL ETHER	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1712	5779-94-2	Dimethylbenzaldehyde	8.82E-02	1.99E-02	4.35E-02	2.37E-02
599	112-40-3	DODECANE	1.90E-02	8.03E-02	9.15E-03	5.22E-02
438	74-84-0	ETHANE	9.26E-01	2.46E-01	8.63E-01	2.86E-01
442	64-17-5	Ethanol	1.40E-01	5.67E-02	2.49E+00	7.63E+00
449	100-41-4	ETHYLBENZENE	1.79E+00	3.37E+00	1.37E+00	2.18E+00
450	1678-91-7	ETHYLCYCLOHEXANE	2.24E-02	1.75E-01	2.44E-02	1.07E-01
451	1640-89-7	ETHYLCYCLOPENTANE	1.95E-03	0.00E+00	1.13E-02	0.00E+00
452	74-85-1	ETHYLENE	8.94E+00	1.79E+00	1.01E+01	1.94E+00
465	50-00-0	Formaldehyde	1.61E+00	3.60E-01	1.45E+00	4.86E-01
600	142-82-5	HEPTANE	2.60E-01	1.15E+00	2.22E-01	6.18E-01

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
840	66-25-1	Hexanaldehyde	9.63E-04	1.89E-03	4.49E-03	1.91E-03
601	110-54-3	HEXANE	1.89E-01	7.55E-01	4.29E-01	6.99E-01
602	1077-16-3	HEXYLBENZENE	0.00E+00	1.78E-02	0.00E+00	2.84E-02
485	496-11-7	INDAN	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	538-93-2	ISOBUTYLBENZENE	5.12E-02	7.17E-02	3.68E-02	5.53E-02
2119	78-84-2	ISOBUTYRALDEHYDE	1.37E-02	9.61E-03	1.97E-02	9.95E-03
514	98-82-8	ISOPROPYLBENZENE (CUMENE)	9.56E-02	1.08E-01	3.83E-02	6.22E-02
2560	3875-51-2	ISOPROPYLCYCLOPENTANE	4.85E-03	1.13E-02	6.00E-03	3.37E-02
517	590-86-3	Isovaleraldehyde	5.06E-02	1.39E-02	4.42E-02	1.85E-02
522	1330-20-7	m-& p-XYLENE	3.58E+00	6.30E+00	4.49E+00	5.27E+00
2164	1334-78-7	m/p-Tolualdehyde	2.67E-01	4.58E-02	1.94E-01	7.57E-02
536	78-93-3	MEK	1.38E-02	9.61E-03	1.97E-02	9.95E-03
529	74-82-8	METHANE	1.59E+01	1.70E+00	1.54E+01	1.74E+00
531	67-56-1	Methanol	1.68E-01	7.63E-02	1.72E-01	1.29E-01
548	1634-04-4	Methyl t-butyl ether (MTBE)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
550	108-87-2	METHYLCYCLOHEXANE	8.24E-02	4.30E-01	2.30E-01	6.30E-01
551	96-37-7	METHYLCYCLOPENTANE	5.96E-02	4.13E-01	2.12E-01	5.99E-01
611	91-20-3	NAPHTHALENE	3.36E-02	5.84E-02	7.17E-02	4.58E-02
595	71-36-3	N-butyl alcohol	5.64E-02	0.00E+00	3.21E-02	0.00E+00
596	104-51-8	n-Butylbenzene	1.15E-01	2.97E-02	5.86E-02	2.33E-02
603	111-84-2	NONANE	1.70E-01	3.41E-01	6.08E-02	1.56E-01
606	538-68-1	N-PENT-BENZENE	2.62E-02	7.75E-02	2.77E-02	8.99E-02
608	103-65-1	n-PROPYLBENZENE	2.76E-01	6.70E-01	2.40E-01	4.75E-01
604	00111-65-9	OCTANE	2.21E-01	4.49E-01	1.44E-01	3.01E-01
1467	529-20-4	o-Tolualdehyde	6.87E-02	4.46E-02	3.34E-02	1.77E-02
620	95-47-6	o-XYLENE	1.20E+00	2.27E+00	1.26E+00	1.82E+00
605	109-66-0	PENTANE	3.33E-01	8.44E-01	3.21E-01	8.67E-01
671	74-98-6	PROPANE	2.68E-01	4.51E-02	7.13E-02	3.05E-02
673	123-38-6	Propionaldehyde	4.07E-02	4.94E-02	3.43E-02	5.10E-02
677	2040-96-2	Propylcyclopentane	0.00E+00	2.99E-03	0.00E+00	6.71E-03
678	115-07-1	PROPYLENE	5.29E+00	1.14E+00	5.29E+00	1.26E+00
109	74-99-7	PROPYNE	3.60E-03	2.27E-02	0.00E+00	1.88E-02
698	100-42-5	STYRENE	7.93E-01	2.18E-01	5.86E-01	1.73E-01
701	994-05-8	T-amylmethylether	0.00E+00	0.00E+00	0.00E+00	0.00E+00
86	1074-92-6	TERT-1-BUT-2-METHYLBENZENE	3.58E-03	1.29E-01	3.00E-02	1.57E-01
63	98-19-1	TERT-1-BUT-3,5-DIMETHYLBENZENE	2.24E-03	1.16E-01	7.28E-04	1.36E-01
2329	7364-19-4	TERT-1-BUTYL-4-ETHYLBENZENE	0.00E+00	5.62E-02	2.33E-02	6.05E-02
703	98-06-6	TERT-BUTYLBENZENE	0.00E+00	2.98E-02	0.00E+00	3.14E-02
717	108-88-3	TOLUENE	8.64E+00	8.64E+00	7.77E+00	7.77E+00
724	6876-23-9	TRANS-1,2-DIMETHYLCYCLOHEXANE	5.85E-03	3.84E-01	2.20E-02	1.73E-01
725	822-50-4	TRANS-1,2-DIMETHYLCYCLOPENTANE	2.86E-02	1.01E-01	2.88E-02	9.91E-02

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
726	2207-03-6	TRANS-1,3-DIMETHYLCYCLOHEXANE	1.14E-03	3.07E-02	7.12E-03	3.03E-02
727	1759-58-6	TRANS-1,3-DIMETHYLCYCLOPENTANE	3.23E-03	2.27E-01	0.00E+00	3.52E-01
729	2207-04-7	TRANS-1,4-DIMETHYLCYCLOHEXANE	0.00E+00	9.26E-03	9.87E-03	2.39E-02
1586	930-90-5	Trans-1-ethyl-2-methyl-cyclopentane	1.60E-03	9.08E-02	2.66E-02	1.12E-01
736	2613-65-2	TRANS-1-METHYL-3-ETHYLCYCLOPENTANE	0.00E+00	1.05E-01	2.55E-02	1.37E-01
737	624-64-6	TRANS-2-BUTENE	3.20E-01	2.04E-01	2.53E-01	2.28E-01
739	14686-13-6	TRANS-2-HEPTENE	1.23E-02	5.96E-02	2.47E-02	6.73E-02
740	4050-45-7	TRANS-2-HEXENE	1.29E-02	1.40E-01	4.27E-02	1.78E-01
2244	6434-78-2	TRANS-2-NONENE	0.00E+00	1.25E-02	0.00E+00	7.99E-03
741	13389-42-9	TRANS-2-OCTENE	6.34E-03	8.23E-02	4.15E-02	1.11E-01
742	646-04-8	TRANS-2-PENTENE	3.34E-02	3.75E-01	9.06E-02	4.91E-01
743	14686-14-7	TRANS-3-HEPTENE	7.30E-04	8.62E-02	2.57E-02	1.09E-01
744	13269-52-8	TRANS-3-HEXENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
745	20063-92-7	TRANS-3-NONENE	0.00E+00	4.49E-02	1.18E-02	5.13E-02
746	14850-23-8	Trans-4-octene	0.00E+00	5.47E-02	0.00E+00	4.55E-02
610	1120-21-4	UNDECANE	3.12E-02	1.14E-01	3.21E-02	1.08E-01
1989	#N/A	UNIDENTIFIED C5 OLEFINS	0.00E+00	1.35E-02	0.00E+00	8.74E-03
1999	#N/A	UNIDENTIFIED C6	1.32E-01	7.24E-02	1.57E-01	6.99E-02
2005	#N/A	UNIDENTIFIED C7	1.03E-01	7.53E-01	9.89E-02	2.70E-01
2011	#N/A	UNIDENTIFIED C8	1.99E-03	1.63E-01	8.50E-03	1.17E-01
327	#N/A	UNIDENTIFIED C9-C12+	1.06E+00	3.86E+00	1.55E+00	3.56E+00
845	110-62-3	Valeraldehyde	1.34E-02	4.47E-03	4.39E-03	4.73E-03

Table A4-4. Composite Transient CI TOG Profile Percentages by Compound Class

Compound	Pre-Tier 1	Tier 1	Tier 2
Paraffins	**16.55**	**17.66**	**17.69**
Aromatics	**11.80**	**6.48**	**9.37**
Olefins	**26.39**	**30.45**	**22.67**
Aldehydes/Ketones	**39.72**	**43.96**	**44.36**
Oxygenates	**0.00**	**0.00**	**0.00**
Unknowns	**5.54**	**1.46**	**5.91**

Table A4-5. Composite Transient CI TOG Profile Percentages of Selected Compounds

Compound	Pre-Tier 1	Tier 1	Tier 2
Methane	1.74	7.09	7.95
Ethylene	16.65	18.94	17.42
Propylene	0.00	3.79	0.00
2,2,4-Trimethylpentane	0.78	0.65	0.61
2-Methylbutane	0.00	0.49	0.00
Toluene	1.17	1.97	3.20
m-& p-Xylene	1.48	1.09	1.07
o-Xylene	0.70	0.41	0.00
Ethylbenzene	0.91	0.36	0.39
2,3-Dimethylpentane	0.09	0.14	0.26

Table A4-6. Composite Transient Cycle CI Organic Gas Exhaust Speciation Profiles Displayed as Weight Percentages of TOG

CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
135-98-8	(1-methylpropyl)benzene	0.00E+00	0.00E+00	0.00E+00
4259-00-1	1,1,2-TRIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
3073-66-3	1,1,3-TRIMETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00
4516-69-2	1,1,3-TRIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
590-66-9	1,1-DIMETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00
1638-26-2	1,1-DIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
16747-50-5	1,1-Methylethylcyclopentane	0.00E+00	0.00E+00	0.00E+00
135-01-3	1,2 DIETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
488-23-3	1,2,3,4-TETRAMETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
527-53-7	1,2,3,5-TETRAMETHYLBENZENE	1.10E-01	3.03E-02	0.00E+00
526-73-8	1,2,3-TRIMETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
95-93-2	1,2,4,5-TETRAMETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
877-44-1	1,2,4-TRIETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
95-63-6	1,2,4-TRIMETHYLBENZENE	3.79E-01	2.34E-02	0.00E+00
933-98-2	1,2-DIMETHYL-3-ETHYLBENZENE	0.00E+00	1.74E-02	0.00E+00
934-80-5	1,2-DIMETHYL-4-ETHYLBENZENE	3.95E-02	6.87E-02	0.00E+00
463-49-0	1,2-PROPADIENE	0.00E+00	0.00E+00	0.00E+00
102-25-0	1,3,5-TRIETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
108-67-8	1,3,5-TRIMETHYLBENZENE	4.41E-01	0.00E+00	0.00E+00
934-74-7	1,3,-DIMETHYL-5-ETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
106-99-0	1,3-BUTADIENE	1.86E-01	1.86E-01	1.86E-01
141-93-5	1,3-DIETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
2870-04-4	1,3-DIMETHYL-2-ETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
874-41-9	1,3-DIMETHYL-4-ETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
4706-89-2	1,3-dimethyl-4-isopropylbenzene	0.00E+00	0.00E+00	0.00E+00
105-05-5	1,4-DIETHYLBENZENE	4.89E-01	2.28E-02	0.00E+00

CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
1758-88-9	1,4-DIMETHYL-2-ETHYLBENZENE	9.40E-02	3.15E-03	0.00E+00
106-98-9	1-BUTENE	0.00E+00	2.98E-01	0.00E+00
107-00-6	1-BUTYNE	0.00E+00	0.00E+00	0.00E+00
15890-40-1	1-CIS,2-TRANS,3-TRIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
872-05-9	1-DECENE	0.00E+00	0.00E+00	0.00E+00
637-92-3	1-ethyltertbutylether	0.00E+00	0.00E+00	0.00E+00
592-76-7	1-HEPTENE	0.00E+00	0.00E+00	0.00E+00
592-41-6	1-HEXENE	6.44E-01	4.10E-01	1.48E-01
611-14-3	1-METHYL-2-ETHYLBENZENE	2.85E-01	3.28E-03	0.00E+00
527-84-4	1-METHYL-2-ISOPROPYLBENZENE	3.85E-01	1.04E-01	0.00E+00
1074-17-5	1-METHYL-2-N-PROPYLBENZENE	0.00E+00	0.00E+00	0.00E+00
620-14-4	1-METHYL-3-ETHYLBENZENE	4.15E-01	1.47E-02	0.00E+00
535-77-3	1-METHYL-3-ISOPROPYLBENZENE	0.00E+00	7.96E-02	0.00E+00
1074-43-7	1-METHYL-3-N-PROPYLBENZENE	0.00E+00	0.00E+00	0.00E+00
622-96-8	1-METHYL-4-ETHYLBENZENE	2.43E-01	0.00E+00	0.00E+00
99-87-6	1-METHYL-4-ISOPROPYLBENZENE	0.00E+00	0.00E+00	0.00E+00
1074-55-1	1-METHYL-4-N-PROPYLBENZENE	2.51E-01	1.16E-02	0.00E+00
693-89-0	1-METHYLCYCLOPENTENE	3.48E-01	0.00E+00	0.00E+00
124-11-8	1-NONENE	7.74E-01	9.19E-02	0.00E+00
111-66-0	1-OCTENE	0.00E+00	0.00E+00	0.00E+00
109-67-1	1-PENTENE	1.27E+00	5.46E-01	2.22E-01
15890-40-1	1-TRANS-2-CIS-3-TRIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
2815-58-9	1-TRANS-2-CIS-4-TRIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
464-06-2	2,2,3-TRIMETHYLBUTANE	6.62E-01	4.47E-03	0.00E+00
564-02-3	2,2,3-TRIMETHYLPENTANE	0.00E+00	2.56E-01	0.00E+00
16747-26-5	2,2,4-TRIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
540-84-1	2,2,4-TRIMETHYLPENTANE	7.78E-01	6.49E-01	7.27E-01
3522-94-9	2,2,5-TRIMETHYLHEXANE	0.00E+00	4.14E-02	0.00E+00
75-83-2	2,2-DIMETHYLBUTANE	3.52E-02	1.69E-01	0.00E+00
1071-26-7	2,2-DIMETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00
590-73-8	2,2-DIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
15869-87-1	2,2-DIMETHYLOCTANE	4.50E-01	1.72E-02	0.00E+00
590-35-2	2,2-DIMETHYLPENTANE	1.84E-02	5.65E-02	5.39E-02
463-82-1	2,2-DIMETHYLPROPANE (NEOPENTANE)	0.00E+00	8.29E-02	0.00E+00
560-21-4	2,3,3-TRIMETHYLPENTANE	7.75E-02	4.07E-01	3.77E-01
921-47-1	2,3,4-TRIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
565-75-3	2,3,4-TRIMETHYLPENTANE	2.50E-01	6.46E-02	4.56E-01
1069-53-0	2,3,5-TRIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
10574-37-5	2,3-DIMETHYL-2-PENTENE	0.00E+00	0.00E+00	0.00E+00
79-29-8	2,3-DIMETHYLBUTANE	0.00E+00	1.55E-01	0.00E+00

CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
3074-71-3	2,3-DIMETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00
584-94-1	2,3-DIMETHYLHEXANE	0.00E+00	3.12E-01	0.00E+00
565-59-3	2,3-DIMETHYLPENTANE	8.81E-02	1.38E-01	2.92E-01
107-39-1	2,4,4-TRIMETHYL-1-PENTENE	0.00E+00	0.00E+00	0.00E+00
107-40-4	2,4,4-TRIMETHYL-2-PENTENE	0.00E+00	0.00E+00	0.00E+00
16747-30-1	2,4,4-TRIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
2213-23-2	2,4-DIMETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00
589-43-5	2,4-DIMETHYLHEXANE	4.93E-01	1.06E-01	0.00E+00
4032-94-4	2,4-DIMETHYLOCTANE	5.29E-01	5.34E-02	0.00E+00
108-08-7	2,4-DIMETHYLPENTANE	1.90E-01	4.33E-01	3.64E-01
2216-30-0	2,5-DIMETHYLHEPTANE	2.19E-01	3.65E-02	0.00E+00
592-13-2	2,5-DIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
1072-05-5	2,6-DIMETHYLHEPTANE	5.40E-01	1.72E-01	9.92E-02
503-17-3	2-BUTYNE	0.00E+00	0.00E+00	0.00E+00
78-79-5	2-METHYL-1,3-BUTADIENE	9.20E-02	3.21E-01	0.00E+00
563-46-2	2-METHYL-1-BUTENE	2.65E-01	1.76E-01	5.69E-01
6094-02-6	2-METHYL-1-HEXENE	0.00E+00	0.00E+00	0.00E+00
763-29-1	2-METHYL-1-PENTENE	6.44E-01	4.10E-01	1.48E-01
513-35-9	2-METHYL-2-BUTENE	0.00E+00	9.71E-02	2.96E-01
2738-19-4	2-METHYL-2-HEXENE	0.00E+00	0.00E+00	0.00E+00
625-27-4	2-METHYL-2-PENTENE	0.00E+00	0.00E+00	0.00E+00
78-78-4	2-METHYLBUTANE (ISOPENTANE)	0.00E+00	4.93E-01	0.00E+00
03968-85-2	2-METHYLBUTYLBENZENE (sec AMYLBENZENE)	0.00E+00	0.00E+00	0.00E+00
592-27-8	2-METHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00
591-76-4	2-METHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
3221-61-2	2-METHYLOCTANE	1.12E+00	1.92E-01	0.00E+00
107-83-5	2-METHYLPENTANE	1.46E-01	2.72E-01	2.19E-01
75-28-5	2-METHYLPROPANE (ISOBUTANE)	0.00E+00	4.46E-01	6.57E-01
115-11-7	2-METHYLPROPENE (ISOBUTYLENE)	3.41E-01	7.38E-01	0.00E+00
558-37-2	3,3-DIMETHYL-1-BUTENE	0.00E+00	0.00E+00	0.00E+00
4032-86-4	3,3-DIMETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00
563-16-6	3,3-DIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
562-49-2	3,3-DIMETHYLPENTANE	0.00E+00	0.00E+00	0.00E+00
7385-78-6	3,4-DIMETHYL-1-PENTENE	0.00E+00	1.45E-02	0.00E+00
922-28-1	3,4-DIMETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00
583-48-2	3,4-DIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
926-82-9	3,5-DIMETHYLHEPTANE	2.19E-01	3.65E-02	0.00E+00
816-79-5	3-ETHYL-2-PENTENE	0.00E+00	0.00E+00	0.00E+00
619-99-8	3-ETHYLHEXANE	1.11E-01	2.44E-02	0.00E+00
617-78-7	3-ETHYLPENTANE	0.00E+00	0.00E+00	0.00E+00

CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
563-45-1	3-METHYL-1-BUTENE	0.00E+00	0.00E+00	0.00E+00
3404-61-3	3-METHYL-1-HEXENE	0.00E+00	0.00E+00	0.00E+00
760-20-3	3-METHYL-1-PENTENE	0.00E+00	0.00E+00	0.00E+00
1067-08-9	3-Methyl-3-ethyl-pentane	0.00E+00	0.00E+00	0.00E+00
922-62-3	3-METHYL-CIS-2-PENTENE	0.00E+00	1.56E-02	0.00E+00
1120-62-3	3-METHYLCYCLOPENTENE	0.00E+00	0.00E+00	0.00E+00
589-81-1	3-METHYLHEPTANE	0.00E+00	2.19E-02	1.92E-01
589-34-4	3-METHYLHEXANE	1.00E-01	9.25E-02	0.00E+00
2216-33-3	3-METHYLOCTANE	5.97E-01	7.07E-02	1.98E-01
96-14-0	3-METHYLPENTANE	5.51E-01	6.93E-01	3.71E-02
616-12-6	3-METHYL-TRANS-2-PENTENE	0.00E+00	0.00E+00	0.00E+00
3899-36-3	3-METHYL-TRANS-3-HEXENE	0.00E+00	0.00E+00	0.00E+00
1068-19-5	4,4-DIMETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00
2216-32-2	4-ETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00
691-37-2	4-METHYL-1-PENTENE	2.62E-01	4.97E-02	3.84E-01
691-38-3	4-METHYL-CIS-2-PENTENE	0.00E+00	0.00E+00	0.00E+00
589-53-7	4-METHYLHEPTANE	3.11E-01	2.48E-02	0.00E+00
2216-34-4	4-METHYLOCTANE	0.00E+00	0.00E+00	0.00E+00
674-76-0	4-METHYL-TRANS-2-PENTENE	0.00E+00	0.00E+00	0.00E+00
75-07-0	ACETALDEHYDE	7.18E+00	7.14E+00	9.51E+00
67-64-1	ACETONE	1.89E+00	1.04E+00	0.00E+00
74-86-2	ACETYLENE	2.91E+00	3.41E+00	1.12E+00
107-02-8	ACROLEIN	2.92E+00	1.47E+00	1.70E+00
100-52-7	BENZALDEHYDE	3.49E-01	8.94E-01	7.02E-01
71-43-2	BENZENE	1.88E+00	1.97E+00	5.07E+00
106-97-8	BUTANE	3.36E-01	9.72E-01	5.47E-01
2207-01-4	CIS-1,2-DIMETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00
1192-18-3	CIS-1,2-DIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
638-04-0	CIS-1,3-DIMETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00
2532-58-3	CIS-1,3-DIMETHYLCYCLOPENTANE	2.31E-01	3.48E-02	0.00E+00
624-29-3	Cis-1,4-Dimethylcyclohexane	0.00E+00	0.00E+00	0.00E+00
930-89-2	Cis-1-ethyl-2-methylcyclopentane	3.52E-02	0.00E+00	0.00E+00
2613-66-3	CIS-1-METHYL-3-ETHYLCYCLOPENTANE	6.16E-01	2.47E-01	0.00E+00
590-18-1	CIS-2-BUTENE	0.00E+00	0.00E+00	0.00E+00
6443-92-1	CIS-2-HEPTENE	0.00E+00	1.76E-01	0.00E+00
7688-21-3	CIS-2-HEXENE	0.00E+00	0.00E+00	0.00E+00
7642-04-8	CIS-2-OCTENE	0.00E+00	0.00E+00	0.00E+00
627-20-3	CIS-2-PENTENE	0.00E+00	2.35E-02	0.00E+00
7642-10-6	CIS-3-HEPTENE	0.00E+00	0.00E+00	0.00E+00
7642-09-3	CIS-3-HEXENE	0.00E+00	2.48E-02	0.00E+00

CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
20237-46-1	CIS-3-NONENE	0.00E+00	0.00E+00	0.00E+00
4170-30-3	CROTONALDEHYDE	1.94E+00	3.85E+00	3.16E+00
110-82-7	CYCLOHEXANE	9.16E-02	0.00E+00	0.00E+00
110-83-8	CYCLOHEXENE	3.93E-01	1.15E-01	0.00E+00
542-92-7	CYCLOPENTADIENE	0.00E+00	8.87E-03	0.00E+00
287-92-3	CYCLOPENTANE	2.02E-01	3.75E-02	0.00E+00
142-29-0	CYCLOPENTENE	4.34E-02	3.71E-02	0.00E+00
124-18-5	DECANE	1.85E-01	2.55E-02	0.00E+00
108-20-3	DI-ISOPROPYL ETHER	0.00E+00	0.00E+00	0.00E+00
5779-94-2	DIMETHYLBENZALDEHYDE	1.42E-01	2.77E-01	3.90E-01
112-40-3	DODECANE	4.43E-01	1.12E-01	0.00E+00
74-84-0	ETHANE	1.26E-01	4.66E-01	0.00E+00
64-17-5	ETHANOL	0.00E+00	0.00E+00	0.00E+00
100-41-4	ETHYLBENZENE	9.09E-01	3.56E-01	3.87E-01
1678-91-7	ETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00
1640-89-7	ETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
74-85-1	ETHYLENE	1.66E+01	1.89E+01	1.84E+01
50-00-0	FORMALDEHYDE	1.99E+01	2.03E+01	2.66E+01
142-82-5	HEPTANE	2.63E-01	9.25E-02	0.00E+00
66-25-1	HEXANALDEHYDE	2.09E-01	2.20E-01	0.00E+00
110-54-3	HEXANE	2.24E-01	2.45E-01	0.00E+00
1077-16-3	HEXYLBENZENE	0.00E+00	0.00E+00	0.00E+00
496-11-7	INDAN	0.00E+00	0.00E+00	0.00E+00
538-93-2	ISOBUTYLBENZENE	1.77E-01	2.40E-02	0.00E+00
78-84-2	ISOBUTYRALDEHYDE	6.16E-01	7.02E-01	8.43E-01
98-82-8	ISOPROPYLBENZENE (CUMENE)	3.70E-01	7.32E-02	0.00E+00
3875-51-2	ISOPROPYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
590-86-3	ISOVALERALDEHYDE	6.75E-01	4.90E-01	0.00E+00
1330-20-7	m-& p-XYLENE	1.48E+00	1.09E+00	1.07E+00
1334-78-7	M/P-TOLUALDEHYDE	1.36E+00	1.75E+00	6.78E-01
78-93-3	MEK	6.16E-01	7.07E-01	8.43E-01
74-82-8	METHANE	1.74E+00	7.09E+00	8.28E+00
67-56-1	METHANOL	0.00E+00	0.00E+00	0.00E+00
1634-04-4	Methyl t-butyl ether	0.00E+00	0.00E+00	0.00E+00
108-87-2	METHYLCYCLOHEXANE	3.48E-01	2.56E-01	0.00E+00
96-37-7	METHYLCYCLOPENTANE	1.84E-02	5.51E-02	5.39E-02
91-20-3	NAPHTHALENE	4.74E-02	5.42E-02	0.00E+00
71-36-3	N-butyl alcohol	0.00E+00	0.00E+00	0.00E+00
104-51-8	n-Butylbenzene	2.51E-01	1.16E-02	0.00E+00
111-84-2	NONANE	2.23E+00	4.19E-01	0.00E+00

CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
538-68-1	N-PENT-BENZENE	4.52E-02	0.00E+00	0.00E+00
103-65-1	n-PROPYLBENZENE	9.57E-01	1.95E-02	0.00E+00
00111-65-9	OCTANE	7.49E-01	3.62E-01	2.29E-01
529-20-4	O-TOLUALDEHYDE	1.09E-01	6.03E-01	0.00E+00
95-47-6	o-XYLENE	6.97E-01	4.09E-01	0.00E+00
109-66-0	PENTANE	1.17E-01	6.81E-01	1.56E+00
74-98-6	PROPANE	6.28E-02	5.71E-01	1.48E-01
123-38-6	PROPIONALDEHYDE	1.39E+00	3.55E+00	1.99E+00
2040-96-2	Propylcyclopentane	5.40E-01	1.72E-01	9.92E-02
115-07-1	PROPYLENE	0.00E+00	3.79E+00	0.00E+00
74-99-7	PROPYNE	0.00E+00	0.00E+00	0.00E+00
100-42-5	STYRENE	0.00E+00	0.00E+00	0.00E+00
994-05-8	T-AMYLMETHYLETHER	0.00E+00	0.00E+00	0.00E+00
1074-92-6	TERT-1-BUT-2-METHYLBENZENE	3.52E-01	4.12E-02	0.00E+00
98-19-1	TERT-1-BUT-3,5-DIMETHYLBENZENE	3.41E-01	8.15E-02	0.00E+00
7364-19-4	TERT-1-BUTYL-4-ETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
98-06-6	TERT-BUTYLBENZENE	0.00E+00	0.00E+00	0.00E+00
108-88-3	TOLUENE	1.17E+00	1.97E+00	3.43E+00
6876-23-9	TRANS-1,2-DIMETHYLCYCLOHEXANE	7.14E-02	0.00E+00	0.00E+00
822-50-4	TRANS-1,2-DIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
2207-03-6	TRANS-1,3-DIMETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00
1759-58-6	TRANS-1,3-DIMETHYLCYCLOPENTANE	0.00E+00	8.59E-03	0.00E+00
2207-04-7	TRANS-1,4-DIMETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00
930-90-5	Trans-1-ethyl-2-methyl-cyclopentane	0.00E+00	0.00E+00	0.00E+00
2613-65-2	TRANS-1-METHYL-3-ETHYLCYCLOPENTANE	0.00E+00	2.88E-02	0.00E+00
624-64-6	TRANS-2-BUTENE	1.50E+00	4.79E-01	0.00E+00
14686-13-6	TRANS-2-HEPTENE	0.00E+00	8.08E-03	0.00E+00
4050-45-7	TRANS-2-HEXENE	0.00E+00	6.71E-03	0.00E+00
6434-78-2	TRANS-2-NONENE	0.00E+00	0.00E+00	0.00E+00
13389-42-9	TRANS-2-OCTENE	0.00E+00	6.58E-02	0.00E+00
646-04-8	TRANS-2-PENTENE	7.47E-02	3.72E-03	5.32E-01
14686-14-7	TRANS-3-HEPTENE	0.00E+00	0.00E+00	0.00E+00
13269-52-8	TRANS-3-HEXENE	0.00E+00	0.00E+00	0.00E+00
20063-92-7	TRANS-3-NONENE	0.00E+00	0.00E+00	0.00E+00
14850-23-8	TRANS-4-OCTENE	0.00E+00	9.29E-03	0.00E+00
1120-21-4	UNDECANE	4.41E-01	2.65E-01	7.61E-01
	UNIDENTIFIED C5 OLEFINS	0.00E+00	1.08E-01	0.00E+00
	UNIDENTIFIED C6	4.50E-01	5.63E-01	0.00E+00
	UNIDENTIFIED C7	4.60E-02	5.85E-02	0.00E+00
	UNIDENTIFIED C8	3.95E-02	2.82E-02	0.00E+00

CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
	UNIDENTIFIED C9-C12+	5.00E+00	6.98E-01	6.08E+00
110-62-3	VALERALDEHYDE	4.53E-01	9.24E-01	1.85E-01

Table A4-7. Composite SI VOC Profile Percentages by Compound Class

Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
Paraffins	20.96	50.01	18.95	46.31
Aromatics	31.61	31.97	28.46	27.15
Olefins	41.57	12.07	43.56	13.29
Aldehyde/Ketones	3.68	0.83	3.47	1.19
Oxygenates	0.58	0.15	3.35	7.94
Unknowns	1.60	4.97	2.20	4.12

Table A4-8. Composite SI VOC Profile Percentages of Selected Compounds

Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
Formaldehyde	1.98	0.37	1.76	0.50
Acetaldehyde	0.43	0.10	0.90	0.34
Ethylene	11.00	1.83	12.32	1.99
Propylene	6.51	1.17	6.44	1.30
2,2,4-Trimethylpentane	4.61	8.11	5.72	13.01
2-Methylbutane	2.73	10.47	1.79	6.28
Toluene	8.64	8.64	7.77	7.77
m-& p-Xylene	4.40	6.44	5.46	5.39
o-Xylene	1.46	2.32	1.53	1.86
Ethylbenzene	2.20	3.44	1.67	2.23

Table A4-9. Composite SI VOC profile percentages with all compounds

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
1	135-98-8	(1-methylpropyl)benzene	0.00E+00	3.41E-03	5.38E-02	3.31E-03
9	4259-00-1	1,1,2-TRIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	3073-66-3	1,1,3-TRIMETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	4516-69-2	1,1,3-TRIMETHYLCYCLOPENTANE	2.84E-02	0.00E+00	3.11E-02	0.00E+00
19	590-66-9	1,1-DIMETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	1638-26-2	1,1-DIMETHYLCYCLOPENTANE	3.99E-03	8.79E-03	3.81E-03	2.99E-03
21	16747-50-5	1,1-Methylethylcyclopentane	7.32E-04	1.90E-02	1.90E-03	1.94E-02
36	135-01-3	1,2 DIETHYLBENZENE	3.39E-02	9.03E-02	0.00E+00	7.78E-02
22	488-23-3	1,2,3,4-TETRAMETHYLBENZENE	1.87E-03	7.15E-02	5.00E-02	7.12E-02
23	527-53-7	1,2,3,5-TETRAMETHYLBENZENE	1.07E-01	1.32E-02	6.05E-02	1.19E-02
25	526-73-8	1,2,3-TRIMETHYLBENZENE	2.75E-01	2.13E-02	1.98E-01	6.57E-02
28	95-93-2	1,2,4,5-TETRAMETHYLBENZENE	1.77E-02	1.28E-01	1.07E-02	1.44E-01

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
29	877-44-1	1,2,4-TRIETHYLBENZENE	8.47E-04	2.37E-02	0.00E+00	2.07E-02
30	95-63-6	1,2,4-TRIMETHYLBENZENE	1.71E+00	2.14E+00	1.58E+00	2.05E+00
37	933-98-2	1,2-dimethyl-3-ethylbenzene	0.00E+00	5.79E-03	0.00E+00	4.18E-03
39	934-80-5	1,2-DIMETHYL-4-ETHYLBENZENE	1.53E-01	3.67E-02	1.16E-01	2.81E-02
42	463-49-0	1,2-PROPADIENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	102-25-0	1,3,5-TRIETHYLBENZENE	0.00E+00	2.47E-02	0.00E+00	1.88E-02
44	108-67-8	1,3,5-TRIMETHYLBENZENE	5.36E-01	7.68E-01	6.95E-01	7.37E-01
55	934-74-7	1,3,-DIMETHYL-5-ETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	106-99-0	1,3-BUTADIENE	1.28E+00	2.14E-01	1.24E+00	2.72E-01
51	141-93-5	1,3-DIETHYLBENZENE	7.93E-02	1.77E-01	7.83E-02	1.73E-01
52	2870-04-4	1,3-DIMETHYL-2-ETHYLBENZENE	7.72E-02	1.78E-02	3.04E-02	1.42E-02
53	874-41-9	1,3-DIMETHYL-4-ETHYLBENZENE	4.13E-02	8.14E-02	1.14E-01	7.96E-03
54	4706-89-2	1,3-dimethyl-4-isopropylbenzene	3.13E-02	0.00E+00	7.21E-02	0.00E+00
59	105-05-5	1,4-DIETHYLBENZENE	2.36E-02	4.19E-01	0.00E+00	4.00E-01
60	1758-88-9	1,4-DIMETHYL-2-ETHYLBENZENE	6.99E-02	2.55E-01	7.94E-02	2.45E-01
64	106-98-9	1-BUTENE	4.43E-01	1.20E-01	5.27E-01	1.30E-01
65	107-00-6	1-butyne	0.00E+00	0.00E+00	0.00E+00	0.00E+00
357	15890-40-1	1-CIS,2-TRANS,3-TRIMETHYLCYCLOPENTANE	4.34E-02	1.48E-01	6.27E-02	1.60E-01
996	872-05-9	1-DECENE	0.00E+00	1.55E-02	9.41E-02	1.39E-02
75	637-92-3	1-ethyltertbutylether	0.00E+00	0.00E+00	0.00E+00	0.00E+00
76	592-76-7	1-HEPTENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
78	592-41-6	1-HEXENE	4.08E-02	9.50E-02	1.18E-01	1.11E-01
80	611-14-3	1-METHYL-2-ETHYLBENZENE	4.15E-01	6.28E-01	4.09E-01	5.05E-01
81	527-84-4	1-METHYL-2-ISOPROPYLBENZENE	2.17E-01	6.66E-02	3.24E-01	5.19E-02
84	1074-17-5	1-METHYL-2-N-PROPYLBENZENE	4.63E-02	3.73E-02	1.12E-01	2.88E-02
89	620-14-4	1-METHYL-3-ETHYLBENZENE	1.25E+00	1.85E+00	1.11E+00	1.57E+00
90	535-77-3	1-METHYL-3-ISOPROPYLBENZENE	3.46E-01	4.03E-02	2.73E-01	2.71E-02
92	1074-43-7	1-METHYL-3-N-PROPYLBENZENE	1.56E-01	2.25E-01	2.82E-01	1.88E-01
94	622-96-8	1-METHYL-4-ETHYLBENZENE	5.13E-01	7.87E-01	3.64E-01	6.51E-01
97	99-87-6	1-METHYL-4-ISOPROPYLBENZENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
100	1074-55-1	1-METHYL-4-N-PROPYLBENZENE	1.40E-01	4.47E-02	7.16E-02	2.39E-02
103	693-89-0	1-METHYLCYCLOPENTENE	1.76E-02	1.14E-01	7.73E-02	1.70E-01
106	124-11-8	1-NONENE	1.34E-01	1.78E-01	2.94E-02	7.05E-02
107	111-66-0	1-OCTENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
108	109-67-1	1-pentene	0.00E+00	1.75E-01	0.00E+00	2.28E-01
607	71-23-8	1-Propanol	1.17E-01	0.00E+00	7.27E-02	0.00E+00
730	15890-40-1	1-TRANS-2-CIS-3-TRIMETHYLCYCLOPENTANE	8.82E-03	6.46E-02	2.15E-02	7.98E-02
1540	2815-58-9	1-TRANS-2-CIS-4-TRIMETHYLCYCLOPENTANE	0.00E+00	7.61E-02	0.00E+00	7.06E-02
112	464-06-2	2,2,3-TRIMETHYLBUTANE	3.01E-02	5.95E-02	5.49E-02	7.01E-02
113	564-02-3	2,2,3-TRIMETHYLPENTANE	5.17E-01	9.61E-01	3.64E-01	1.07E+00
117	16747-26-5	2,2,4-trimethylhexane	5.29E-03	2.63E-02	0.00E+00	1.98E-02
118	540-84-1	2,2,4-TRIMETHYLPENTANE	4.61E+00	8.11E+00	5.72E+00	1.30E+01
121	3522-94-9	2,2,5-TRIMETHYLHEXANE	3.78E-01	5.90E-01	6.16E-02	4.18E-02
122	75-83-2	2,2-DIMETHYLBUTANE	3.61E-02	9.26E-02	5.02E-02	7.14E-02
123	1071-26-7	2,2-DIMETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
124	590-73-8	2,2-DIMETHYLHEXANE	5.44E-03	1.01E-01	9.04E-03	9.03E-02

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
125	15869-87-1	2,2-DIMETHYLOCTANE	6.82E-02	9.52E-02	3.41E-02	5.68E-02
126	590-35-2	2,2-DIMETHYLPENTANE	7.50E-02	4.30E-01	2.62E-01	6.25E-01
127	463-82-1	2,2-DIMETHYLPROPANE (NEOPENTANE)	0.00E+00	8.74E-02	0.00E+00	7.21E-02
128	560-21-4	2,3,3-TRIMETHYLPENTANE	7.43E-01	1.48E+00	1.31E-01	2.13E-01
129	921-47-1	2,3,4-TRIMETHYLHEXANE	0.00E+00	2.03E-02	0.00E+00	2.09E-02
130	565-75-3	2,3,4-TRIMETHYLPENTANE	1.14E+00	2.46E+00	2.65E-01	6.80E-01
132	1069-53-0	2,3,5-TRIMETHYLHEXANE	5.92E-02	9.31E-02	1.39E-02	3.83E-02
135	10574-37-5	2,3-DIMETHYL-2-PENTENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
136	79-29-8	2,3-DIMETHYLBUTANE	4.76E-01	7.50E-01	2.37E-01	5.52E-01
137	3074-71-3	2,3-DIMETHYLHEPTANE	0.00E+00	1.85E-02	0.00E+00	2.50E-02
138	584-94-1	2,3-DIMETHYLHEXANE	1.70E-01	0.00E+00	1.40E-02	1.32E-01
140	565-59-3	2,3-DIMETHYLPENTANE	2.28E+00	6.31E-01	1.72E+00	1.49E-03
141	107-39-1	2,4,4-TRIMETHYL-1-PENTENE	8.70E-03	9.19E-02	7.99E-02	1.09E-01
142	107-40-4	2,4,4-TRIMETHYL-2-PENTENE	0.00E+00	1.19E-02	6.27E-02	1.88E-02
143	16747-30-1	2,4,4-TRIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
148	2213-23-2	2,4-DIMETHYLHEPTANE	5.42E-02	8.05E-02	2.81E-02	6.13E-02
149	589-43-5	2,4-DIMETHYLHEXANE	5.85E-01	1.32E+00	4.26E-01	1.17E+00
151	4032-94-4	2,4-DIMETHYLOCTANE	9.48E-03	6.06E-02	3.94E-02	6.85E-02
152	108-08-7	2,4-DIMETHYLPENTANE	1.34E+00	1.44E+00	4.00E-01	9.68E-01
155	2216-30-0	2,5-DIMETHYLHEPTANE	6.60E-02	9.15E-02	3.93E-02	6.90E-02
156	592-13-2	2,5-dimethylhexane	0.00E+00	2.45E-03	0.00E+00	0.00E+00
160	1072-05-5	2,6-DIMETHYLHEPTANE	0.00E+00	4.56E-03	0.00E+00	6.88E-03
170	503-17-3	2-butyne	0.00E+00	0.00E+00	0.00E+00	0.00E+00
511	78-79-5	2-METHYL-1,3-BUTADIENE	2.33E-01	1.12E-01	3.19E-01	1.47E-01
181	563-46-2	2-methyl-1-butene	0.00E+00	2.97E-01	0.00E+00	4.52E-01
2185	6094-02-6	2-METHYL-1-HEXENE	0.00E+00	2.72E-02	5.24E-03	3.04E-02
184	763-29-1	2-METHYL-1-PENTENE	4.08E-02	1.06E-01	1.18E-01	1.31E-01
185	513-35-9	2-METHYL-2-BUTENE	2.45E-01	5.99E-01	2.92E-01	7.74E-01
186	2738-19-4	2-methyl-2-hexene	0.00E+00	1.08E-01	1.58E-02	1.35E-01
187	625-27-4	2-METHYL-2-PENTENE	4.53E-02	1.34E-01	8.68E-02	1.88E-01
508	78-78-4	2-METHYLBUTANE (ISOPENTANE)	2.73E+00	1.05E+01	1.79E+00	6.28E+00
2568	03968-85-2	2-METHYLBUTYLBENZENE (sec AMYLBENZENE)	1.44E-02	1.58E-01	0.00E+00	1.58E-01
193	592-27-8	2-METHYLHEPTANE	2.66E-01	7.91E-01	2.51E-01	5.62E-01
194	591-76-4	2-METHYLHEXANE	0.00E+00	2.66E+00	0.00E+00	5.14E+00
198	3221-61-2	2-METHYLOCTANE	2.24E-01	6.29E-01	1.99E-01	4.80E-01
199	107-83-5	2-METHYLPENTANE	4.07E-01	1.77E+00	9.50E-01	2.38E+00
491	75-28-5	2-METHYLPROPANE (ISOBUTANE)	1.72E-01	2.29E-01	3.85E-02	1.62E-02
497	115-11-7	2-METHYLPROPENE (ISOBUTYLENE)	3.28E+00	7.64E-01	3.74E+00	1.04E+00
513	67-63-0	2-Propanol	1.76E-02	1.71E-02	5.81E-03	0.00E+00
203	558-37-2	3,3-DIMETHYL-1-BUTENE	2.22E-02	9.98E-03	4.66E-02	1.02E-02
205	4032-86-4	3,3-DIMETHYLHEPTANE	0.00E+00	3.24E-02	0.00E+00	3.83E-02
206	563-16-6	3,3-DIMETHYLHEXANE	3.10E-02	8.73E-02	5.36E-02	8.27E-02
208	562-49-2	3,3-DIMETHYLPENTANE	3.20E-02	9.83E-02	8.52E-03	4.17E-02
209	7385-78-6	3,4-DIMETHYL-1-PENTENE	1.01E-02	1.73E-02	1.56E-02	2.18E-02
211	922-28-1	3,4-DIMETHYLHEPTANE	0.00E+00	4.35E-02	0.00E+00	2.96E-02

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
212	583-48-2	3,4-DIMETHYLHEXANE	4.71E-02	8.84E-02	1.13E-02	7.29E-02
215	926-82-9	3,5-DIMETHYLHEPTANE	6.61E-02	9.15E-02	3.93E-02	6.90E-02
221	816-79-5	3-ethyl-2-pentene	0.00E+00	1.03E-02	0.00E+00	1.24E-02
226	619-99-8	3-ETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
229	617-78-7	3-ETHYLPENTANE	3.23E-02	2.19E-01	1.23E-01	3.35E-01
230	563-45-1	3-METHYL-1-BUTENE	5.11E-02	2.03E-01	9.65E-02	1.31E-01
231	3404-61-3	3-methyl-1-hexene	0.00E+00	1.96E-02	0.00E+00	2.03E-02
232	760-20-3	3-METHYL-1-PENTENE	3.78E-02	8.18E-02	5.11E-02	9.03E-02
233	1067-08-9	3-Methyl-3-ethyl-pentane	4.71E-02	8.84E-02	1.13E-02	7.29E-02
236	922-62-3	3-METHYL-CIS-2-PENTENE	3.95E-02	1.60E-01	8.21E-02	2.40E-01
242	1120-62-3	3-METHYLCYCLOPENTENE	4.18E-03	3.06E-03	2.24E-02	3.40E-03
244	589-81-1	3-METHYLHEPTANE	3.29E-01	1.23E+00	2.81E-01	7.42E-01
245	589-34-4	3-METHYLHEXANE	2.35E-01	1.61E+00	4.95E-01	1.38E+00
247	2216-33-3	3-METHYLOCTANE	1.40E-01	4.45E-01	1.15E-01	3.18E-01
248	96-14-0	3-METHYLPENTANE	2.47E-01	1.09E+00	6.51E-01	1.58E+00
239	616-12-6	3-METHYL-TRANS-2-PENTENE	4.54E-02	2.01E-01	1.12E-01	2.80E-01
240	3899-36-3	3-methyl-trans-3-hexene	0.00E+00	0.00E+00	0.00E+00	0.00E+00
253	1068-19-5	4,4-DIMETHYLHEPTANE	5.18E-03	9.77E-02	1.13E-02	7.37E-02
1471	2216-32-2	4-ETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
258	691-37-2	4-METHYL-1-PENTENE	0.00E+00	1.23E-03	0.00E+00	2.00E-02
260	691-38-3	4-METHYL-CIS-2-PENTENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
264	589-53-7	4-METHYLHEPTANE	7.24E-02	7.48E-01	4.15E-02	1.80E-01
267	2216-34-4	4-methyloctane	0.00E+00	0.00E+00	0.00E+00	0.00E+00
262	674-76-0	4-METHYL-TRANS-2-PENTENE	6.44E-03	6.68E-02	0.00E+00	8.35E-02
279	75-07-0	Acetaldehyde	4.25E-01	1.03E-01	8.97E-01	3.36E-01
282	74-86-2	ACETYLENE	1.66E+01	3.17E+00	1.59E+01	2.75E+00
283	107-02-8	Acrolein	3.71E-02	3.12E-02	4.49E-02	4.43E-02
301	100-52-7	Benzaldehyde	5.24E-01	1.08E-01	2.59E-01	6.66E-02
302	71-43-2	BENZENE	6.94E+00	1.39E+00	4.59E+00	1.26E+00
592	106-97-8	BUTANE	7.65E-01	1.72E+00	6.09E-01	1.20E+00
351	2207-01-4	CIS-1,2-DIMETHYLCYCLOHEXANE	4.37E-02	1.13E-01	4.37E-02	1.02E-01
360	1192-18-3	CIS-1,2-DIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
352	638-04-0	Cis-1,3-dimethylcyclohexane	0.00E+00	0.00E+00	0.00E+00	0.00E+00
353	2532-58-3	CIS-1,3-DIMETHYLCYCLOPENTANE	2.61E-02	7.00E-02	1.07E-01	1.96E-02
354	624-29-3	Cis-1,4-Dimethylcyclohexane	1.42E-03	2.65E-02	8.64E-03	2.77E-02
362	930-89-2	Cis-1-ethyl-2-methylcyclopentane	1.22E-02	8.66E-02	2.02E-02	6.71E-02
364	2613-66-3	CIS-1-METHYL-3-ETHYLCYCLOPENTANE	2.20E-02	4.80E-02	4.86E-02	5.97E-02
367	590-18-1	CIS-2-BUTENE	2.21E-01	7.86E-02	2.37E-01	1.06E-01
368	6443-92-1	CIS-2-HEPTENE	1.98E-02	5.24E-02	2.67E-02	5.82E-02
369	7688-21-3	CIS-2-HEXENE	2.94E-02	7.79E-02	2.52E-02	9.75E-02
370	7642-04-8	CIS-2-OCTENE	0.00E+00	7.71E-02	0.00E+00	1.29E-02
371	627-20-3	CIS-2-PENTENE	1.24E-01	2.20E-01	1.74E-01	2.87E-01
2616	7642-10-6	CIS-3-HEPTENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
372	7642-09-3	CIS-3-HEXENE	6.63E-03	9.40E-02	3.38E-02	1.18E-01
373	20237-46-1	CIS-3-NONENE	0.00E+00	6.86E-03	0.00E+00	6.37E-03
382	4170-30-3	Crotonaldehyde	3.67E-02	1.96E-02	2.96E-02	2.41E-02

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
385	110-82-7	CYCLOHEXANE	6.54E-02	5.38E-02	6.40E-01	7.75E-02
388	110-83-8	CYCLOHEXENE	1.43E-01	2.83E-02	5.54E-02	3.80E-02
48	542-92-7	CYCLOPENTADIENE	4.27E-01	1.20E-01	4.77E-01	1.24E-01
390	287-92-3	CYCLOPENTANE	4.50E-02	7.61E-02	6.80E-02	1.06E-01
391	142-29-0	CYCLOPENTENE	3.61E-02	9.25E-02	8.73E-02	1.30E-01
598	124-18-5	DECANE	6.56E-02	7.76E-02	4.72E-02	5.99E-02
2735	108-20-3	DI-ISOPROPYL ETHER	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1712	5779-94-2	Dimethylbenzaldehyde	1.08E-01	2.03E-02	5.23E-02	2.42E-02
599	112-40-3	DODECANE	2.32E-02	8.21E-02	1.12E-02	5.34E-02
442	64-17-5	Ethanol	1.72E-01	5.79E-02	3.03E+00	7.81E+00
449	100-41-4	ETHYLBENZENE	2.20E+00	3.44E+00	1.67E+00	2.23E+00
450	1678-91-7	ETHYLCYCLOHEXANE	2.72E-02	1.78E-01	2.98E-02	1.09E-01
451	1640-89-7	ETHYLCYCLOPENTANE	2.43E-03	0.00E+00	1.41E-02	0.00E+00
452	74-85-1	ETHYLENE	1.10E+01	1.83E+00	1.23E+01	1.99E+00
465	50-00-0	Formaldehyde	1.98E+00	3.68E-01	1.76E+00	4.98E-01
600	142-82-5	HEPTANE	3.18E-01	1.18E+00	2.70E-01	6.31E-01
840	66-25-1	Hexanaldehyde	1.19E-03	1.93E-03	5.32E-03	1.95E-03
601	110-54-3	HEXANE	2.33E-01	7.72E-01	5.20E-01	7.15E-01
602	1077-16-3	HEXYLBENZENE	0.00E+00	1.82E-02	0.00E+00	2.90E-02
485	496-11-7	INDAN	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	538-93-2	ISOBUTYLBENZENE	6.19E-02	7.32E-02	4.46E-02	5.65E-02
2119	78-84-2	ISOBUTYRALDEHYDE,	1.68E-02	9.85E-03	2.37E-02	1.02E-02
514	98-82-8	ISOPROPYLBENZENE (CUMENE)	1.18E-01	1.11E-01	4.69E-02	6.35E-02
2560	3875-51-2	ISOPROPYLCYCLOPENTANE	6.02E-03	1.16E-02	7.23E-03	3.45E-02
517	590-86-3	Isovaleraldehyde	6.12E-02	1.42E-02	5.26E-02	1.90E-02
522	1330-20-7	m-& p-XYLENE	4.40E+00	6.44E+00	5.46E+00	5.39E+00
2164	1334-78-7	m/p-Tolualdehyde	3.27E-01	4.65E-02	2.35E-01	7.74E-02
536	78-93-3	MEK	1.69E-02	9.85E-03	2.37E-02	1.02E-02
531	67-56-1	Methanol	2.05E-01	7.84E-02	2.09E-01	1.32E-01
548	1634-04-4	Methyl t-butyl ether (MTBE)	0.00E+00	0.00E+00	0.00E+00	0.00E+00
550	108-87-2	METHYLCYCLOHEXANE	1.02E-01	4.40E-01	2.79E-01	6.44E-01
551	96-37-7	METHYLCYCLOPENTANE	7.35E-02	4.22E-01	2.57E-01	6.13E-01
611	91-20-3	NAPHTHALENE	4.15E-02	5.96E-02	8.86E-02	4.68E-02
595	71-36-3	N-butyl alcohol	6.80E-02	0.00E+00	3.94E-02	0.00E+00
596	104-51-8	n-Butylbenzene	1.40E-01	3.03E-02	7.16E-02	2.39E-02
603	111-84-2	NONANE	2.08E-01	3.49E-01	7.42E-02	1.59E-01
606	538-68-1	N-PENT-BENZENE	3.23E-02	7.90E-02	3.38E-02	9.19E-02
608	103-65-1	n-PROPYLBENZENE	3.39E-01	6.85E-01	2.91E-01	4.86E-01
604	00111-65-9	OCTANE	2.71E-01	4.59E-01	1.75E-01	3.08E-01
1467	529-20-4	o-Tolualdehyde	8.48E-02	4.58E-02	4.04E-02	1.82E-02
620	95-47-6	o-XYLENE	1.46E+00	2.32E+00	1.53E+00	1.86E+00
605	109-66-0	PENTANE	4.11E-01	8.63E-01	3.90E-01	8.87E-01
671	74-98-6	PROPANE	3.30E-01	4.61E-02	8.69E-02	3.12E-02
673	123-38-6	Propionaldehyde	4.94E-02	5.06E-02	4.11E-02	5.23E-02
677	2040-96-2	Propylcyclopentane	0.00E+00	3.06E-03	0.00E+00	6.88E-03
678	115-07-1	PROPYLENE	6.51E+00	1.17E+00	6.44E+00	1.30E+00

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
109	74-99-7	PROPYNE	4.52E-03	2.31E-02	0.00E+00	1.94E-02
698	100-42-5	STYRENE	9.76E-01	2.23E-01	7.15E-01	1.77E-01
701	994-05-8	T-amylmethylether	0.00E+00	0.00E+00	0.00E+00	0.00E+00
86	1074-92-6	TERT-1-BUT-2-METHYLBENZENE	4.44E-03	1.32E-01	3.64E-02	1.61E-01
63	98-19-1	TERT-1-BUT-3,5-DIMETHYLBENZENE	2.66E-03	1.19E-01	8.90E-04	1.39E-01
2329	7364-19-4	TERT-1-BUTYL-4-ETHYLBENZENE	0.00E+00	5.73E-02	2.85E-02	6.18E-02
703	98-06-6	TERT-BUTYLBENZENE	0.00E+00	3.05E-02	0.00E+00	3.22E-02
717	108-88-3	TOLUENE	8.64E+00	8.64E+00	7.77E+00	7.77E+00
724	6876-23-9	TRANS-1,2-DIMETHYLCYCLOHEXANE	7.25E-03	3.92E-01	2.67E-02	1.77E-01
725	822-50-4	TRANS-1,2-DIMETHYLCYCLOPENTANE	3.52E-02	1.03E-01	3.51E-02	1.01E-01
726	2207-03-6	TRANS-1,3-DIMETHYLCYCLOHEXANE	1.42E-03	3.14E-02	8.64E-03	3.09E-02
727	1759-58-6	TRANS-1,3-DIMETHYLCYCLOPENTANE	4.02E-03	2.32E-01	0.00E+00	3.60E-01
729	2207-04-7	TRANS-1,4-DIMETHYLCYCLOHEXANE	0.00E+00	9.47E-03	1.18E-02	2.45E-02
1586	930-90-5	Trans-1-ethyl-2-methyl-cyclopentane	1.99E-03	9.29E-02	3.28E-02	1.14E-01
736	2613-65-2	TRANS-1-METHYL-3-ETHYLCYCLOPENTANE	0.00E+00	1.08E-01	3.10E-02	1.40E-01
737	624-64-6	TRANS-2-BUTENE	3.93E-01	2.08E-01	3.08E-01	2.34E-01
739	14686-13-6	TRANS-2-HEPTENE	1.50E-02	6.09E-02	3.01E-02	6.89E-02
740	4050-45-7	TRANS-2-HEXENE	1.56E-02	1.43E-01	5.20E-02	1.82E-01
2244	6434-78-2	TRANS-2-NONENE	0.00E+00	1.28E-02	0.00E+00	8.18E-03
741	13389-42-9	TRANS-2-OCTENE	7.72E-03	8.42E-02	5.05E-02	1.14E-01
742	646-04-8	TRANS-2-PENTENE	4.11E-02	3.83E-01	1.10E-01	5.02E-01
743	14686-14-7	TRANS-3-HEPTENE	9.04E-04	8.81E-02	3.13E-02	1.12E-01
744	13269-52-8	TRANS-3-HEXENE	0.00E+00	0.00E+00	0.00E+00	0.00E+00
745	20063-92-7	TRANS-3-NONENE	0.00E+00	4.59E-02	1.41E-02	5.24E-02
746	14850-23-8	Trans-4-octene	0.00E+00	5.59E-02	0.00E+00	4.67E-02
610	1120-21-4	UNDECANE	3.85E-02	1.17E-01	3.94E-02	1.11E-01
1989		UNIDENTIFIED C5 OLEFINS	0.00E+00	1.38E-02	0.00E+00	8.96E-03
1999		UNIDENTIFIED C6	1.62E-01	7.41E-02	1.91E-01	7.17E-02
2005		UNIDENTIFIED C7	1.26E-01	7.69E-01	1.21E-01	2.77E-01
2011		UNIDENTIFIED C8	2.48E-03	1.68E-01	1.03E-02	1.20E-01
327		UNIDENTIFIED C9-C12+	1.31E+00	3.94E+00	1.88E+00	3.64E+00
845	110-62-3	Valeraldehyde	1.62E-02	4.58E-03	5.35E-03	4.83E-03

Table A4-10. Composite Transient Cycle CI VOC Profile Percentages by Compound Class

Compound	Pre-Tier 1	Tier 1	Tier 2
Paraffins	15.26	11.16	7.54
Aromatics	12.23	7.13	10.79
Olefins	27.56	33.16	24.04
Aldehydes/Ketones	39.22	47.00	51.08
Oxygenates	0.00	0.00	0.00
Unknowns	5.73	1.54	6.55

Table A4-11. Composite Transient Cycle CI VOC Profile Percentages of Selected Compounds

Compound	Pre-Tier 1	Tier 1	Tier 2
Formaldehyde	20.67	22.27	29.19
Acetaldehyde	7.46	7.83	10.41
Ethylene	17.36	20.74	20.34
Propylene	0.00	4.10	0.00
2,2,4-Trimethylpentane	0.81	0.71	0.78
2-Methylbutane	0.00	0.53	0.00
Toluene	1.22	2.15	3.78
m-& p-Xylene	1.53	1.20	1.16
o-Xylene	0.73	0.44	0.00
Ethylbenzene	0.94	0.38	0.44

Table A4-12. Composite Transient Cycle CI VOC Exhaust Speciation Profiles Displayed as Weight Percentages of Total VOCs

Specie ID	CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
1	135-98-8	(1-methylpropyl)benzene	0.00E+00	0.00E+00	0.00E+00
9	4259-00-1	1,1,2-TRIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
12	3073-66-3	1,1,3-TRIMETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00
13	4516-69-2	1,1,3-TRIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
19	590-66-9	1,1-DIMETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00
20	1638-26-2	1,1-DIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
21	16747-50-5	1,1-Methylethylcyclopentane	0.00E+00	0.00E+00	0.00E+00
36	135-01-3	1,2 DIETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
22	488-23-3	1,2,3,4-TETRAMETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
23	527-53-7	1,2,3,5-TETRAMETHYLBENZENE	1.15E-01	3.11E-02	0.00E+00
25	526-73-8	1,2,3-TRIMETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
28	95-93-2	1,2,4,5-TETRAMETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
29	877-44-1	1,2,4-TRIETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
30	95-63-6	1,2,4-TRIMETHYLBENZENE	3.95E-01	2.47E-02	0.00E+00
37	933-98-2	1,2-DIMETHYL-3-ETHYLBENZENE	0.00E+00	1.74E-02	0.00E+00
39	934-80-5	1,2-DIMETHYL-4-ETHYLBENZENE	4.06E-02	7.23E-02	0.00E+00

Specie ID	CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
42	463-49-0	1,2-PROPADIENE	0.00E+00	0.00E+00	0.00E+00
43	102-25-0	1,3,5-TRIETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
44	108-67-8	1,3,5-TRIMETHYLBENZENE	4.59E-01	0.00E+00	0.00E+00
55	934-74-7	1,3,-DIMETHYL-5-ETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
46	106-99-0	1,3-BUTADIENE	1.86E-01	1.86E-01	1.86E-01
51	141-93-5	1,3-DIETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
52	2870-04-4	1,3-DIMETHYL-2-ETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
53	874-41-9	1,3-DIMETHYL-4-ETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
54	4706-89-2	1,3-dimethyl-4-isopropylbenzene	0.00E+00	0.00E+00	0.00E+00
59	105-05-5	1,4-DIETHYLBENZENE	5.04E-01	2.33E-02	0.00E+00
60	1758-88-9	1,4-DIMETHYL-2-ETHYLBENZENE	9.66E-02	3.36E-03	0.00E+00
64	106-98-9	1-BUTENE	0.00E+00	3.05E-01	0.00E+00
65	107-00-6	1-BUTYNE	0.00E+00	0.00E+00	0.00E+00
357	15890-40-1	1-CIS,2-TRANS,3-TRIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
996	872-05-9	1-DECENE	0.00E+00	0.00E+00	0.00E+00
75	637-92-3	1-ethyltertbutylether	0.00E+00	0.00E+00	0.00E+00
76	592-76-7	1-HEPTENE	0.00E+00	0.00E+00	0.00E+00
78	592-41-6	1-HEXENE	6.66E-01	4.31E-01	1.48E-01
80	611-14-3	1-METHYL-2-ETHYLBENZENE	2.90E-01	3.37E-03	0.00E+00
81	527-84-4	1-METHYL-2-ISOPROPYLBENZENE	3.96E-01	1.11E-01	0.00E+00
84	1074-17-5	1-METHYL-2-N-PROPYLBENZENE	0.00E+00	0.00E+00	0.00E+00
89	620-14-4	1-METHYL-3-ETHYLBENZENE	4.32E-01	1.54E-02	0.00E+00
90	535-77-3	1-METHYL-3-ISOPROPYLBENZENE	0.00E+00	8.13E-02	0.00E+00
92	1074-43-7	1-METHYL-3-N-PROPYLBENZENE	0.00E+00	0.00E+00	0.00E+00
94	622-96-8	1-METHYL-4-ETHYLBENZENE	2.48E-01	0.00E+00	0.00E+00
97	99-87-6	1-METHYL-4-ISOPROPYLBENZENE	0.00E+00	0.00E+00	0.00E+00
100	1074-55-1	1-METHYL-4-N-PROPYLBENZENE	2.62E-01	1.17E-02	0.00E+00
103	693-89-0	1-METHYLCYCLOPENTENE	3.89E-01	0.00E+00	0.00E+00
106	124-11-8	1-NONENE	8.04E-01	9.49E-02	0.00E+00
107	111-66-0	1-OCTENE	0.00E+00	0.00E+00	0.00E+00
108	109-67-1	1-PENTENE	1.33E+00	5.86E-01	2.22E-01
730	15890-40-1	1-TRANS-2-CIS-3-TRIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
1540	2815-58-9	1-TRANS-2-CIS-4-TRIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
112	464-06-2	2,2,3-TRIMETHYLBUTANE	7.36E-01	4.77E-03	0.00E+00
113	564-02-3	2,2,3-TRIMETHYLPENTANE	0.00E+00	2.79E-01	0.00E+00
117	16747-26-5	2,2,4-TRIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
118	540-84-1	2,2,4-TRIMETHYLPENTANE	8.07E-01	7.12E-01	7.83E-01
121	3522-94-9	2,2,5-TRIMETHYLHEXANE	0.00E+00	4.41E-02	0.00E+00
122	75-83-2	2,2-DIMETHYLBUTANE	3.68E-02	1.82E-01	0.00E+00
123	1071-26-7	2,2-DIMETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00

Specie ID	CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
124	590-73-8	2,2-DIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
125	15869-87-1	2,2-DIMETHYLOCTANE	4.60E-01	1.76E-02	0.00E+00
126	590-35-2	2,2-DIMETHYLPENTANE	1.91E-02	5.95E-02	6.15E-02
127	463-82-1	2,2-DIMETHYLPROPANE (NEOPENTANE)	0.00E+00	8.75E-02	0.00E+00
128	560-21-4	2,3,3-TRIMETHYLPENTANE	8.10E-02	4.85E-01	4.30E-01
129	921-47-1	2,3,4-TRIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
130	565-75-3	2,3,4-TRIMETHYLPENTANE	2.58E-01	7.42E-02	4.88E-01
132	1069-53-0	2,3,5-TRIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
135	10574-37-5	2,3-DIMETHYL-2-PENTENE	0.00E+00	0.00E+00	0.00E+00
136	79-29-8	2,3-DIMETHYLBUTANE	0.00E+00	1.77E-01	0.00E+00
137	3074-71-3	2,3-DIMETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00
138	584-94-1	2,3-DIMETHYLHEXANE	0.00E+00	3.63E-01	0.00E+00
140	565-59-3	2,3-DIMETHYLPENTANE	9.07E-02	1.60E-01	3.00E-01
141	107-39-1	2,4,4-TRIMETHYL-1-PENTENE	0.00E+00	0.00E+00	0.00E+00
142	107-40-4	2,4,4-TRIMETHYL-2-PENTENE	0.00E+00	0.00E+00	0.00E+00
143	16747-30-1	2,4,4-TRIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
148	2213-23-2	2,4-DIMETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00
149	589-43-5	2,4-DIMETHYLHEXANE	5.11E-01	1.30E-01	0.00E+00
151	4032-94-4	2,4-DIMETHYLOCTANE	5.50E-01	5.52E-02	0.00E+00
152	108-08-7	2,4-DIMETHYLPENTANE	1.94E-01	5.06E-01	4.08E-01
155	2216-30-0	2,5-DIMETHYLHEPTANE	2.27E-01	3.78E-02	0.00E+00
156	592-13-2	2,5-DIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
160	1072-05-5	2,6-DIMETHYLHEPTANE	5.62E-01	1.83E-01	1.11E-01
170	503-17-3	2-BUTYNE	0.00E+00	0.00E+00	0.00E+00
511	78-79-5	2-METHYL-1,3-BUTADIENE	9.85E-02	3.59E-01	0.00E+00
181	563-46-2	2-METHYL-1-BUTENE	2.74E-01	1.87E-01	5.92E-01
2185	6094-02-6	2-METHYL-1-HEXENE	0.00E+00	0.00E+00	0.00E+00
184	763-29-1	2-METHYL-1-PENTENE	6.66E-01	4.31E-01	1.48E-01
185	513-35-9	2-METHYL-2-BUTENE	0.00E+00	1.09E-01	2.96E-01
186	2738-19-4	2-METHYL-2-HEXENE	0.00E+00	0.00E+00	0.00E+00
187	625-27-4	2-METHYL-2-PENTENE	0.00E+00	0.00E+00	0.00E+00
508	78-78-4	2-METHYLBUTANE (ISOPENTANE)	0.00E+00	5.29E-01	0.00E+00
2568	03968-85-2	2-METHYLBUTYLBENZENE (sec AMYLBENZENE)	0.00E+00	0.00E+00	0.00E+00
193	592-27-8	2-METHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00
194	591-76-4	2-METHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
198	3221-61-2	2-METHYLOCTANE	1.15E+00	1.98E-01	0.00E+00
199	107-83-5	2-METHYLPENTANE	1.54E-01	3.19E-01	2.19E-01
491	75-28-5	2-METHYLPROPANE (ISOBUTANE)	0.00E+00	5.45E-01	6.57E-01
497	115-11-7	2-METHYLPROPENE (ISOBUTYLENE)	3.54E-01	7.71E-01	0.00E+00
203	558-37-2	3,3-DIMETHYL-1-BUTENE	0.00E+00	0.00E+00	0.00E+00

Specie ID	CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
205	4032-86-4	3,3-DIMETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00
206	563-16-6	3,3-DIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
208	562-49-2	3,3-DIMETHYLPENTANE	0.00E+00	0.00E+00	0.00E+00
209	7385-78-6	3,4-DIMETHYL-1-PENTENE	0.00E+00	1.48E-02	0.00E+00
211	922-28-1	3,4-DIMETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00
212	583-48-2	3,4-DIMETHYLHEXANE	0.00E+00	0.00E+00	0.00E+00
215	926-82-9	3,5-DIMETHYLHEPTANE	2.27E-01	3.78E-02	0.00E+00
221	816-79-5	3-ETHYL-2-PENTENE	0.00E+00	0.00E+00	0.00E+00
226	619-99-8	3-ETHYLHEXANE	1.14E-01	2.53E-02	0.00E+00
229	617-78-7	3-ETHYLPENTANE	0.00E+00	0.00E+00	0.00E+00
230	563-45-1	3-METHYL-1-BUTENE	0.00E+00	0.00E+00	0.00E+00
231	3404-61-3	3-METHYL-1-HEXENE	0.00E+00	0.00E+00	0.00E+00
232	760-20-3	3-METHYL-1-PENTENE	0.00E+00	0.00E+00	0.00E+00
233	1067-08-9	3-Methyl-3-ethyl-pentane	0.00E+00	0.00E+00	0.00E+00
236	922-62-3	3-METHYL-CIS-2-PENTENE	0.00E+00	1.58E-02	0.00E+00
242	1120-62-3	3-METHYLCYCLOPENTENE	0.00E+00	0.00E+00	0.00E+00
244	589-81-1	3-METHYLHEPTANE	0.00E+00	2.77E-02	1.92E-01
245	589-34-4	3-METHYLHEXANE	1.01E-01	9.78E-02	0.00E+00
247	2216-33-3	3-METHYLOCTANE	6.20E-01	7.34E-02	2.22E-01
248	96-14-0	3-METHYLPENTANE	5.69E-01	7.72E-01	3.71E-02
239	616-12-6	3-METHYL-TRANS-2-PENTENE	0.00E+00	0.00E+00	0.00E+00
240	3899-36-3	3-METHYL-TRANS-3-HEXENE	0.00E+00	0.00E+00	0.00E+00
253	1068-19-5	4,4-DIMETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00
1471	2216-32-2	4-ETHYLHEPTANE	0.00E+00	0.00E+00	0.00E+00
258	691-37-2	4-METHYL-1-PENTENE	2.71E-01	5.18E-02	4.07E-01
260	691-38-3	4-METHYL-CIS-2-PENTENE	0.00E+00	0.00E+00	0.00E+00
264	589-53-7	4-METHYLHEPTANE	3.24E-01	2.76E-02	0.00E+00
267	2216-34-4	4-METHYLOCTANE	0.00E+00	0.00E+00	0.00E+00
262	674-76-0	4-METHYL-TRANS-2-PENTENE	0.00E+00	0.00E+00	0.00E+00
279	75-07-0	ACETALDEHYDE	7.46E+00	7.83E+00	1.04E+01
282	74-86-2	ACETYLENE	3.04E+00	3.78E+00	1.15E+00
283	107-02-8	ACROLEIN	3.02E+00	1.60E+00	1.87E+00
301	100-52-7	BENZALDEHYDE	3.56E-01	9.84E-01	7.21E-01
302	71-43-2	BENZENE	1.96E+00	2.25E+00	5.41E+00
592	106-97-8	BUTANE	3.56E-01	1.09E+00	5.47E-01
351	2207-01-4	CIS-1,2-DIMETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00
360	1192-18-3	CIS-1,2-DIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
352	638-04-0	CIS-1,3-DIMETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00
353	2532-58-3	CIS-1,3-DIMETHYLCYCLOPENTANE	2.36E-01	3.64E-02	0.00E+00
354	624-29-3	Cis-1,4-Dimethylcyclohexane	0.00E+00	0.00E+00	0.00E+00

Specie ID	CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
362	930-89-2	Cis-1-ethyl-2-methylcyclopentane	3.68E-02	0.00E+00	0.00E+00
364	2613-66-3	CIS-1-METHYL-3-ETHYLCYCLOPENTANE	6.38E-01	2.62E-01	0.00E+00
367	590-18-1	CIS-2-BUTENE	0.00E+00	0.00E+00	0.00E+00
368	6443-92-1	CIS-2-HEPTENE	0.00E+00	1.87E-01	0.00E+00
369	7688-21-3	CIS-2-HEXENE	0.00E+00	0.00E+00	0.00E+00
370	7642-04-8	CIS-2-OCTENE	0.00E+00	0.00E+00	0.00E+00
371	627-20-3	CIS-2-PENTENE	0.00E+00	2.58E-02	0.00E+00
2616	7642-10-6	CIS-3-HEPTENE	0.00E+00	0.00E+00	0.00E+00
372	7642-09-3	CIS-3-HEXENE	0.00E+00	2.65E-02	0.00E+00
373	20237-46-1	CIS-3-NONENE	0.00E+00	0.00E+00	0.00E+00
382	4170-30-3	CROTONALDEHYDE	1.98E+00	4.27E+00	3.47E+00
385	110-82-7	CYCLOHEXANE	9.57E-02	0.00E+00	0.00E+00
388	110-83-8	CYCLOHEXENE	4.39E-01	1.21E-01	0.00E+00
48	542-92-7	CYCLOPENTADIENE	0.00E+00	9.20E-03	0.00E+00
390	287-92-3	CYCLOPENTANE	2.09E-01	3.93E-02	0.00E+00
391	142-29-0	CYCLOPENTENE	4.41E-02	3.84E-02	0.00E+00
598	124-18-5	DECANE	1.86E-01	2.70E-02	0.00E+00
2735	108-20-3	DI-ISOPROPYL ETHER	0.00E+00	0.00E+00	0.00E+00
1712	5779-94-2	DIMETHYLBENZALDEHYDE	1.47E-01	3.01E-01	4.28E-01
599	112-40-3	DODECANE	4.58E-01	1.14E-01	0.00E+00
442	64-17-5	ETHANOL	0.00E+00	0.00E+00	0.00E+00
449	100-41-4	ETHYLBENZENE	9.44E-01	3.84E-01	4.38E-01
450	1678-91-7	ETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00
451	1640-89-7	ETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
452	74-85-1	ETHYLENE	1.74E+01	2.07E+01	2.03E+01
465	50-00-0	FORMALDEHYDE	2.07E+01	2.23E+01	2.92E+01
600	142-82-5	HEPTANE	2.73E-01	9.71E-02	0.00E+00
840	66-25-1	HEXANALDEHYDE	2.14E-01	2.40E-01	0.00E+00
601	110-54-3	HEXANE	2.30E-01	2.79E-01	0.00E+00
602	1077-16-3	HEXYLBENZENE	0.00E+00	0.00E+00	0.00E+00
485	496-11-7	INDAN	0.00E+00	0.00E+00	0.00E+00
3	538-93-2	ISOBUTYLBENZENE	1.79E-01	2.54E-02	0.00E+00
2119	78-84-2	ISOBUTYRALDEHYDE	6.31E-01	7.96E-01	9.19E-01
514	98-82-8	ISOPROPYLBENZENE (CUMENE)	3.71E-01	7.41E-02	0.00E+00
2560	3875-51-2	ISOPROPYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
517	590-86-3	ISOVALERALDEHYDE	7.01E-01	5.20E-01	0.00E+00
522	1330-20-7	m-& p-XYLENE	1.53E+00	1.20E+00	1.16E+00
2164	1334-78-7	M/P-TOLUALDEHYDE	1.41E+00	1.92E+00	7.52E-01
536	78-93-3	MEK	6.31E-01	8.01E-01	9.19E-01
531	67-56-1	METHANOL	0.00E+00	0.00E+00	0.00E+00

Specie ID	CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
548	1634-04-4	Methyl t-butyl ether	0.00E+00	0.00E+00	0.00E+00
550	108-87-2	METHYLCYCLOHEXANE	3.63E-01	2.74E-01	0.00E+00
551	96-37-7	METHYLCYCLOPENTANE	1.91E-02	5.81E-02	6.15E-02
611	91-20-3	NAPHTHALENE	4.87E-02	6.07E-02	0.00E+00
595	71-36-3	N-butyl alcohol	0.00E+00	0.00E+00	0.00E+00
596	104-51-8	n-Butylbenzene	2.62E-01	1.17E-02	0.00E+00
603	111-84-2	NONANE	2.31E+00	4.37E-01	0.00E+00
606	538-68-1	N-PENT-BENZENE	4.52E-02	0.00E+00	0.00E+00
608	103-65-1	n-PROPYLBENZENE	9.92E-01	2.03E-02	0.00E+00
604	00111-65-9	OCTANE	7.81E-01	3.76E-01	2.80E-01
1467	529-20-4	O-TOLUALDEHYDE	1.12E-01	6.44E-01	0.00E+00
620	95-47-6	o-XYLENE	7.26E-01	4.44E-01	0.00E+00
605	109-66-0	PENTANE	1.23E-01	7.39E-01	1.63E+00
671	74-98-6	PROPANE	6.94E-02	6.30E-01	1.48E-01
673	123-38-6	PROPIONALDEHYDE	1.41E+00	3.86E+00	2.20E+00
677	2040-96-2	Propylcyclopentane	5.62E-01	1.83E-01	1.11E-01
678	115-07-1	PROPYLENE	0.00E+00	4.10E+00	0.00E+00
109	74-99-7	PROPYNE	0.00E+00	0.00E+00	0.00E+00
698	100-42-5	STYRENE	0.00E+00	0.00E+00	0.00E+00
701	994-05-8	T-AMYLMETHYLETHER	0.00E+00	0.00E+00	0.00E+00
86	1074-92-6	TERT-1-BUT-2-METHYLBENZENE	3.65E-01	4.17E-02	0.00E+00
63	98-19-1	TERT-1-BUT-3,5-DIMETHYLBENZENE	3.54E-01	8.22E-02	0.00E+00
2329	7364-19-4	TERT-1-BUTYL-4-ETHYLBENZENE	0.00E+00	0.00E+00	0.00E+00
703	98-06-6	TERT-BUTYLBENZENE	0.00E+00	0.00E+00	0.00E+00
717	108-88-3	TOLUENE	1.22E+00	2.15E+00	3.78E+00
724	6876-23-9	TRANS-1,2-DIMETHYLCYCLOHEXANE	7.36E-02	0.00E+00	0.00E+00
725	822-50-4	TRANS-1,2-DIMETHYLCYCLOPENTANE	0.00E+00	0.00E+00	0.00E+00
726	2207-03-6	TRANS-1,3-DIMETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00
727	1759-58-6	TRANS-1,3-DIMETHYLCYCLOPENTANE	0.00E+00	9.03E-03	0.00E+00
729	2207-04-7	TRANS-1,4-DIMETHYLCYCLOHEXANE	0.00E+00	0.00E+00	0.00E+00
1586	930-90-5	Trans-1-ethyl-2-methyl-cyclopentane	0.00E+00	0.00E+00	0.00E+00
736	2613-65-2	TRANS-1-METHYL-3-ETHYLCYCLOPENTANE	0.00E+00	3.00E-02	0.00E+00
737	624-64-6	TRANS-2-BUTENE	1.57E+00	5.01E-01	0.00E+00
739	14686-13-6	TRANS-2-HEPTENE	0.00E+00	8.36E-03	0.00E+00
740	4050-45-7	TRANS-2-HEXENE	0.00E+00	6.71E-03	0.00E+00
2244	6434-78-2	TRANS-2-NONENE	0.00E+00	0.00E+00	0.00E+00
741	13389-42-9	TRANS-2-OCTENE	0.00E+00	6.93E-02	0.00E+00
742	646-04-8	TRANS-2-PENTENE	7.74E-02	3.98E-03	5.55E-01
743	14686-14-7	TRANS-3-HEPTENE	0.00E+00	0.00E+00	0.00E+00
744	13269-52-8	TRANS-3-HEXENE	0.00E+00	0.00E+00	0.00E+00

Specie ID	CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
745	20063-92-7	TRANS-3-NONENE	0.00E+00	0.00E+00	0.00E+00
746	14850-23-8	TRANS-4-OCTENE	0.00E+00	9.37E-03	0.00E+00
610	1120-21-4	UNDECANE	4.44E-01	2.69E-01	8.52E-01
1989		UNIDENTIFIED C5 OLEFINS	0.00E+00	1.15E-01	0.00E+00
1999		UNIDENTIFIED C6	4.59E-01	5.91E-01	0.00E+00
2005		UNIDENTIFIED C7	4.77E-02	6.80E-02	0.00E+00
2011		UNIDENTIFIED C8	4.06E-02	2.87E-02	0.00E+00
327		UNIDENTIFIED C9-C12+	5.18E+00	7.38E-01	6.55E+00
845	110-62-3	VALERALDEHYDE	4.66E-01	9.75E-01	1.85E-01

Appendix B TOG Speciation Map for Nonroad emissions

Table A4-13. Total Organic Gas SPECIATE Profiles assigned to nonroad engines, fuels, and emission processes

Profile	Profile Description	Engine Type	Engine Tech	Fuel	Fuel Subtype	Emission Process
1001	CNG Exhaust	All	all	CNG	all	exhaust
95331	CI PreTier 1	CI	PreTier 1	Diesel	all	exhaust
95332	CI Tier 1	CI	Tier 1	Diesel	all	exhaust
95333	CI Tier 2	CI	Tier 2, Tier 3	Diesel	all	exhaust
95333	CI Tier 2	CI	Tier 4: No DPF, and Tier 4M[a]	Diesel	all	exhaust
8775	ACES Phase 1 Diesel Onroad	CI Tier 4	Tier 4: DPF, no SCR	Diesel	all	exhaust
95335a	ACES Phase 2 Diesel Onroad	CI Tier 4	Tier 4: DPF+SCR	Diesel	all	exhaust
8753	E0 Evap	SI	all	Gasoline	E0	evaporative
8869	E0 Headspace	SI	all	Gasoline	E0	headspace
8766	E0 evap permeation	SI	all	Gasoline	E0	permeation
95327	SI 2-stroke E0	SI 2-stroke	all	Gasoline	E0	exhaust
95329	SI 4-stroke E0	SI 4-stroke	all	Gasoline	E0	exhaust
8754	E10 Evap	SI	all	Gasoline	E10	evaporative
8870	E10 Headspace	SI	all	Gasoline	E10	headspace
8769	E10 evap permeation	SI	all	Gasoline	E10	permeation
95328	SI 2-stroke E10	SI 2-stroke	all	Gasoline	E10	exhaust
95330	SI 4-stroke E10	SI 4-stroke	all	Gasoline	E10	exhaust
8860	LPG exhaust	All	all	LPG	all	exhaust

[a]Engine Tech Tier4M refers to recreational marine engines subject to the full phase-in of the recreational marine Tier 3
standards. These engines are not submitted to Tier 4 nonroad emission standards as discussed in the Exhaust and Crankcase Emission Factors for Nonroad Compression-Ignition Engines in MOVES2014b report.[17]

Appendix C PM Speciation Map for Nonroad emissions

Table A4-14. PM SPECIATE Profiles assigned to nonroad engines by engine technology and fuels

Profile	Profile Description	EC/PM ratio	Engine Type	Engine Tech	Fuel
8994[a]	HDDV Exhaust - Composite	77.1%	CI	All non-DPF equipped engines	Diesel
8996	2007 and Newer Diesel Exhaust- Composite	9.98%	CI	Tier 4: DPF equipped	Diesel
91113	Nonroad Gasoline Exhaust - Composite	12.2%	SI	all	Gasoline
95219	CNG transit bus exhaust - Oxidation Catalyst (95219)	9.25%	all	all	LPG, CNG

[a]MOVES3.0.3 and earlier versions assigned profile 91106. However, recent studies[38,39] showed an EC/PM ratio closer to profile 8994 and we have updated the assigned profile accordingly in MOVES3.0.4.

Appendix D Post-Processing Nonroad For Air Quality Modeling

To prepare nonroad inventories for air quality modeling, every county-month is run for the region and time period of interest. For EPA's air quality modeling platforms, the region includes the lower 48 states plus Puerto Rico and the Virgin Islands, and the period is a calendar year.

Most of the pollutants needed by air quality models are present in nonroad MOVES output, but two categories are not: 1) chemical mechanism species that represent the components of TOG and 2) components of Exhaust $PM_{2.5}$. These missing pollutants must be calculated in a post-processing step, after the MOVES run is complete. This post-processing is not strictly part of MOVES2014b.

For onroad vehicles, unlike for nonroad equipment, MOVES2014b produces output that includes chemical mechanism species for TOG and $PM_{2.5}$. These species are generated inside MOVES for onroad output and are partially post-processed for nonroad output. The three mechanisms are CB05, CB6CMAQ, and SAPRC07T. For more information on chemical mechanisms and speciation for air quality modeling, see "Speciation of Total Organic Gas and Particulate Matter Emissions from On-road Vehicles in MOVES2014b[27]."

D.1 TOG Speciation

TOG speciation required for air quality models is different than PM speciation, due to the concept of chemical mechanisms. Chemical mechanisms are used to simplify the thousands of individual organic compounds into a manageable set of CM species to use for air quality modeling. For the purposes of MOVES, a chemical mechanism may be thought of as a set of CM species and the mapping between regular MOVES output species and the CM species. The mapping from nonroad MOVES pollutants to chemical mechanism species depends on engine technology, process, and fuelsubtype. Each combination of these parameters is associated with a "speciation profile." In practice, a profile is the product of a measurement program, as comprehensive as practicable, of all the individual TOG species actually emitted by the engine technology when burning the fuel subtype and engaged in the process associated with the profile. The profiles for TOG for nonroad equipment are listed in the table in Appendix B.

D.2 $PM_{2.5}$ Speciation

Unlike TOG, PM is not mapped into CM species, but is split into various real species and some aggregated groups for use in air quality models. The mapping from nonroad MOVES pollutants to $PM_{2.5}$ species depends on engine technology, process, and fuelsubtype. As for TOG, each combination of these parameters is associated with a "profile." In practice, a profile is the product of a measurement program, as comprehensive as practicable, of all the individual $PM_{2.5}$ species actually emitted by the engine technology when burning the fuel subtype and engaged in the process associated with the profile. The profiles for $PM_{2.5}$ for nonroad equipment are listed in the table in Appendix C.

D.3 Updates for MOVES3.0.4

Speciating nonroad emissions in post-processing remains the same as in previous versions of MOVES. However, in MOVES3.0.4, we updated the post-processing script mentioned in section 1.2 to provide similar capabilities than the onroad emissions speciation post-processing, and to include the necessary elements to allow future speciation under the Reactive Organic Carbon framework[40]. The new script has been incorporated into the Tools menu of the MOVES GUI.

To fulfill the new requirements of the updated post-processing script, we have created a new table in the default database called *nrrocSpeciation* that records the mapping between the emissions output by engine type, engine technology, engine size, fuel and fuel subtype and emission process for each of the speciation profiles for TOG and PM presented in Appendix A and C. The new table contains the following columns: fuelSubTypeID, tierID, strokes, engTechID, processID, pmSpeciationProfileID, CROCCode, CROCOMratio, togSpeciationProfileID, GROCCode and GROCNMOGRatio. The first five columns characterize the equipment source; togSpeciationProfileID and pmSpeciationProfileID indicate the traditional speciation profiles[41] associated with each equipment source; the "Code" columns specify the ROC speciation profiles[42] (listed in EPA's SPECIATE5.2[4141]) associated with a given equipment source and the "Ratio" columns contain adjustment factors applied within the post-processing script to generate Condensable Reactive Organic Carbon (CROC) mass and Gaseous Reactive Organic Carbon (GROC) mass. The new *nrrocSpeciation* table is not used by MOVES and it is only intended to be used by the new post-processing script.

For modelers planning to speciate nonroad emissions outside of MOVES, the runspec must include the appropriate pollutants (NONHAPTOG, $PM_{2.5}$) in addition to specifying output by SCC, fuel type, emission process, engine technology and HP class to provide the information required by the post-processing step. The post-processing script generates a SQL database with NONHAPTOG and $PM_{2.5}$ speciated emissions grouped into SMOKE SCCs to facilitate the combination with vehicle activity within SMOKE-MOVES. Further details on how to run the script and how to use the output are provided in the instructions associated with the post-processing speciation script included in the MOVES GUI.

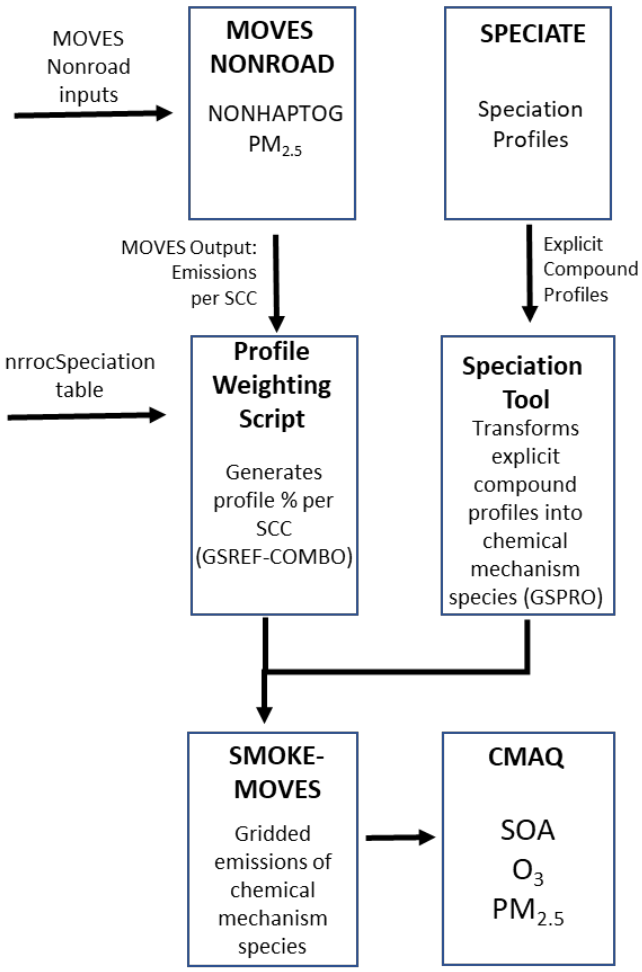

Figure D-1. Diagram showing the new workflow to post-process the speciation of nonroad emissions into chemical mechanism species and how it interacts with other modeling platform tools.

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