Speciation Profiles and Toxic Emission Factors for Non-road Engines

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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1.0 Introduction

Air pollution inventory modelers have traditionally estimated emissions from nonroad, or non-highway, engines and equipment by using EPA's NONROAD model. With the release of MOVES2014, users are able to model emissions from both onroad highway vehicles and nonroad engines and equipment within the same interface.[A] However, MOVES2014 did not estimate emissions of nonroad toxics or speciated hydrocarbons. This capability has been added to MOVES2014a. This document describes the data used to generate speciation profiles and emission rates for toxic compounds emitted from nonroad engines and equipment in the MOVES2014a database and model.

Substantial updates to nonroad air toxic emission factors, historically estimated from the National Mobile Inventory Model (NMIM)[1], were provided by incorporating data from several test programs on speciated emissions from gasoline and diesel engines and equipment.

This document details the research and development behind how MOVES2014a estimates air toxic emissions for nonroad engines and equipment run on conventional gasoline without ethanol (E0) and gasoline blended with 10% ethanol (E10) as well as diesel fuel, compressed natural gas (CNG), and liquefied petroleum gas (LPG). For diesel engines, air toxic emissions may also be differentiated by large and small engine horsepower classifications (described in greater detail in Section 3.1).

In addition, this document 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 – CH4 (methane).

[A] Prior to MOVES, the National Mobile Inventory Model (NMIM) was used to develop county level criteria pollutant and toxics inventories. NMIM incorporated onroad and the NONROAD model to calculate emission inventories.

Non-Methane Organic Gases (NMOG): NMOG = TOG – CH4 (methane).

1.1 Air Toxics in MOVES2014a

The air toxics included in MOVES2014a are classified into four categories:

1) 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]
2) 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.
3) Dioxins and furans: This category includes polychlorinated organic compounds which are persistent in the environment and considered bioaccumulative in aquatic and terrestrial food chains.
4) 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 through Table 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).

In November 2016, we released a patch to MOVES2014a (the 'MOVES2014a November 2016 patch'), which updated the units of dioxin and furan emission rates to be in units of mass, rather than toxic equivalency. Additional discussion on the change is included in the onroad air toxics report, released with the patch[11]. This report updates the dioxin and furan emission rates from the previously posted report.[4]

Table 1. Hydrocarbons and volatile organic compounds included in MOVES2014a

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
Methyl-Tertiary-Butyl Ether (MTBE)	22	1634-04-4
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)[1]	46	1330-20-7

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

Table 2. Polycyclic aromatic hydrocarbons included in MOVES2014a

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 3. Dioxins and furans included in MOVES2014a

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 4. Metals included in MOVES2014a

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 (SO_2), MOVES2014a 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.

Previous versions of MOVES produced highway vehicle emission estimates for a subset of species that contribute to TOG and $PM_{2.5}$. These include important organic gaseous toxics (e.g., formaldehyde and benzene), and toxic particle-phase elements (e.g., nickel and manganese). These also include semi-volatile organic compounds, such as 15 individual polycyclic aromatic hydrocarbons (e.g., benzo(*g*,*h*,*i*)perylene) that can exist in both the gaseous and particle phases under different measurement conditions.

However, prior to MOVES2014, the individual species produced by MOVES had to be estimated outside MOVES by emission pre-processors into a form suitable for use in air-quality modeling, such as the Community Multi-scale Air Quality (CMAQ) model. The process of apportioning aggregate TOG and $PM_{2.5}$ into sets of separate components is called "speciation." MOVES2014 incorporated the process of TOG and $PM_{2.5}$ speciation for highway vehicles, and, thus, for these sources, can produce the TOG and $PM_{2.5}$ species needed by air quality models. The reasoning for bringing the speciation capability inside MOVES is further described elsewhere.[5]

In MOVES2014a, toxics are estimated from the nonroad portion of the model, similar to the highway sources. However, detailed TOG speciation, including the calculation of chemical mechanism species[B], and $PM_{2.5}$ speciation from nonroad sources continue to be conducted via post-processing of MOVES2014a results.[6] Nonetheless, nonroad emissions from MOVES2014a include a higher level of detail than in NONROAD2008, and can be distinguished by engine type, engine technology, engine size, fuel and fuel sub-type, and emission processes. These are the factors used to categorize distinctions in TOG and PM speciation profiles stored in EPA's database SPECIATE. By outputting the emissions by these factors, the speciation of nonroad emissions can occur in the Sparse Matrix Operator Kernel Emissions (SMOKE) processor without any loss of information.

1.3 Methods

We conducted a literature review of air toxics from nonroad engines and concluded that the best available data sets for nonroad engines 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 VOC speciation profiles and gaseous toxic emission fractions for nonroad spark-ignition (SI) engines[7] and nonroad compression ignition (CI) engines.[8,9] The test programs and derivation of these speciation profiles are explained further in Appendix A and in the literature.[10] 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% 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.

Where data on nonroad emissions were absent, nonroad emission factors were derived from onroad vehicles. Onroad emission factors surrogates were used for nonroad gasoline engine emissions of PAHs, metals, and dioxins/furans; diesel engine emissions of VOCs for Tier 4

[B] 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.

≥56kW engines, PAHs for Tier 4 ≥56kW engines, metals, and dioxins/furans; and all air toxics from CNG and LPG engines. For detailed information on the data and derivation of emission factors for onroad vehicles, please refer to the peer-reviewed EPA report entitled Air Toxic Emissions from Onroad Vehicles in MOVES2014 (referred to in this document as the "onroad air toxics report").[11]

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 different operating conditions which could affect composition of the emissions.

2.0 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[C]; 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 (Equation 1):[12]

Equation 1

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

Where:
m_{NMHC} = the mass of NMHC and all oxygenated hydrocarbons in the exhaust
m_{NMOG} = the mass of NMOG in the exhaust

[C] For MY 2011, 54% of the small 2-cycle SI nonroad engines in EPA's certification database are equipped with aftertreatment, with 28% of the small 4-cycle SI nonroad engines certified with aftertreatment. In MY 2015, 57% of the small 2-cycle SI nonroad engines include aftertreatment, with 23% 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. (http://www3.epa.gov/otaq/certdata.htm#smallsi)

$m_{oxygenates}$ = the mass of formaldehyde and acetaldehyde
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 as indicated in Table 19
$\rho_{oxygenate\ i}$ = 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.

Equation 2

$$VOC = NMOG - ethane - acetone$$

Table 5 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 are derived from these values are also presented.

Table 5. Organic gas aggregations estimated from THC for nonroad gasoline engines in MOVES 2014a

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	36235	31510	6667	5855
NMHC	35491	30875	5622	4981
NMOG	35687	32733	5774	5232
TOG	36432	33368	6819	6107
VOC	35586	32631	5692	5156
CH4	744	635	1045	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

[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 6). The remaining VOC species have been integrated into the term NONHAPTOG which is listed at the bottom of Table 6.

Table 6. Nonroad gasoline toxic fractions for VOC included in MOVES2014a

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
Methyl t-butyl ether (MTBE)	0.00000	0.00000	0.00000	0.00000
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 (Equations 3 and 4). PAH emission factors for nonroad gasoline engines were adapted from onroad gasoline engine data (described in section 2.2.1 of the on-road air toxics report) due to unavailability of data for nonroad engines, which includes the same partitioning assumptions between gas and particle as onroad gasoline. Since the nonroad portion of MOVES2014a does not produce speciated $PM_{2.5}$ measurements (in particular, it does not estimate the carbon fraction of $PM_{2.5}$), nonroad PAH emissions are estimated from total $PM_{2.5}$ emissions as opposed to the $OC_{2.5}$[D] used for onroad emissions. The onroad gasoline PAH emission factor is applied to both 2-stroke and 4-stroke gasoline engines and both E0 and E10 fuel subtypes.

Equation 3

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

Equation 4

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

[D] $OC_{2.5}$ refers to the organic carbon portion of PM2.5 emissions

PAH_i = ith species of PAH

Table 7. 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	2.07E-03	6.38E-05
Acenaphthylene	1.81E-04	2.09E-05
Acenaphthene	3.99E-05	0.0
Fluorene	8.08E-05	0.0
Anthracene	3.35E-05	2.21E-05
Phenanthrene	2.14E-04	7.80E-05
Fluoranthene	5.60E-05	7.81E-05
Pyrene	6.40E-05	8.47E-05
Benz(a)anthracene	5.40E-06	2.03E-04
Chrysene	6.05E-06	1.72E-04
Benzo(a)pyrene	2.94E-07	5.09E-04
Benzo(b)fluoranthene	4.01E-06	2.48E-04
Benzo(k)fluoranthene	4.01E-06	2.48E-04
Benzo(g,h,i)perylene	0.0	1.38E-03
Indeno(1,2,3,c,d)pyrene	0.0	5.17E-04
Dibenzo(a,h)anthracene	0.0	1.19E-05

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 existing onroad gasoline emission factors in MOVES2014 (Table 51 of the onroad air toxics report) due to the lack of nonroad emissions tests data for these compounds. Onroad emission factors from MOVES2014 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. These data were collected 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 Appendix A of the onroad air toxics report. Eighteen percent of chromium was assumed to be hexavalent, based on combustion data from stationary combustion turbines burning diesel fuel.[13] To obtain the chromium 6 nonroad gasoline emission factor, 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, Appendix B. Nonroad grams-per-gallon emission factors were calculated from the onroad factors using a fuel economy estimate of 17 miles per gallon, based on average fuel economy estimates for gasoline vehicles used to develop the onroad estimates.[11]

Emission rates for manganese and nickel were developed from 99 vehicles sampled for chemical composition in the Kansas City test program.[14] 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.[15] 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.

A single factor for each metal is applied to all nonroad gasoline engines and fuel sub-types (E0 and E10).

Table 8. Metal emission factors for nonroad gasoline engines

Pollutant	**Emission Factor (g/gal)**
Chromium 6	2.20E-07
Manganese	2.72E-05
Nickel	3.06E-05
Elemental Gas-Phase Hg	1.80E-06
Reactive Gas-Phase Hg	1.70E-07
Particulate Hg	6.90E-09
Arsenic	6.33E-05

2.4 Dioxins and Furans

Emission factors for 17 dioxins and furans were developed (Table 9) based on onroad emission factors (detailed in section 2.4 of the onroad air toxics report) because of a lack of available data for nonroad engines. Onroad emission rates from MOVES2014 were obtained from a tunnel study[16] and used in EPA's dioxin assessment.[17] 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 9 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 (2839 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 Section 4 and 5.

Table 9. Dioxin and furan emission factors for nonroad gasoline engines.

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

[E] In MOVES2014a, the gasoline emission rate for 1,2,3,6,7,8-Hexachlorodibenzo-p-Dioxin was incorrect. It was 1.86e-10, (in TEQ), it should have been 1.86-12 (TEQ). Now the units are in grams, and are correct in the Table above.

3.0 Diesel Exhaust

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] In the absence of data, we applied the VOC profile developed for Tier 2 engines to Tier 3 engines. The same VOC profiles are being applied across all engine sizes within each of the Tier 3-and-earlier technology groups.

The stringency of the nonroad diesel Tier 4 emission standards varies considerably depending on engine size. The NMHC standards are relatively unchanged for engines smaller than 56 kW with Tier 4, so we have continued to apply the developed Tier 2 VOC emission profile to all Tier 4 engines smaller than 56 kW.

For engines greater than 56 kW, the emission standards for NMHC and NOx standards are significantly reduced with Tier 4 vehicles. These standards have forced different configurations of emission control technologies, utilizing advanced technology such as diesel oxidation catalysts, diesel particulate filters, selective reduction catalysts, and ammonia slip catalysts. An onroad 2007 heavy-duty diesel profile was used to represent these engines. This profile was based on heavy-duty diesel onroad engines equipped with diesel oxidation catalysts and diesel particulate filters. For Tier 4 diesel engines ≥56 kW, we applied the speciated emissions factors derived from Phase 1 of the Advanced Collaborative Emissions Study (ACES), directed by the Health Effects Institute and Coordinating Research Council, with participation from a range of government and private-sector sponsors.[18] It should be noted that manufacturers have been able to meet Tier 4 nonroad standards without diesel particulate filters; thus, applying a profile based on 2007 onroad engines introduces considerable uncertainty.

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 10. NMOG was calculated using Equation 1 but the effective C_1-equivalent density of NMHC was calculated from a diesel #2 C:H molar ratio of 1:1.8. VOC and methane emission rates used to develop emission factors for all diesel engines except Tier 4 ≥56kW engines were from the final TOG speciation profiles listed in Appendix A of this document. The methane/THC value for Tier 4 ≥56kW diesel engines is based on the same ratio as the Tier 2 & 3, and small Tier 4 value. . The NMOG/NMHC and VOC/NMHC rates for Tier 4 ≥56kW diesel engines are taken from the onroad model year group of 2007-2050, as documented in the MOVES2014 Speciation of TOG and PM Emissions report.[5]

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 (Table 11). The remaining VOC species have been integrated into the term NONHAPTOG, which is listed at the bottom of Table 11.

Table 10. Methane emission rates and organic gas ratios estimated from THC for nonroad diesel engines in MOVES 2014a

Engine technology	**Pre-Tier 1**	**Tier 1**	**Tiers 2 & 3**	**Tier 4**	**Tier 4**
Fuel type	**Diesel**	**Diesel**	**Diesel**	**Diesel**	**Diesel**
Engine power	**All**	**All**	**All**	**<56 kW**	**≥56 kW**
CH_4 [a]	3.567	4.722	7.960	7.960	
NMOG/NMHC	1.067	1.116	1.233	1.233	1.3431
CH_4/THC	0.005	0.022	0.098	0.098	0.098
VOC/NMHC	1.062	1.110	1.233	1.233	1.3058

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

Table 11. Toxic fractions of VOC for nonroad diesel vehicles by engine standard

	Toxic fraction				
Pollutant	**Pre-Tier 1**	**Tier 1**	**Tiers 2 & 3**	**Tier 4 (<56 kW)**	**Tier 4 (≥56 kW)**
1,3-Butadiene	0.00186	0.00186	0.00186	0.00186	0.00080
2,2,4-Trimethylpentane	0.00807	0.00712	0.00783	0.00783	0.00782
Acetaldehyde	0.0746	0.0783	0.104	0.104	0.06934
Acrolein	0.0302	0.0160	0.0187	0.0187	0.00999
Benzene	0.0196	0.0225	0.0541	0.0541	0.01291
Ethyl Benzene	0.00944	0.00384	0.00438	0.00438	0.00627
Formaldehyde	0.207	0.223	0.292	0.292	0.21744
Hexane	0.00230	0.00279	0.000	0.000	0.00541
Xylenes	0.02256	0.01644	0.0116	0.0116	0.0380
Propionaldehyde	0.0141	0.0386	0.0220	0.0220	0.00314
Styrene	0.000	0.000	0.000	0.000	0.000
Toluene	0.0122	0.0215	0.0378	0.0378	0.02999
NONHAPTOG	0.598	0.568	0.446	0.446	0.59889

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 (Table 58). The data used 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 (Equations 3 and 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 <56kW 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 engines ≥56kW), we relied on onroad engine speciated emissions data from Phase 1 of the ACES study, which tested vehicles equipped with diesel particulate filters.[18] The PAH toxic fractions for nonroad Tier 4 ≥56kW engines were taken from the same onroad conventional heavy duty diesel engines (hot stabilized running, profile 8995) detailed in Table 63 of the onroad air toxics report. 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 3-2 of Appendix A. The resulting PAH EFs are displayed in Table 12

Table 12. PAH emission factors for nonroad diesel engines

	Pre-Tier 1		**Tier 1**		**Tier 2, Tier 3, & Tier 4 <56kW**		**Tier 4 ≥56kW**	
Pollutant	***Gaseous***	***Particle***	***Gaseous***	***Particle***	***Gaseous***	***Particle***	***Gaseous***	***Particle***
Benz(a)anthracene	2.56E-06	4.51E-06	3.22E-06	3.24E-06	7.81E-06	7.76E-06	3.00E-07	8.00E-07
Benzo(a)pyrene	0.0	2.14E-06	0.0	2.13E-06	0.0	6.67E-06	0.0	3.30E-06
Benzo(b)fluoranthene	0.0	2.47E-06	0.0	2.60E-06	0.0	1.07E-05	0.0	1.40E-06
Benzo(k)fluoranthene	0.0	2.09E-06	0.0	2.03E-06	0.0	8.10E-06	0.0	1.40E-06
Chrysene	1.96E-06	7.89E-06	3.85E-06	6.26E-06	7.68E-06	1.31E-05	5.00E-07	2.50E-06
Dibenz(a,h)anthracene	0.0	1.89E-06	0.0	9.64E-07	0.0	9.52E-07	0.0	1.00E-06
Indeno(1,2,3-cd)pyrene	0.0	2.02E-06	0.0	1.53E-06	0.0	6.72E-06	0.0	5.00E-07
Benzo(ghi)perylene	6.20E-07	1.80E-06	1.22E-06	1.62E-06	5.70E-06	7.55E-06	2.00E-07	2.00E-07
Acenapthene	9.59E-04	0.0	3.79E-04	0.0	6.06E-04	0.0	5.26E-05	0.0
Acenapthylene	4.64E-04	0.0	4.95E-04	0.0	1.24E-03	0.0	8.53E-05	0.0
Anthracene	8.74E-05	6.63E-05	4.63E-05	1.95E-05	8.81E-05	2.90E-05	3.04E-05	2.65E-05
Fluoranthene	2.27E-05	2.07E-05	5.22E-05	1.78E-05	1.45E-04	5.59E-05	4.57E-05	4.87E-05
Fluorene	1.15E-03	2.71E-04	5.00E-04	5.75E-05	7.90E-04	7.98E-05	1.96E-04	5.38E-05
Napthalene	3.18E-03	0.0	2.73E-03	0.0	4.64E-03	0.0	1.63E-02	0.0
Phenanthrene	1.56E-03	6.79E-04	1.03E-03	2.03E-04	1.28E-03	2.37E-04	8.51E-04	4.29E-04
Pyrene	7.51E-05	8.28E-05	6.65E-05	3.20E-05	1.30E-04	6.15E-05	3.79E-05	4.67E-05

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 MOVES2014 (Tables 60 and 64 of the onroad air toxics report) 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. Study-specific fuel economy estimates were unavailable for metals on some engine types, therefore average fuel economies were used. 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 an onroad gasoline engine. The chromium 6 emission factor for Tier 0 – Tier 3 and Tier 4 <56kW diesel engines was obtained by multiplying the highway gasoline vehicle emission rate (documented in Appendix A of the onroad air toxics report) by the ratio of total chromium in diesel exhaust[19] to that in gasoline exhaust.[20] For Tier 4 engines ≥ 56kW, the chromium 6 emission rate was obtained by multiplying the gasoline vehicle emission rate by the ratio of total chromium from diesel and gasoline engines. The total chromium estimates came from the ACES[18] and Kansas City test programs, respectively.

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.[15] The fuel average economy for these vehicles was not reported, so, because most of the data was collected in 2000, the model-year-2000 average heavy-duty diesel fuel economy of 7 miles-per-gallon was used.

Emission factors for manganese and nickel were developed from the CRC E-55/59[21] test program for Tier 0 – Tier 3 and Tier 4 <56kW diesel engines. 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 report. For Tier 4 ≥56 kW nonroad diesel engines, emission factors were developed from ACES.[11,18] A study-specific fuel economy of 6 mile-per-gallon was used from page 31 of the ACES report.[18]

Table 13. Metal emission factors for nonroad diesel engines

Engine Tier & Power	Pollutant	Emission Factor (g/gal)
Tier 0 – Tier 3, Tier 4 (<56 kW)	Chromium 6	3.70E-07
	Manganese	3.46E-05
	Nickel	6.05E-05
	Elemental Gas-Phase Hg	1.20E-07
	Reactive Gas-Phase Hg	6.20E-08
	Particulate Hg	3.20E-08
	Arsenic	1.61E-05
Tier 4 (≥56 kW)	Chromium 6	1.00E-07
	Manganese	3.30E-06
	Nickel	3.90E-06
	Elemental Gas-Phase Hg	1.20E-07
	Reactive Gas-Phase Hg	6.20E-08
	Particulate Hg	3.20E-08
	Arsenic	1.61E-05

3.4 Dioxins and Furans

Emission factors for 17 dioxins and furans were developed and based on onroad emission factors because of a lack of available data for nonroad engines. Onroad emission rates from MOVES2014 were used as surrogates and converted from grams-per-mile to grams-per-gallon (Table 14).

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.[22] 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[23] More information on the development of the onroad diesel emission rates and the studies used can be found in Sections 3.4 and 4.4 of the onroad air toxics report.

To apply 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.[22] 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.[23] Thus, for Tier 3

and Tier 4 diesel engines ≥ 56kW, we used the emission factor from representing 2010 on-highway engine (including DPF+SCR).

Table 14. 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)	4.04E-12	ND*
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	1.88E-12	ND
130	19408743	1,2,3,7,8,9-Hexachlorodibenzo-p-Dioxin	8.68E-12	ND
132	35822469	1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	7.59E-11	1.90E-11
131	3268879	Octachlorodibenzo-p-dioxin	2.93E-10	1.27E-10
136	51207319	2,3,7,8-Tetrachlorodibenzofuran	1.18E-10	9.24E-13
139	57117416	1,2,3,7,8-Pentachlorodibenzofuran	2.52E-11	1.95E-12
138	57117314	2,3,4,7,8-Pentachlorodibenzofuran	4.03E-11	5.86E-12
145	70648269	1,2,3,4,7,8-Hexachlorodibenzofuran	1.46E-11	4.00E-12
140	57117449	1,2,3,6,7,8-Hexachlorodibenzofuran	7.71E-12	4.41E-12
146	60851345	1,2,3,7,8,9-Hexachlorodibenzofuran	5.51E-12	3.27E-12
143	72918219	2,3,4,6,7,8-Hexachlorodibenzofuran	ND	ND
144	67562394	1,2,3,4,6,7,8-Heptachlorodibenzofuran	3.93E-11	1.80E-11
137	55673897	1,2,3,4,7,8,9-Heptachlorodibenzofuran	ND	1.06E-12
133	39001020	Octachlorodibenzofuran	3.37E-11	3.15E-11

*ND = non-detect, fractions set to zero. Detection limits ranged from 2 to 18 pg/L, depending on the compound.
1. Used an average of the on-road 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

4.0 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 were borrowed from onroad exhaust CNG transit buses (Table 66 of the onroad air toxics report). Toxic fractions were based on uncontrolled (pre-2002) transit buses (Table 15), 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 15. 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 CNG NMOG/NMHC and VOC/NMHC rates is documented in the 2014 Heavy-Duty Emissions Report[24] and comes from CNG transit bus emissions with no control technologies (Table 16).[25]

Table 16. Organic gas aggregations estimated from THC for nonroad CNG engines in MOVES 2014a

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 PAH toxic fractions from gasoline engines, using equations 3 and 4. The PAH toxic fractions for CNG engines are developed from onroad CNG transit buses (Table 67 of the onroad air toxics report[9]) and are displayed in Table 17.

Table 17. PAH emission factors for CNG engines

	Gaseous Phase (PAH/VOC)	Particulate Phase (PAH/$PM_{2.5}$)
Naphthalene	9.554E-06	1.144E-05
Acenaphthylene	4.230E-06	ND
Acenaphthene	1.243E-06	9.027E-06
Fluorene	2.986E-06	1.580E-05
Anthracene	1.164E-06	1.315E-06
Phenanthrene	8.356E-06	1.062E-05
Fluoranthene	1.936E-06	1.507E-05
Pyrene	3.743E-06	2.891E-05
Benz(a)anthracene	1.682E-07	5.155E-06
Chrysene	2.441E-07	1.083E-05
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	2.633E-06
Dibenz(a,h)anthracene	ND	ND

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 MOVES2014 (Table 68 of the onroad air toxics report[8]) due to the lack of nonroad emissions tests data for these compounds. For Chromium 6 and nickel, the CNG onroad emission factors originate from measurements made by Okamoto et al. (2006)[26] on a CNG transit bus operating on the Central Business District (CBD) driving cycle. We used Equation 5 to calculate fuel-based chromium 6 and nickel emission factors for nonroad equipment. The energy rate (45137.4 KJ/mile) is the average energy rate measured for a model year 2000 CNG bus operating on the CBD driving cycle reported in the MOVES HD emissions rate report[24]. The energy content (48.632 KJ/g) is the default CNG energy content in MOVES,

and the fuel density (2.767 g/gallon) is the density of CNG at ambient temperature and pressure (i.e uncompressed).

Equation 5

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

The resulting emission rates calculated using Equation 5 are located in Table 18.

Table 18. 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+	2.20E-07	2.37E-10	6.56E-10
Nickel	3.06E-05	3.30E-08	9.14E-08

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 19 to grams-per-grams gasoline using the energy density of conventional onroad gasoline in MOVES (2839 g/gal). We then converted the grams-per-grams-gasoline emission rates to grams-per-gallon-CNG using Equation 6.

Equation 6

$$Nonroad\ CNG\ emission\ factor_{(\frac{g}{gal})} = Gasoline\ emission\ rate_{(\frac{g}{g-fuel})} \times CNG\ Fuel\ Density_{(\frac{g-fuel}{gal})}$$
$$= Gasoline\ emission\ rate_{(\frac{g}{g-fuel})} \times 2.767_{(\frac{g-fuel}{gallon})}$$

The resulting emission rates calculated using Equation 6 are located in Table 19.

Table 19. 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	2.72E-05	9.57E-09	2.65E-08
Elemental Gas-Phase Hg	1.80E-06	6.34E-10	1.75E-09
Reactive Gas-Phase Hg	1.70E-07	5.99E-11	1.66E-10
Particulate Hg	6.90E-09	2.43E-12	6.73E-12
Arsenic	6.33E-05	2.23E-08	6.16E-08

4.4 Dioxins and Furans

Emission factors for 17 dioxins and furans were developed and based on emission factors from onroad gasoline engines[16,17] (section 5.4 of the onroad air toxics report) because of a lack of available data for nonroad CNG engines (Table 19). 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,[27] it is reasonable to expect dioxin emissions from CNG engines and we concluded it was better to use surrogate data rather than assume emissions were zero. Onroad emission rates from MOVES2014 were used as surrogates, and we assume that the grams-per-grams-fuel burned 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 (2.676 g/gallon). We converted the grams-per-gram-fuel to grams-per-gallon-CNG using Equation 7. The gasoline fuel-based emission rates and resulting CNG grams-per-gallon emission factors are shown in Table 20.

Equation 7

$$Nonroad\ CNG\ emission\ factor_{\left(\frac{g}{gal}\right)} = Gasoline\ emission\ rate_{\left(\frac{g}{g-fuel}\right)} \times CNG\ Fuel\ Density(2.767)_{\left(\frac{g-fuel}{gal}\right)}$$

Table 20. 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)	6.85E-15	1.89E-14
1,2,3,7,8-Pentachlorodibenzo-*p*-Dioxin	3.06E-15	8.47E-15
1,2,3,4,7,8-Hexachlorodibenzo-p-Dioxin	3.20E-15	8.86E-16
1,2,3,6,7,8-Hexachlorodibenzo-p-Dioxin	6.56E-15	1.81E-14
1,2,3,7,8,9-Hexachlorodibenzo-p-Dioxin	4.08E-15	1.13E-14
1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	4.93E-14	1.36E-13
Octachlorodibenzo-p-dioxin	3.90E-13	1.08E-12
2,3,7,8-Tetrachlorodibenzofuran	2.28E-14	6.32E-14
1,2,3,7,8-Pentachlorodibenzofuran	1.09E-14	3.02E-14
2,3,4,7,8-Pentachlorodibenzofuran	8.00E-15	2.21E-14
1,2,3,4,7,8-Hexachlorodibenzofuran	9.02E-15	2.50E-14
1,2,3,6,7,8-Hexachlorodibenzofuran	9.60E-15	2.66E-14
1,2,3,7,8,9-Hexachlorodibenzofuran	2.62E-15	7.26E-15
2,3,4,6,7,8-Hexachlorodibenzofuran	1.13E-14	3.11E-14
1,2,3,4,6,7,8-Heptachlorodibenzofuran	1.00E-13	2.77E-13
1,2,3,4,7,8,9-Heptachlorodibenzofuran	3.20E-15	8.86E-15
Octachlorodibenzofuran	1.13E-13	3.14E-13

5.0 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 21).[28,29] This profile is based on the average of three light duty onroad LPG vehicles equipped with three-way catalysts and 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 fleet.

Table 21. 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

VOC ratios were calculated from the 8860 speciation profile following a method similar to that used for nonroad gasoline engines (Table 22). In absence of a THC or NMHC measurement, we calculated NMHC by reversing the equation in 40 CFR §1066.635:

Equation 8

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

Where:
m_{NMHC} = the mass of NMHC and all oxygenated hydrocarbons in the exhaust
m_{NMOG} = the mass of NMOG in the exhaust
$m_{oxygenates}$ = the mass of formaldehyde and acetaldehyde
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 as indicated in Table 19
$\rho_{oxygenate\ i}$ = the C_1-equivalent density of oxygenated species *i*

Table 22. Organic gas aggregations estimated from THC for nonroad LPG engines in MOVES 2014a

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 17).

5.3 Metals

For metals, we used the same gram-per-gram-fuel 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 (1923 g/gallon), as shown in Equation 9. Table 23 presents g/g-fuel emission rates and resulting g/gal emission factors.

Equation 9

$$Nonroad\ LPG\ emission\ factor_{(\frac{g}{gal})} = CNG\ emission\ factor_{(\frac{g}{g-fuel})} \times LPG\ fuel\ density_{(\frac{g}{gallon})}$$
$$Nonroad\ LPG\ emission\ factor_{(\frac{g}{gal})} = CNG\ emission\ factor_{(\frac{g}{g-fuel})} \times 1923_{(\frac{g}{gallon})}$$

Table 23. Metal emission factors for nonroad LPG engines

Pollutant	Emission Factor (g/g-fuel)	LPG Nonroad Emission Factor (g/gal)
CR6+	2.37E-10	4.56E-07
Nickel	3.30E-08	6.35E-05
Manganese	9.57E-09	1.84E-05
Elemental Gas-Phase Hg	6.34E-10	1.22E-06
Reactive Gas-Phase Hg	5.99E-11	1.15E-07
Particulate Hg	2.43E-12	4.67E-09
Arsenic	2.23E-08	4.28E-05

5.4 Dioxins and Furans

As for nonroad CNG engines, we used the gasoline g/g-fuel 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 (1923 g/gallon) as shown in Equation 10. The resulting dioxin and furan emission factors are shown in Table 24.

Equation 10

$$Nonroad\ LPG\ emission\ factor_{(\frac{g}{gal})} = Gasoline\ emission\ factor_{(\frac{g}{g-fuel})} \times LPG\ fuel\ density_{(\frac{g}{gallon})}$$
$$Nonroad\ LPG\ emission\ factor_{(\frac{g}{gal})} = Gasoline\ emission\ factor_{(\frac{g}{g-fuel})} \times 1923_{(\frac{g}{gallon})}$$

Table 24. 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)	6.85E-15	1.32E-11
1,2,3,7,8-Pentachlorodibenzo-*p*-Dioxin	3.06E-15	5.89E-12
1,2,3,4,7,8-Hexachlorodibenzo-p-Dioxin	3.20E-15	6.16E-12
1,2,3,6,7,8-Hexachlorodibenzo-p-Dioxin	6.56E-15	1.26E-11
1,2,3,7,8,9-Hexachlorodibenzo-p-Dioxin	4.08E-15	7.85E-12
1,2,3,4,6,7,8-Heptachlorodibenzo-p-Dioxin	4.93E-14	9.47E-11
Octachlorodibenzo-p-dioxin	3.90E-13	7.47E-10
2,3,7,8-Tetrachlorodibenzofuran	2.28E-14	4.39E-11
1,2,3,7,8-Pentachlorodibenzofuran	1.09E-14	2.10E-11
2,3,4,7,8-Pentachlorodibenzofuran	8.00E-15	1.54E-11
1,2,3,4,7,8-Hexachlorodibenzofuran	9.02E-15	1.74E-11
1,2,3,6,7,8-Hexachlorodibenzofuran	9.60E-15	1.85E-11
1,2,3,7,8,9-Hexachlorodibenzofuran	2.62E-15	5.05E-12
2,3,4,6,7,8-Hexachlorodibenzofuran	1.13E-14	2.16E-11
1,2,3,4,6,7,8-Heptachlorodibenzofuran	1.00E-13	1.93E-10
1,2,3,4,7,8,9-Heptachlorodibenzofuran	3.20E-15	6.16E-12
Octachlorodibenzofuran	1.13E-13	2.18E-10

6.0 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 currently only estimated in MOVES from nonroad gasoline engines. 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.[30,31] These toxic fractions are listed below in Table 25.

Table 25. 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. Work to characterize permeation emissions was conducted by Southwest Research Institute for EPA and the Coordinating Research Council in the CRC E-77-2b test program.[32] 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 26. Each of the toxic fractions listed in Table 26 are applied across all nonroad gasoline engine types.

Table 26. 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 CH4/THC values are zero for these processes, and the NMOG/NMHC and VOC/NMHC values are set to one. These values are consistent with the data in SPECIATE profile 4547 'Diesel Headspace,' where there are no measurements of methane, ethane, acetone, formaldehyde, acetaldehyde, or ethanol.

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 CH4/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).[33] Table 27 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 CH4/THC, NMOG/NMHC, and VOC/NMHC values as shown in Table 28.

Table 27. Speciation of CNG fuel reported by Kato et al. (2005)[33]

	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 28. Estimated organic gas aggregations used for evaporative and refueling CNG emissions calculated from Table 27.

Pollutant Ratio	Calculation	Value
CH4/THC	CH4/(CH4 + 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)[28]. The weight percent of the organic species are provided in Table 28.

Table 29. Organic speciation of LPG fuel reported by SPECIATE Profile 2444[28], 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.

7.0 Crankcase Exhaust Emissions

Unlike onroad, MOVES does not estimate nonroad CO, NOx, and PM crankcase emission rates. However, MOVES2014 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 30. The crankcase/exhaust THC ratios are documented in the NONROAD2008 spark-ignition[34] and compression-ignition[35] 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). By model year 2011, all diesel engines are modeled to have no crankcase emissions across all horsepower classes, due to the implementation of the Tier 4 standards.

Table 30. 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

MOVES2014 models crankcase CH4, NMHC, NMOG, VOC, and TOG using the corresponding ratios for tailpipe exhaust. From crankcase VOC emissions, MOVES2014 estimates all of the VOC toxics listed in Table 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

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A1.0 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% 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.

A2.0 Methods

A2.1 Exhaust Emissions Data

A2.1.1 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. 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

A2.1.2 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

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

A2.1.3 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 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.

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

A2.1.4 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.

A2.2 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.

A3.0 Speciation Profile Development

A3.1 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% to 12.48 %). 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).[28] Specifically, toluene was adjusted to 8.64% for the E0 profiles and 7.77% 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%) and erroneously strong influence (1%) 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% in the hot-start bag), causing the composite profile fraction to be subsequently high (2.5%). 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.

A3.2 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%. 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% where other tests were 0.00%). Finally, a different Caterpillar 3196 test (E12DBHL1) had an unrealistically high acetylene value (10.82% where the other tests averaged to 1.15%); 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.

A4.0 Results

Chemical comparisons between currently used onroad profiles and the profiles developed in this report are also detailed in the literature.[10] 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 A4-18.

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	3.33E-03	4.43E-02	3.23E-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	2.30E-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
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

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
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
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

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
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
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

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
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
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

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
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
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

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
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
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
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

CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
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
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

CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
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
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

CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
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
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

CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
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
	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
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

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
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

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
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
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

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
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
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

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
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
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

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
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
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

Specie ID	CAS Number	Compound	E0 % 4 stroke	E0 % 2 stroke	E10 % 4 stroke	E10 % 2 stroke
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

Specie ID	CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
39	934-80-5	1,2-DIMETHYL-4-ETHYLBENZENE	4.06E-02	7.23E-02	0.00E+00
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
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

Specie ID	CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
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
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

Specie ID	CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
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
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

Specie ID	CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
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
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

Specie ID	CAS Number	COMPOUND	Pre-Tier 1	Tier 1	Tier 2
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
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. Responses to Peer-Review Comments

B.1 Overview of the Peer-Review

Two reviewers reviewed the March 2015 draft of the "Speciation Profiles and Toxic Emission Factors for Nonroad Engines." The two peer-reviewers were:

Tom Durbin, PhD
Research Engineer
University of California, Riverside
CE-CERT

Timothy H. DeFries, PhD
Principal Scientist
Eastern Research Group, Inc.

The Peer-reviewers were given the following charge:

We are submitting this material for you to review selected methods and underlying assumptions, their consistency with the current science as you understand it, and the clarity and completeness of the presentation. For this review, no independent data analysis is required. Rather, we ask that you assess whether the information provided is representative of the state of current understanding, and whether incorporating the information in MOVES will result in appropriate predictions and conclusions.

We request you provide us comments on content sequentially. Grammatical/formatting and other minor comments can be provided separately.

Below are questions to define the scope of the review; we are not expecting individual responses to the questions, but would like them to help guide your response.

General Questions to Consider

1. Does the presentation describe the selected data sources sufficiently to allow the reader to form a general view of the quantity, quality and representativeness of data used in the development of emission rates? Are you able to recommend alternate data sources that might better allow the model to estimate national or regional default values?

2. Is the description of analytic methods and procedures clear and detailed enough to allow the reader to develop an adequate understanding of the steps taken and assumptions made by EPA while developing the model inputs? Are examples selected for tables and figures well chosen and designed to assist the reader in understanding approaches and methods?

3. Are the methods and procedures employed technically appropriate and reasonable, with respect to the relevant disciplines, including physics, chemistry, engineering, mathematics and statistics? Are you able to suggest or recommend alternate approaches that might better achieve the goal of developing accurate and representative model inputs? In making recommendations please distinguish between cases involving reasonable disagreement in adoption of methods as opposed to cases where you conclude that current methods involve specific technical errors.

4. In areas where EPA has concluded that applicable data is meager or unavailable, and consequently has made assumptions to frame approaches and arrive at solutions, do you agree that the assumptions are appropriate and reasonable? If not, and you are so able, please suggest alternative sets of assumptions that might lead to more reasonable or accurate model inputs while allowing a reasonable margin of environmental protection.

5. Are the resulting model inputs appropriate, and to the best of your knowledge and experience, reasonably consistent with physical and chemical processes involved in mobile source emissions formation and control? Are the resulting model inputs empirically consistent with the body of data and literature that has come to your attention?

B.2 General Comments from Tom Durbin:

1.0 Introduction – footnote A is worded very awkwardly… "incorporated onroad and the NONROAD model"…

RESPONSE: Wording was corrected.

Section 1.2

End of 1st paragraph – The current regulation under 1065 require a 2.5 micron cyclone for PM measurements. So, is PM as defined as material collected on a filter using EPA-defined sampling practices thus defined as PM2.5.

RESPONSE: 40 CFR 1065.145(f) provides the option to use a cyclonic separator as a PM classifier, however it is not required. The derivation of the PM emission rates for nonroad equipment, including PM2.5/PM10 ratios are discussed in the Nonroad Technical reports available at: http://www.epa.gov/otaq/nonrdmdl.htm.

4th paragraph – 2nd sentence – The second sentence needs to be clarified about how…. PM2.5 speciation from nonroad sources continue to be conducted in SMOKE with the use of MOVES2014a. What is MOVES2014a used within the SMOKE model. Also, a reference to SMOKE should be given.

RESPONSE: Edited the text to read, "…PM2.5 speciation from nonroad sources continues to be conducted via post-processing of MOVES2014a results." Also, a citation was added for SMOKE.

Section 1.3

References 3,4,5, which represent the heart of the report, do not seem to be as complete as they should be. Are these documents publically available? Was a report ever done for the 2004 studies? Did they get document numbers? Can someone put these document/work assignment numbers into a web search and find these documents readily?

RESPONSE: These documents will be made available on the web along with the final version of this technical report.

Section 2.1

The sentence about Equation 2 – The sentence implies that the derivation of VOCs from NMOG by removal of ethane and acetone is clearly defined in the introduction, but the NMOG/ethane/acetone combination is not really alluded to in the introduction.

RESPONSE: The reference to the introduction has been removed.

Equations 3 and 4 need better clarification. Such as, the PAH gaseous and particulate emissions factors are those for the ith species. Also, the term "emissions factor" seems to really be a "fraction".

RESPONSE: The suggested changes were made.

Section 2.3

3rd paragraph – It talks about using a fuel economy estimate of 17 mpg. A description of where the 17 mpg number is from should be given (just one sentence), and a reference or footnote.

RESPONSE: We added a sentence and citation stating the source of the fuel economy estimate.

For this and section 2.4, in deriving nonroad emissions factors for metals and dioxins and furans from onroad emission factors, an important consideration should be whether the source has or does not have a catalyst. With the onroad sources predominantly being catalyst equipped, it seems like some discussion should be given on this point. This does not necessary mean that the emissions rates would be significantly higher for these emissions for the nonroad sources without catalysts, but it just seemed like some related discussion would be worthwhile.

RESPONSE: We added a sentence that discusses this source of uncertainty, in applying catalyst-derived emission rates to nonroad equipment without catalytic aftertreatment.

Section 3.1

In terms of the estimates for Tier 4 nonroad engines, it is important to point out that the emissions standards are slightly looser than those for the corresponding 2007+ model year onroad engines. Thus, it is my understanding that DPFs are not as universally applied as for the onroad vehicles. While ACES data for newer onroad engines is probably the best estimate for filling in data for Tier 4 nonroad engines, some explanation of this caveat should be included in this report, as it is an important distinction.

RESPONSE: We added a sentence in order to acknowledge this source of uncertainty.

Paragraph 5 – It says NMHC is derived from equation 1, but equation 1 is for NMOG, so some discussion of rearrangement needed to get NMHC should be provided.

RESPONSE: The discussion has been corrected to correctly link NMOG to equation 1. NMHC is calculated from THC and methane as defined in the expanded introduction.

It seems commas could be added to the final sentences in both paragraph 5 and 6. Paragraph 5 .. , as document in…. Paragraph 6 …. , which is listed …

RESPONSE: Commas added.

Section 3.2

1st paragraph final sentence …. Represent partitioning <u>as seen in</u> the sampled diluted exhaust,

RESPONSE: Added.

Section 3.3

In the first paragraph, it talks about studies used in developing onroad emissions factor and study specific fuel economy estimates are outlined in the notes of Table 13. I don't see any of that information in Table 13 and it would be useful. This could include some information in the footnotes.

RESPONSE: We incorporated the vehicles, and respective fuel economy in the text (paragraph 3).

Section 3.4

3rd paragraph – (75hp) add space to (75 hp)

Appendix A

It seems like the numbering system for Appendix A should be different than that used in the main test. Maybe call the section A-1.0 Introduction.

In paragraph 2 of Introduction 1.0, the references 3,4,5 should be superscripted.

RESPONSE: We updated the format of the report in response to these suggestions.

Some of the text near the end of the 2nd paragraph on CMAQ/SPECIATE might be worth adding to the main text to strengthen the introduction.

RESPONSE: We added definition and brief discussion of CMAQ and SPECIATE in Section 1.2 of the Introduction

Section 2.1.2

A reference should be added for the ARB study that is discussed in the 1st paragraph.

RESPONSE: The concurrent ARB study was a study being conducted at Southwest Research Institute at the same time as the testing conducted for the US EPA. We do not have details on that study.

Section 2.1.3

Paragraph 2. Why were the FTPs for the ATVs and motorcycles run as 4 bag as opposed to 3 bag FTPs.

RESPONSE: We tested two test intervals of the UDDS cycles (hot and cold) for completeness. We agree that for certification purposes on the FTP according to 40 CFR 1066, a 3-bag test can be used to estimate the FTP composite emissions.

Paragraph 3. A little more detail should be given on the Phase II Auto-Oil methods for the 4 methods used for C_1-C_4, C_5-C_{12} species (include subscripts), benzene and toluene, and alcohols.

RESPONSE: We added a reference to the SI test report, Appendix A where additional details on the test procedures are provided.

Section 2.1.4

It would be worthwhile discussing a bit more about how many replicate tests were conducted for the different tests.

RESPONSE: We added text stating that the results were from a single-tests.

Paragraph 4 – Is an array of impingers 2 or more impingers?

RESPONSE: Yes, an array of impingers refers to two or more impingers.

Section A3.1

At the end of the 2nd paragraph, it talks about there being no outliers, but it then goes on to discuss data adjustments in the 3rd paragraph.

RESPONSE: We added revised the text to state "We evaluated data to identify potential outliers, defined as outside the range of 3.5 standard deviations. No SI data met this criterion."

Final paragraph – It indicates that the 2-stroke catalyst data were not utilized due to various issues with the data. First, it would be useful to know how common or what percentage of the nonroad population are 2-stroke catalyst engines, and where would they most commonly be used.

RESPONSE: We added a footnote to Section 2.1, where we present the percentage of certified engines with aftertreatment of small gasoline engines.

Secondly, for the abnormalities in the data, could some of this be due to making measurements at very low emission levels. For example, are the numbers for the abnormalities still much lower than those for the uncatalyzed 2-stroke engines?

RESPONSE: The 2-stroke engines equipped with catalyst aftertreatment were small off-road engines, and were tested in the same test cell as the 4-stroke small off-road engines. The NMOG emissions from the catalyzed 2-stroke engines were at the same level or higher than the 4-stroke counterparts. Thus, it does not appear the abnormalities could be due to lower NMOG emissions.

We do not have an explanation for the abnormalities in the test results, and have not updated the text.

Section A3.2

2nd paragraph – 1st sentence …transient data would be used …. Should be written….. transient data was used. Also +50 hp (a space is needed).

RESPONSE: Corrected.

4th paragraph right below Table 3-3. It talks about zeroing out a high acetylene value. Doesn't this wind up biasing the 1.15% average low? Maybe it rather be not available (NA) as opposed to being zeroed.

RESPONSE: We decided it was more defensible to report a 0.0% acetone value, than to use a 1.15% value from another test.

Section 4

The reviewer agrees that data on toxic emissions from NGVs is limited, hence necessitating the use of on-road emissions factors. So this seems to be a reasonable estimate to make. In addition, to the source that is cited in the report, additional data on a subset of toxic species should be available from recent work done by UCR as part of a series of programs that have been conducted to evaluate the effects of varying natural gas fuel composition on emissions. These studies focused on measuring just carbonyl species. Additionally, West Virginia University (WVU) conducted some studies of NGVs that included some toxics measurements, such as BTEX species and carbonyls. It is expected that more work in characterizing CNG emissions from heavy-duty vehicles will be conducted over the next several years as part of additional efforts that are being planned in California.

Sections 4.2 and 4.3 both reference emission factors from the onroad air toxics report. I expect that these also originate from reference 22, but that reference should be included in both sections as the original source of the raw emissions data. It is worth noting that we also conducted some analyses on some of our filters from NGV testing, but no PAHs were detected with the level of sample collected, as these runs were not designed to be elongated to collect higher levels of mass.

The reviewer agrees that dioxin and furan emissions are probably not available for natural gas engines, and the estimates from the onroad gasoline vehicles seems as reasonable as any.

It is worth noting that if it is desired to obtain additional toxics data from natural gas vehicles that the addition of these measurement to the upcoming California efforts to study natural gas vehicle emissions could be considered.

> *RESPONSE: References were added to sections 4.2 and 4.3. Also, we decided not to use data from studies where only a subset of toxics were measured, since we wanted consistency between toxics estimates and speciation profiles.*

Section 5

It is agreed that there is an absence of toxics data from LPG nonroad engines, and that estimates based on onroad vehicles are needed to fill this category. Profiles developed from the 3 light-duty LPG vehicles are probably not terribly representative of nonroad engines, even if these data may be the only available. It should be worth mentioning that utilizing emission factors from catalyst-equipped vehicles could under report the toxics for engines without catalysts. It might also be useful to compare the relative hydrocarbon levels from the light-duty vehicles to those of some recent testing of LPG heavy-duty vehicles conducted at UC Riverside. It would also be useful to provide the reference of the original source data from which the 3 light-duty LPG vehicles was derived. In the absence of data for PAHs, metals, and dioxins and furans, utilizing estimates based on the CNG engines seems reasonable.

> *RESPONSE: The caveat suggested above was added, as well as the reference for the original source data.*

Section 6

Toxics measurements of evaporative emissions are relatively limited. The EPA was a part of the most recent E-77-2b test program on permeation emissions. For the permeation emissions, there is a good discussion of some of the limitations that tank and hose permeation are not differentiated in the onroad portion of MOVES. For section 6.1 on the vapor venting and refueling emissions, the data date back to the early 1990s. It would be useful to reference the original Auto/Oil source materials as well as the Environ study. I thought that studies of evaporative emission toxics were also conducted by EPA in a similar timeframe, although these are quite old as well. I have included a list of some of these older references at the end of this document.

> *RESPONSE: The original reference for Auto/Oil data was added.*

Section 7

The approach for developing the crankcase running exhaust emissions from the onroad gasoline and diesel engines profiles seems to be a reasonable methodology. In terms of explanation, some of the details are provided in Sections 2.1 and 3.1. The crankcase to exhaust ratios are the other key piece of information in developing these emissions factors. Although these are included in this document by reference, it really would be useful to have some values for the ratios for at least THC in this document as well, as this provides an important context for understanding the air toxic emission factors in this report.

> *RESPONSE: We added Table 29, which summarizes the THC crankcase/exhaust ratios. We also revised the text in this section to clarify how nonroad computes THC crankcase emissions, and then the corresponding VOC and toxic crankcase emissions.*

Some clarifications could be added to the PAH section. It seems reasonable to use the gaseous phase PAH fractions from Table 7 and 12.

> *RESPONSE: We have revised the text, to clarify that crankcase gaseous PAH emissions are calculated in the same way as crankcase VOC toxics.*

One question about this methodology is how the distribution of gaseous VOCs might change between gaseous exhaust emissions and vapor from lubricant oil.

> *RESPONSE: We agree that this is a worthwhile question. There has been research on the distribution of particle-bound PAHs between the crankcase and tailpipe exhaust from on-road diesel engines (Zielinska et al. 2008). However, we are not aware of research that have evaluated gaseous-phase toxics between the crankcase and tailpipe exhaust.*

It seems unlikely that there would be significant metal or dioxin/furan emissions from the lubricant oil, so the assumption that these emissions would be negligible in comparison with exhaust emissions seems reasonable.

Tom Durbin: Comments in Response to the Charge Questions

1. *Does the presentation describe the selected data sources sufficiently to allow the reader to form a general view of the quantity, quality and representativeness of data to be used in the development of emission rates? Are you able to recommend alternate data sources that might better allow the model to estimate national or regional default values?*

Overall, speciation data from nonroad sources are pretty limited, so the data sets identified and utilized appear to be good selections in terms of developing the speciation profiles. Two other questions of importance are how representative are these data, and what areas should EPA be looking to collect data in the future.

In terms of the representativeness of the data, it might be useful to discuss in the document how representative the data are in describing the data sources. For example, for the NRMC and ATVs, the data set did not include any 4-stroke NDMC/ATVs. While 4-stroke represent a smaller percentage of the overall sales, it would be useful to provide or obtain information on what percentage of these vehicles are actually 4-stroke, and as such not accounted for. This could be more important for the nonroad compared to onroad sources because there is such a diverse mix of engines in the nonroad category compared to onroad vehicles.

In terms of characterizing NRMCs and their use, it appears that EPA has done some work in this area, and may have other resources at its disposal.

http://www.epa.gov/nonroad/proposal/r01046.pdf
The California Air Resources Board (CARB) is also in the process of evaluating the respective populations of 2-stroke and 4-stroke NRMC. Cassie Lopinais working to compile this information, which should be available shortly.

Similarly, for other spark-ignited SORE[H] engines, the test matrix included only 4-stroke engines with the mowers, generators, and blower. A large percentage of smaller hand held and other equipment are equipped with 2-stroke engines, however. Some discussion of how prevalent 2-stroke engines are in these applications would be useful to the reader in determining how representative these data actually are.

It is worth noting that CARB is in the process of conducting speciation measurements on a small subset of NRMC[I]s. This data collection effort is scheduled to begin shortly, and should be considered by EPA in future updates of nonroad speciation profiles. The contact would be Sherry Zhang.

> *RESPONSE: Toxic emissions for 4-stroke NRMC/ATVs are accounted for using the toxic to VOC fractions for 4-strokes in Table 6. These fractions were obtained from mowers, generators and blowers. We added a caveat to the introductions that data from a limited number of equipment types were applied to other equipment types with different operating conditions which could affect composition of the emissions. We also added text in Appendix A that the engines we relied on are not representative of the fleet as a whole.*

2. *Is the description of analytic methods and procedures clear and detailed enough to allow the reader to develop an adequate understanding of the steps taken and the assumptions made by EPA in developing the model inputs? Are examples selected for tables and figures well chosen and do they assist the reader in understanding the intended approaches and methods?*

Most of the recommendations related to this question are included above. The discussion of getting VOCs from Equation 2 in section 2.1 and getting NMHC from equation 1 in section 3.1. In section 2.3, the origin of the 17 mpg fuel economy estimate used in the conversion. Including information on the applicable studies in Table 13. Also, in the Appendix, section 2.1.3, providing more information on the Auto-Oil methods utilized. Zeroing out the acetylene values before averaging is also something that could use some consideration. In sections 4, 5, and 6, references to the original source material where data is derived from should be added. In section 7, more information on the crankcase to exhaust ratios should be added, since this is key to understanding this section.

> *RESPONSE: These comments are addressed above.*

3. *Are the methods and procedures employed technically appropriate and reasonable with respect to the relevant disciplines, including physics, chemistry, engineering, mathematics and statistics? Are you able to suggest or recommend alternate approaches that might better achieve the goal of developing accurate and representative model inputs? In making recommendations please distinguish between cases involving reasonable disagreement in adoption of methods as opposed to cases where you conclude that current methods involve specific technical errors.*

Again, most of the recommendations related to this question are included above. One of the bigger ones in this category is using the onroad sources from catalyzed vehicles to make estimates for nonroad sources without catalysts, as discussed in sections 2.3 and 2.4. Also, the subtleties of the differences between the certification

[H] Small Off-Road Engines (SORE)
[I] Nonroad motorcycle (NRMC)

levels for the Tier 4 nonroad diesel engines vs. the 2007+ onroad diesel engines should be explained in section 3.1. Also, the zeroing out the acetylene values before averaging.

RESPONSE: These comments are addressed above.

4. *In areas where EPA has concluded that applicable data is meager or unavailable, and consequently has made assumptions to frame approaches and arrive at solutions, do you agree that the assumptions are appropriate and reasonable? If not, and you are so able, please suggest an alternative set(s) of assumptions that might lead to more reasonable or accurate model inputs while allowing a reasonable margin of environmental protection.*

Overall, the estimates and assumptions made appear to be reasonable for cases where little or no data is applicable. In making assumptions, one of the aspects worth noting in the report is where estimates from catalyst equipped vehicles are utilized for nonroad engines that may not be equipped with catalysts. Again, the subtleties of the differences between the certification levels for the Tier 4 nonroad diesel engines vs. the 2007+ onroad diesel engines should be explained in the report.

In terms of additional data sets, consideration should be given to work that has been carried out in California in terms of testing of natural gas vehicles, as well as upcoming studies that will be carried out in nonroad motorcycles. A listing of references that would be worth considering for MOVES (most of which being onroad) is provided at the end of this document.

RESPONSE: These comments are addressed above. We will evaluate additional emissions research for future updates of MOVES.

5. *Are the resulting model inputs appropriate, and to the best of your knowledge and experience, reasonably consistent with physical and chemical processes involved in mobile source emissions formation and control? Are the resulting model inputs empirically consistent with the body of data and literature that has come to your attention?*

The results appear to be consistent with the larger body of literature available on speciation and toxics, including data from onroad vehicles for which data are more readily available.

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Natural Gas On-road

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B.3 General Comments from Tom DeFries:

1A. In many places the report uses emission data from onroad engine measurements when nonroad emissions measurements are not available. It makes sense to me that the emissions between onroad and nonroad engines would be the same, but maybe I am just naïve. I would like to see a discussion (up front somewhere) of why the emissions of nonroad and onroad engines might be expected to be different. Is it a consequence of different emission standards, different emission controls (as a result of standard differences), and a difference in how the vehicles are used, or what?

> *RESPONSE: Speciation profiles may differ between onroad and nonroad engines due to differences in operating conditions. In addition, data from 2007 and later highway diesel engines are used for Tier 4 nonroad diesels, although the former have particulate filters and nonroad diesels do not. This could result in differences. Finally, for some pollutants, data from onroad vehicles with catalysts were applied to emissions from nonroad engines without catalysts. These potential sources of differences have all been highlighted in the revised report.*

1B. In several (many) places in the report an analysis of emission factors for the sought after nonroad vehicle, fuel type, and emissions type cannot be performed because the needed data does not exist. In each instance a substitute dataset is analyzed. For example, the dioxin and furan emission factors for nonroad CNG exhaust are based on an analysis of onroad gasoline exhaust dioxin and furan data. The reasons why these substitutions might be reasonable are not given – other than the substitute data exists. To me the lack of discussion makes the substitution highly questionable. The argument that "MOVES needs <u>something</u>" doesn't really cut it for me. There are those who would argue that zero is a better guess than a completely incorrect emission factor value. So, what can be done about this? Let me suggest there be a separate discussion of the believed formation mechanism or source for each emission category. Ideally, there would be research to reference that identifies the sources. This discussion could be in the Introduction, perhaps in Subsection 1.1, which already has a presentation of each emission category. For example, one category of emissions are the PAHs. Are PAHs in the exhaust derived from PAHs in the fuel, from fuel combustion, from PAHs in the engine oil, from combustion of engine oil, or what? If the predominant source is known, it could provide a reason for choosing the substitute dataset used to determine the PAH emission factors. If none of the sources are known, then the reader at least knows that we tried to find a reasonable substitute based on some sort of logic.

> *RESPONSE: We agree that the substitution of dioxin data from onroad gasoline vehicles to CNG nonroad needs additional justification. However, since onroad CNG vehicles emit compounds like PAHs, which can form dioxins and furans in the presence of chlorine, we felt it reasonable to use emission factors from highway gasoline engines rather than assume emissions were zero. Some discussion was added to the report. Other substitutions, such as use of onroad diesel speciation for nonroad diesels, are much more obvious substitutions and we elected not to include discussion of formation mechanisms.*

2. The second paragraph of the Intro says that factors are updated using from test program data of gasoline and diesel. Are there no test programs on CNG and LPG?

> *RESPONSE: We are not aware of CNG or LPG test programs for nonroad engines that include full speciation. Recent CNG highway vehicle test programs have been conducted with measurements of a subset of toxics species.*

3. The section heading for 1.1 in the text and in the TOC differ.

> *RESPONSE: This has been corrected.*

4. Section 1.2, second paragraph: benzo(g,h,i)perylene.

RESPONSE: Correct.

5. Section 1.2, fourth paragraph, second line: "chemical mechanism species" is a term I don't recognize.

RESPONSE: We have added a footnote explaining this term.

6. Section 1.3, second paragraph: Why is it "important to note"? Do you expect that emission factors would vary greatly by the factors mentioned? I guess that without any data you don't know, but maybe you could mention that for other emission factors where data does exist as a function of the factors mentioned, the emission factors vary greatly. By inference the nonroad emission factors are also likely to vary greatly. We just don't know by how much.

RESPONSE: We added text pointing out there is significant variation in highway vehicles.

7. Section 2.1, first paragraph: I don't understand why the section starts out with "In the absence of data" when it seems that data does exist and it is used for the analysis.

RESPONSE: We have deleted this clause.

8. Section 2.1, first paragraph: The "single" test program apparently actually measured emissions of nonroad vehicles. Many of the sections that follow mention that nonroad data was not available so onroad data was used for the analysis. So, I think it is important to make clear for Section 2.1 that nonroad data <u>was</u> actually used.

RESPONSE: Clarifying language has been added.

9. Section 2.1, second paragraph: I am a novice when it comes to the definitions and differences among VOC, NMOG, NMHC, THC, and TOG. Then, Equation 2 throws ethane and acetone into the mix, and I am lost. I know this was explained in Section 1.2, but I need a graphic or something to make clear the differences. As it is, when I get to the two paragraphs above Table 5, I just say to myself, "if you say so…" Maybe "those in the know" don't need anything more, and it's OK as is for them.

RESPONSE: We have added text to the introduction to better define VOC, NMOG, NMHC, THC and TOG.

10. Section 2.2, first paragraph: Is $OC_{2.5}$ the correct term, or is it a typo and should be $PM_{2.5}$? If it's correct, it is out of the blue for me.

RESPONSE: $OC_{2.5}$ *is now defined as organic carbon fraction of* $PM_{2.5}$ *in a footnote.*

11. I thought that I had understood what was going on, but when I got to Section 3.1 I began to get confused. I guess maybe this confusion may have begun in my mind with the introduction of the terms "VOC profiles" and "VOC emission profile," which are first mentioned in Section 3.1. I presume these terms mean a set of VOC fractions. But I then realized that I was not really certain what all of this work was trying to get. I think (but I'm not sure) that it's two things:

1) emission rates for THC, NMHC, NMOG, TOG, VOC, etc., and

2) the fraction of each by species that make up the VOCs.

So, for example, for Item 1, Table 5 says that for 2-stroke, E0 the VOC emission rate is 35586 mg/mi. And for Item 2, Table 6 gives the fractions of the 35586 mg/mi that it attributed to 1,3-butadiene (0.00214), etc. Multiplying, that would mean that the 1,3-butadiene emission rate is 76 mg/mi (=35586*0.00214). Is that what the report is trying to figure? That is what is stated at the beginning of the second paragraph of Section 2.1 "In the MOVES model, individual VOC fractions are multiplied by total VOC emissions to obtain emission factors."
It seems that the toxic fractions (as in Table 6) apply only to VOCs. So, then why are THC, NMHC, NMOG, TOG, and CH4 shown in Table 5? So, it's not clear to me the distinction between 1) how MOVES will do a calculation and 2) how the literature data is being used to come up with emissions numbers to put into MOVES.

I think this could be solved by adding another subsection to the Introduction. It would tell what MOVES needs to do the calculations, that is, what this report is trying to figure out. Section 1.1 starts out by listing the species, but doesn't complete the idea by telling how calculations are done in MOVES. Section 1.2 talks about the operational definitions of THC, NMOG, etc., what previous MOVES versions lacked, … Section 1.3 talks about what literature was used to calculate the numbers in this report. But what is missing is what quantities we are trying to calculate.
The idea would be that for each type of fuel/emission (gasoline exhaust, diesel exhaust, CNG exhaust, LPG exhaust, evaporative emissions, and crankcase running exhaust emissions) we want to calculate X, Y, Z for use in MOVES. Basically the section needs to say: "MOVES needs the following information: X, Y, Z. So, we're going to estimate these quantities from literature studies." This could be perhaps most clearly portrayed using a table with blank cells. Please tell me in the Introduction. I think that this new subsection could go between Speciation and Methods, and it might be called something like Emission Factors to be Determined. Then, in the later sections, if the report used the same tabular layout, but now with the numbers for the fuel type, the clarity would be much better.

Somewhere around where you tell what you are going to calculate, you could include Equations 1, 2, 3, 4. It looks to me like they may apply to more fuels than just gasoline exhaust, so putting them early in the report and explaining them may be more appropriate for the Introduction.

> *RESPONSE: We agreed that the text was unclear and added a section to the introduction explaining that the report presents estimates for organic gas aggregations and then defining them.*

12. Section 3.1, fourth paragraph: Why are you talking about MY 2007 all of a sudden?

> *RESPONSE: The paragraph was restructured for improved clarity.*

13. Section 3.1, fifth paragraph, fourth line: Better to say "diesel #2 C:H molar ratio of". At first I thought it was a weight ratio.

> *RESPONSE: This change has been made.*

14. Section 3.4, second paragraph: What's a congener?

> *RESPONSE: We have defined the term.*

15. Table 14: Is it possible to tell what the detection limits are so that we know what the emission factors with ND are less than? I don't mind that in MOVES NDs will be set to zero, but I think that you should tell in this document what the ND values are.

RESPONSE: Detection limits varied among compounds, but we have added a range to the document.

16. Section 4.1, first paragraph: What does "conservative" mean? "Conservative" from the environmentalist's point of view or from the engine manufacturer's point of view? Does it mean that the real emissions, which we have no data for, are expected to be less or more than the emissions that the existing data provides? Let me say that "conservative" is always a poor term for use in a technical report.

RESPONSE: We concur and the language has been revised.

17. Section 4.1, first paragraph: It strikes me that a transit bus is quite different from a nonroad vehicle. Can you say anything that might make us think that the CNG transit bus is a reasonable surrogate for a CNG nonroad engine? Are even the overall (i.e., non-speciated) emissions similar?

RESPONSE: We added language indicating that since these two types of engines are much different, the quality of the surrogate is unclear.

18. Section 4.2, first paragraph, first sentence: Does "in a manner similar" mean using Equations 3 and 4? If that's it, say so. My suggestion, as I have stated earlier, is that the technique may best be covered in a new subsection in the Introduction. Then, here, you could just refer to the Introduction.

RESPONSE: We added text referring to equations 3 and 4.

19. Table 17: Is it possible to tell what the detection limits are so that we know what the emission factors with ND are less than? I don't mind that in MOVES NDs will be set to zero, but I think that you should tell in this document what the ND values are.

RESPONSE: Unfortunately, the source reference did not provide detection limits for PAHs.

20. Table 18. To follow along with Equation 5, shouldn't the title for Column 2 be Onroad CNG Emission Factor (g/mi) and the title for Column 3 be <u>Nonroad CNG</u> Emission Factor (g/gal)? I think that would make the table clearer. So, I am assuming that Column 3 has the values that we need for nonroad vehicles, and Column 2 just shows the onroad values that they are derived from.

RESPONSE: This change has been made.

21. Section 4.4: Boy, this is a stretch! CNG dioxins and furans from onroad gasoline engines! All we can do is convert the units using Equation 5? Can you mention ANY reason that these guesses are at all reasonable (see comment 1B)?

RESPONSE: Please see response to comment 1B

22. Table 19. To follow along with Equation 5, shouldn't the title for Column 2 be Onroad CNG Emission Rate TEQ (g/mi) and the title for Column 3 be <u>Nonroad CNG</u> Emission Factor TEQ (g/gal)? I think that would make the table clearer. So, I am assuming that Column 3 has the values that we need for nonroad vehicles, and Column 2 just shows the onroad values that they are derived from.

RESPONSE: This change has been made.

23. Section 6.1.1: In the case of evaporative emissions using toxic fraction data from onroad vehicles makes complete sense because the mechanism of evaporation is independent of the type of vehicle.

24. Section 6.1.1: An alternate source of toxic fraction information is Sam Reddy's ReddyEvap model. This model uses physical chemistry and compound properties to calculate gasoline vapor compositions for different liquid gasoline compositions. The model also calculates vapor composition for different conditions such as Reid vapor pressure, ethanol content, fuel tank fill level, atmospheric pressure, and tank temperature.

RESPONSE: We will consider this model for future versions of MOVES.

25. Section 6.1.2: I seem to recall (I could be remembering incorrectly) that ReddyEvap also calculates the increased permeation of gasoline hydrocarbon compounds when ethanol is present in the gasoline – a synergistic effect. The data in Table 23 don't seem to show this effect.

RESPONSE: We will consider this model for future versions of MOVES.

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