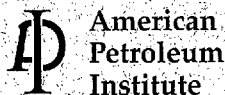


AIR TOXICS EMISSION FACTORS FOR COMBUSTION SOURCES USING PETROLEUM-BASED FUELS

VOLUME 1 DEVELOPMENT OF EMISSION FACTORS USING API/WSPA APPROACH

Health and Environmental Affairs Department
Publication Number 348
August 1998



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Air Toxics Emission Factors for Combustion Sources Using Petroleum-Based Fuels

Volume 1 Development of Emission Factors Using API/WSPA Approach

Health and Environmental Affairs Department

API PUBLICATION NUMBER 348

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ABSTRACT

The Western States Petroleum Association (WSPA) and American Petroleum Institute (API) sponsored a program to develop air toxics emission factors for combustion devices using petroleum-based fuels from source test data collected under California Assembly Bill 2588 (AB2588), entitled the Air Toxics Hot Spots Information and Assessment Act of 1987. The California Air Resources Board (CARB) provided WSPA and API with access to more than 161 petroleum industry combustion source reports, from which data were extracted to derive emission factors. The types of devices represented include process heaters, boilers, reciprocating internal combustion engines, gas turbines, steam generators, asphalt blowers, and coke calciners. The substances quantified include: trace metals; polychlorinated dibenzo[*p*]dioxins and dibenzofurans; polycyclic aromatic hydrocarbons and other semivolatile organic compounds; benzene, toluene and other volatile organic compounds; formaldehyde and other aldehydes; and hydrochloric acid.

Procedures developed in a separate CARB-sponsored program were used to screen and validate data, eliminating those data points or sets with significant problems and/or reporting deficiencies. Through this process, the best data sets were selected for emission factor development. Emission factors were developed encompassing all industries in California, and petroleum-industry-specific emission factors.

As a result of this study, air toxics emission factors for combustion devices have been developed using the best available source testing information. These emission factors can be used by environmental health and safety engineers to develop more accurate and complete emission inventories without additional source testing.

This report consists of three volumes: Volume 1 presents emission factors derived specifically for petroleum industry combustion devices. Volume 2, which presents emission factors derived for inclusion in the CARB database, and Volume 3, providing detailed results of data validation and statistical comparisons are available from API's web site: <http://www.api.org/ehs/Publications/348.htm>.

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ACRONYMS

2S	two stroke reciprocating internal combustion engine
4S	four stroke reciprocating internal combustion engine
AB2588	Air Toxics "Hot Spots" Information and Assessment Act of 1987
Aldehyde Total	acetaldehyde, formaldehyde
APC	air pollution control
API	American Petroleum Institute
BTX	benzene, toluene, xylene
CAAA	Clean Air Act Amendments of 1990
CARB	California Air Resources Board
CATEF	California Air Toxics Emission Factors
CO	carbon monoxide
COCCO	catalyst
CVRG	casing vapor recovery gas
DeNO _x (SNCR)	selective non-catalytic NO _x reduction
DL	detection limit
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
HAP	hazardous air pollutants
HCHO	formula for formaldehyde
HRMS	high-resolution mass spectrometry
LNB	low-NO _x burner
LRMS	low-resolution mass spectrometry
LS	low sensitivity data
MACT	maximum achievable control technology
Mgal	thousand gallons
MMBtu	million British thermal units
Mmcf	million cubic feet
NC	not used in statistical comparison

NO _x	nitrogen oxides
PAH	polycyclic aromatic hydrocarbon
RICE	reciprocating internal combustion engine
S	small data set
SCC	source classification code
SCR	selective catalytic NO _x reduction
SNCR (DeNO _x)	selective non-catalytic NO _x reduction
WSPA	Western States Petroleum Association

EXECUTIVE SUMMARY

This project was performed with the cooperation of the California Air Resources Board (CARB) to develop updated air toxics emission factors for combustion sources using petroleum-based fuels. The emission factors developed in this project will be integrated into CARB's California Air Toxics Emission Factor (CATEF) database. They also may be used by environmental health and safety engineers to develop air toxics emissions inventories in response to state and federal requirements. In addition, these emission factors provide an improved scientific basis for technical and policy decision-making related to the development of new environmental regulations such as federal National Emission Standards for Hazardous Air Pollutants (NESHAPs) for petroleum industry sources.

California Assembly Bill 2588 (AB2588), entitled "Air Toxics Hot Spots Information and Assessment Act of 1987," requires facilities to provide an inventory of their air emissions for the purpose of assessing the potential health risk to surrounding communities. Source testing to characterize air toxics emissions is required when recognized emission factors or reliable engineering estimating techniques do not exist. The results of the source testing performed to comply with AB2588 were used to develop emission factors, which relate the quantity of emissions of a substance to a process-related rate.

DATA VALIDATION

To develop emission factors based on the best available source test results, the petroleum industry AB2588 source test results were screened using a data validation procedure developed by CARB for the CATEF database (Hansell, 1996). Using initial screening, detailed validation, and outlier analysis, this procedure identifies data points and data sets with significant problems and/or reporting deficiencies. Initial screening identifies source tests without sufficient documentation for emission factor development and assessment of data quality. The results of 93 of the 161 source tests were eliminated during the screening procedure. Most of the 93 source tests were eliminated because process rates needed for emission factor derivation were not provided. The

detailed validation step was conducted on the remaining 68 source tests. Detailed validation includes checking to ensure the use of correct sampling and analysis procedures, qualifying significant problems such as high field blanks, checking calculations, and evaluating the accuracy of the test results. The impact of problems identified in the detailed validation process is quantified by conducting an outlier analysis. Outliers are identified statistically using the Dixon method. Each outlier is examined to determine if a process and/or method problem occurred as documented in the results of the detailed validation. If a documented problem occurred, then the outlier is eliminated.

EMISSION FACTOR DEVELOPMENT

The validated source test data were separated into five groups: external combustion devices, reciprocating internal combustion engines, gas turbines, asphalt blowers, and coke calciners. In general, the emissions data for each substance in each group were observed to vary over several orders of magnitude. This variability is due to a combination of measurement uncertainty and differences in the design and operation of devices tested. The variability was reduced, if possible, by identifying design and operating parameters responsible for the variation and further dividing the group into subgroups, if warranted. Engineering judgment and statistical analysis were used to determine whether the design or operating parameters had a significant impact on emissions. Pooling of different system and fuel types within each of the five groups was allowed to increase the quality of the resultant emissions factors. Low sensitivity data also were eliminated from the subgroup evaluation process and emission factor calculations.

FINDINGS

Key observations and findings from the subgroup analysis are listed below.

External Combustion Devices (Boilers and Process Heaters)

- Hazardous air pollutant (HAP) emission factors for boilers and process heaters are similar;
- HAP emission factors for external combustion sources fired by natural gas and process gas are similar;

- Polycyclic aromatic hydrocarbon (PAH) emission factors for liquid-fired sources are higher than for gas-fired sources;
- Benzene, toluene, and xylene (BTX) and formaldehyde emission factors for liquid- and gas-fired sources are similar; and
- HAP emission factors for boilers and process heaters with and without NOx emission controls are similar.

Reciprocating Internal Combustion Engines

- HAP emission factors for gas- and diesel oil-fired sources are similar, except that formaldehyde emissions from diesel sources are lower;
- HAP emission factors for 2 and 4 stroke sources are similar, except that total BTX emissions from 2 stroke sources are higher; and
- Rich burn reciprocating internal combustion engines (RICE) have higher total BTX and lower formaldehyde emissions than lean burn RICE.

Based on these observations, external combustion devices and reciprocating internal combustion engines were divided into the subgroups shown in Tables ES-1 and ES-2, respectively. The arithmetic mean emission factor and EPA quality rating are provided in these tables for each substance. Gas turbines were divided into two subgroups—with and without duct burners (Table ES-3). Emission factors for direct-fired devices (asphalt blowing and coke calcining) are provided in Table ES-4. The gas turbine and asphalt blower subgroups were developed from small data sets and could not be evaluated statistically for significance. The coke calcining emission factors were developed from source testing results on a single unit, therefore, no subgroup development was possible.

The EPA ratings listed in Tables ES-1 through ES-4 are assigned on a scale of A to E:

<u>EPA Quality Rating</u>	<u>Emission Factors</u>
A - Excellent	28
B - Above Average	2
C - Average	12
D - Below Average	260
E - Poor	107
NR - Not Reported	25

ES-3

As shown, most of the emission factors developed in this project have EPA ratings of D or E. The predominant reason for low EPA ratings is that emission factors were developed from tests of only one or two sources. Under the EPA rating system, these emission factors can only receive a D or E rating even though the measurement data may be of high quality as a result of the screening and validation procedures. With additional future testing, most of the D-rated emission factors would move to the A through C categories because these factors were collected using CARB or EPA source test methodologies. Emission factors with E ratings also were developed using sound source test methodologies and data points with significant problems have been identified and eliminated. The E rating was assigned because the source test methodologies used (mainly CARB Method 428, CARB Method 430, and EPA Method 29/CARB Method 436 results) have been significantly revised since tests were performed. CARB has not required any retesting for data collected using previous versions of test methods and still considers data collected using these methods to be valid.

Some discussion of the gas turbine and oil-fired external combustion metals data is warranted because these data were collected using versions of EPA Method 29/CARB Method 436 which have been significantly revised to reduce contamination. Specifically, Manganese emission factors for the oil-fired external combustion sources and gas turbines are suspect because of possible cross-contamination between the $\text{HNO}_3/\text{H}_2\text{O}_2$ and $\text{KMnO}_4/\text{H}_2\text{SO}_4$ impingers. Arsenic, Chromium, Copper, Lead and Zinc for oil-fired external combustion sources were detected in levels of significance in field blanks compared to the sample. A significant level is defined as one where the ratio of the blank to sample is greater than 0.10. The gas turbine trip blanks indicated significant levels of Mercury and Zinc for the sources with duct burners. A complete assessment of contamination was not possible for the gas turbine data sets because field blanks were not collected.

REPORT ORGANIZATION

Only Volume 1 is presented here; Volumes 2 and 3 are available from API's web site:

<http://www.api.org/ehs/Publications/348.htm>. Volumes 1 and 2 describe emission factors

developed specifically for combustion sources using petroleum-based fuels and for CATEF, respectively. Data collection and validation procedures are summarized in Volume 1 and a detailed description is provided in Volume 2. Volume 3 provides supporting information, including detailed procedures used for validation of source test data, validation results, and detailed statistical comparison results.

This volume (Volume 1), which presents petroleum-industry-specific emission factors, is divided into three sections:

Section 1 - Introduction.

Section 2 - Data Validation. This section summarizes the data validation process to which the emission test data were subjected in calculating emission factors of known quality. A more complete discussion of the data validation procedures can be found in Volume 2.

Section 3 - Emission Factors. This section presents the results of analyses of the impact of design and operating parameters on HAP emissions from petroleum industry combustion sources.

TABLE ES-1. EXTERNAL COMBUSTION EMISSION FACTORS (lb/MMBtu)

Category	Substance	Crude/Pipeline Oil - Fired		Fuel Oil No. 6 - Fired		Gas - Fired	
		EPA Rating	Emission Factor	EPA Rating	Emission Factor	EPA Rating	Emission Factor
Dioxin/Furan	Dioxin:4D 2378	E	3.5E-12	E	4.3E-12	-	-
	Dioxin:5D 12378	E	1.7E-11	E	2.5E-12	-	-
	Dioxin:6D 123478	E	1.5E-11	E	2.5E-12	-	-
	Dioxin:6D 123678	E	2.1E-11	E	2.5E-12	-	-
	Dioxin:6D 123789	E	3.3E-11	E	2.5E-12	-	-
	Dioxin:7D 1234678	E	9.3E-11	E	2.1E-11	-	-
	Dioxin:8D	E	3.3E-10	E	5.1E-10	-	-
	Furan:4F 2378	E	6.2E-10	E	5.5E-12	-	-
	Furan:5F 12378	E	6.0E-11	E	3.1E-12	-	-
	Furan:5F 23478	E	1.1E-10	E	3.1E-12	-	-
	Furan:6F 123478	E	1.3E-10	E	2.5E-12	-	-
	Furan:6F 123678	E	4.3E-11	E	1.9E-12	-	-
	Furan:6F 123789	E	3.5E-12	E	2.5E-12	-	-
	Furan:6F 234678	E	6.1E-11	E	3.7E-12	-	-
	Furan:7F 1234678	E	1.4E-10	E	9.8E-12	-	-
	Furan:7F 1234789	E	8.3E-12	E	3.2E-12	-	-
	Furan:8F	E	7.3E-11	E	4.9E-11	-	-
Halogens	HCl	D	1.3E-06	-	-	-	-
Metals	Antimony	-	-	-	-	D	5.2E-07
	Arsenic	NA	6.7E-06	-	-	E	7.2E-07
	Barium	-	-	-	-	D	5.8E-06
	Beryllium	E	1.9E-06	E	4.3E-07	E	1.3E-07
	Cadmium	NA	2.2E-06	-	-	E	1.5E-06
	Chromium (Hex)	NA	1.1E-06	-	-	-	-
	Chromium (Total)	NA	8.7E-06	E	3.3E-05	D	5.7E-06
	Copper	NA	9.5E-06	E	2.6E-05	D	4.7E-06
	Lead	NA	1.9E-06	-	-	D	3.8E-06
	Manganese	NA	1.8E-05	E	3.9E-05	D	4.9E-06
	Mercury	NA	1.0E-05	E	7.0E-08	D	1.8E-07
	Nickel	NA	2.4E-03	E	2.3E-03	D	7.5E-06
	Phosphorus	E	1.8E-04	-	-	D	6.4E-07
	Selenium	NA	7.9E-06	E	2.0E-05	E	8.8E-07
	Silver	-	-	-	-	D	1.6E-06
	Thallium	-	-	-	-	D	5.8E-06
	Zinc	NA	4.2E-04	E	1.1E-04	E	1.4E-03
PAH	Acenaphthene	C	1.7E-07	D	6.0E-09	A	2.4E-09
	Acenaphthylene	C	2.3E-08	D	2.1E-09	A	6.5E-09
	Anthracene	C	3.7E-08	D	2.1E-09	A	4.7E-09
	Benzo(a)anthracene	C	3.2E-08	D	1.3E-09	A	2.2E-08
	Benzo(a)pyrene	D	1.4E-08	D	1.4E-09	A	5.7E-08

TABLE ES-1. EXTERNAL COMBUSTION EMISSION FACTORS (lb/MMBtu)

Category	Substance	Crude/Pipeline Oil - Fired		Fuel Oil No. 6 - Fired		Gas - Fired	
		EPA Rating	Emission Factor	EPA Rating	Emission Factor	EPA Rating	Emission Factor
	Benzo(b)fluoranthene	D	5.5E-09	D	8.1E-09	A	2.7E-08
	Benzo(b+k)fluoranthene	D	8.1E-08	-	-	-	-
	Benzo(e)pyrene	D	3.9E-09	D	5.8E-09	-	-
	Benzo(g,h,i)perylene	D	1.9E-08	D	6.7E-09	A	1.3E-09
	Benzo(k)fluoranthene	D	2.3E-10	D	4.6E-10	A	1.7E-08
	Chrysene	C	7.5E-08	D	2.6E-08	A	1.6E-09
	Dibenz(a,h)anthracene	D	1.2E-08	-	-	A	1.5E-09
	Fluoranthene	C	6.9E-08	D	5.3E-08	A	8.7E-09
	Fluorene	C	2.0E-07	D	3.1E-08	A	4.8E-08
	Indeno(1,2,3-cd)pyrene	D	1.9E-08	D	3.1E-09	A	7.1E-08
	Naphthalene	C	5.5E-06	D	4.0E-07	A	3.9E-07
	Phenanthrene	C	1.7E-07	D	7.4E-08	A	3.2E-08
	Pyrene	C	1.2E-07	D	2.7E-08	A	9.8E-09
	PAH Total	C	7.2E-06	D	6.5E-07	A	5.1E-07
SVOC	2-Chloronaphthalene	D	8.2E-08	D	1.5E-10	-	-
	2-Methylnaphthalene	D	2.5E-07	D	7.4E-08	-	-
	Benzaldehyde	E	4.7E-05	-	-	-	-
	Ethylbenzene	-	-	-	-	A	1.6E-05
	Perylene	D	5.2E-10	D	7.4E-10	-	-
	Phenol	-	-	-	-	NA	4.0E-06
VOC	Acetaldehyde	E	1.1E-05	D	7.0E-06	NA	1.2E-05
	Formaldehyde	NA	1.1E-05	D	1.7E-05	NA	5.2E-05
	Aldehyde Total	NA	2.6E-05	D	5.2E-05	NA	6.6E-05
	Benzene	D	4.1E-06	-	-	NA	6.0E-05
	Toluene	B	3.5E-05	D	3.9E-05	NA	1.5E-04
	Xylene (Total)	D	2.9E-06	-	-	A	2.5E-05
	BTX Total	D	5.0E-05	-	-	A	5.4E-05
	1,3-Butadiene	D	1.4E-04	-	-	-	-
	Acrolein	E	3.3E-06	-	-	A	1.7E-05
	Chloroform	D	6.0E-05	D	3.4E-05	-	-
	Hydrogen Sulfide	-	-	-	-	B	8.5E-05
	Propylene	D	4.4E-05	-	-	A	1.5E-04

ES-7

TABLE ES-2. RECIPROCATING INTERNAL COMBUSTION ENGINE EMISSION FACTORS (lb/MMBtu)*

Category	Substance	RICE, Diesel/O2<13%			RICE, Diesel/O2>13%			RICE, Gas/2S/Lean**			RICE, Gas/4S/Rich**		
		EPA Rating	Emission Factor		EPA Rating	Emission Factor		EPA Rating	Emission Factor		EPA Rating	Emission Factor	
PAH	Acenaphthene	D	4.5E-06		D	1.4E-06		D	7.1E-07		D	6.8E-07	-
	Acenaphthylene	D	9.0E-06		D	5.1E-06		D	1.1E-05		D	7.2E-06	-
	Anthracene	D	1.2E-06		D	1.9E-06		D	4.3E-06		D	2.4E-07	-
	Benzo(a)anthracene	D	6.1E-07		D	1.7E-06		D	8.5E-07		D	7.4E-08	-
	Benzo(a)pyrene	D	2.5E-07		D	1.0E-08		D	-		D	3.4E-08	-
	Benzo(b)fluoranthene	D	1.1E-06		D	1.9E-07		D	1.4E-07		D	3.1E-07	-
	Benzo(b+k)fluoranthene	-	-		D	1.0E-08		-	-		-	-	-
	Benzo(g,h,i)perylene	D	5.4E-07		D	4.1E-07		D	9.0E-08		D	9.8E-08	-
	Benzo(k)fluoranthene	D	2.1E-07		D	3.0E-07		D	4.3E-06		D	5.0E-07	-
	Chrysene	D	1.5E-06		D	3.5E-07		D	1.6E-06		D	9.2E-08	-
	Dibenz(a,h)anthracene	D	3.4E-07		D	4.1E-07		D	-		D	1.0E-08	-
	Fluoranthene	D	3.9E-06		D	7.6E-06		D	1.6E-07		D	2.4E-07	-
	Fluorene	D	1.2E-05		D	2.9E-05		D	2.3E-06		D	4.4E-07	-
	Indeno(1,2,3-cd)pyrene	D	4.0E-07		D	2.7E-07		D	-		D	1.1E-07	-
	Naphthalene	D	1.3E-04		D	8.5E-05		D	2.1E-04		D	1.2E-04	-
	Phenanthrene	D	4.0E-05		D	2.9E-05		D	4.7E-06		D	8.5E-07	-
	Pyrene	D	3.6E-06		D	4.8E-06		D	2.3E-07		D	1.2E-07	-
SVOC VOC	PAH Total	D	2.1E-04		D	1.7E-04		D	2.4E-04		D	1.3E-04	-
	Benzaldehyde	-	-		E	9.0E-05		-	-		-	-	-
	Acetaldehyde	E	2.4E-05		E	7.6E-04		E	8.4E-03		NA	3.8E-03	E 1.6E-03
	Formaldehyde	E	7.7E-05		E	1.2E-03		E	4.8E-02		NA	3.1E-02	C 5.0E-03
	Aldehyde Total	E	1.0E-04		E	2.0E-03		E	3.3E-02		NA	3.1E-02	E 1.1E-02
	Benzene	D	7.1E-04		D	8.8E-04		D	7.5E-03		A	1.3E-03	D 9.9E-03
	Toluene	D	2.6E-04		D	4.0E-04		D	2.7E-03		A	4.9E-04	D 2.8E-03
	Xylene (m,p)	-	-		D	1.5E-04		D	5.8E-04		A	1.4E-04	D 4.7E-04
	Xylene (o)	-	-		D	1.5E-04		D	2.7E-04		A	5.9E-05	D 2.3E-04
	Xylene (Total)	D	1.9E-04		D	2.6E-04		D	-		-	-	-
	BTX Total	D	1.2E-03		D	1.6E-03		D	1.1E-02		A	2.0E-03	D 1.3E-02
	1,3-Butadiene	-	-		D	3.9E-05		-	-		-	-	-
	Acrolein	E	7.6E-06		E	9.4E-05		E	1.9E-03		NA	1.6E-03	D 5.1E-04
	Propylene	D	2.7E-03		D	2.6E-03		D	2.4E-02		A	1.7E-02	D 2.0E-02

* Assume average Brake-specific fuel consumption (BSFC) value of 7×10^{-3} MMBtu/hp-hr to convert from lb/MMBtu to lb/hp-hr
(See Section 3.4 of AP-42)

** Formaldehyde measured by CARB 430 Method, which is under review for NO₂ interference (emissions may be under-reported)

TABLE ES-3. GAS TURBINE EMISSION FACTORS (lb/MMBtu)

Category	Substance	Turbine, Gas/DB=N		Turbine, Gas/DB=Y	
		EPA Rating	Emission Factor	EPA Rating	Emission Factor
Metals	Cadmium	E	5.3E-06	E	2.9E-06
	Chromium (Hex)	E	1.5E-06	E	1.7E-06
	Chromium (Total)	E	1.3E-05	E	5.0E-05
	Copper	E	4.1E-05	D	1.2E-05
	Lead	E	2.8E-05	E	3.6E-05
	Manganese	E	1.3E-04	D	4.8E-05
	Mercury	D	1.5E-05	D	4.4E-06
	Nickel	E	1.7E-04	E	7.7E-05
	Zinc	E	5.0E-03	D	1.2E-04
PAH	Acenaphthene	D	3.3E-09	D	2.2E-08
	Acenaphthylene	D	2.9E-09	D	1.1E-08
	Anthracene	D	3.4E-08	D	2.5E-08
	Benzo(a)anthracene	D	2.8E-09	D	1.5E-08
	Benzo(b)fluoranthene	D	3.3E-09	D	2.5E-08
	Benzo(g,h,i)perylene	D	1.9E-09	-	-
	Benzo(k)fluoranthene	D	2.3E-09	-	-
	Chrysene	D	4.9E-09	D	1.1E-07
	Fluoranthene	D	1.2E-08	D	9.9E-08
	Fluorene	D	1.5E-08	D	1.8E-07
	Indeno(1,2,3-cd)pyrene	D	1.8E-09	-	-
	Naphthalene	D	7.3E-07	D	3.7E-05
	PAH Total	D	9.1E-07	D	3.9E-05
	Phenanthrene	D	6.5E-08	D	6.4E-07
	Pyrene	D	2.3E-08	D	1.2E-07
SVOC	Phenol	D	6.7E-06	D	2.2E-05
VOC	Acetaldehyde	D	2.7E-05	E	4.1E-06
	Formaldehyde	D	3.1E-04	E	3.1E-03
	Aldehyde Total	D	3.4E-04	E	1.6E-04
	Toluene	NA	3.1E-04	E	1.6E-04
	Xylene (Total)	NA	7.7E-04	E	3.7E-04
	BTX Total	D	1.2E-04	-	-
	Acrolein	D	1.7E-05	-	-
	Propylene	D	1.6E-03	-	-

TABLE ES-4. ASPHALT BLOWING AND COKE CALCINING EMISSION FACTORS
(lb/MMBtu)

Category	Substance	Asphalt, Blow Cycle		Asphalt, No Blow Cycle		Coke Calcining	
		EPA Rating	Emission Factor	EPA Rating	Emission Factor	EPA Rating	Emission Factor
Dioxin/Furan	Dioxin:4D 2378	-	-	-	-	D	3.7E-11
	Dioxin:4D Other	-	-	-	-	D	4.4E-10
	Dioxin:5D 12378	-	-	-	-	D	2.9E-11
	Dioxin:5D Other	-	-	-	-	D	2.7E-10
	Dioxin:6D 123478	-	-	-	-	D	3.5E-11
	Dioxin:6D 123678	-	-	-	-	D	4.4E-11
	Dioxin:6D 123789	-	-	-	-	D	4.2E-11
	Dioxin:6D Other	-	-	-	-	D	2.1E-10
	Dioxin:7D 1234678	-	-	-	-	D	4.2E-10
	Dioxin:7D Other	-	-	-	-	D	4.1E-10
	Dioxin:8D	-	-	-	-	D	5.3E-09
	Furan:4F 2378	-	-	-	-	D	4.2E-11
	Furan:4F Other	-	-	-	-	D	4.3E-10
	Furan:5F 12378	-	-	-	-	D	4.4E-11
	Furan:5F 23478	-	-	-	-	D	4.1E-11
	Furan:5F Other	-	-	-	-	D	3.8E-10
	Furan:6F 123478	-	-	-	-	D	7.9E-11
	Furan:6F 123678	-	-	-	-	D	7.1E-11
	Furan:6F 123789	-	-	-	-	D	2.9E-11
	Furan:6F 234678	-	-	-	-	D	6.5E-11
	Furan:6F Other	-	-	-	-	D	4.8E-10
	Furan:7F 1234678	-	-	-	-	D	4.8E-10
	Furan:7F 1234789	-	-	-	-	D	8.0E-11
	Furan:7F Other	-	-	-	-	D	1.8E-10
	Furan:8F	-	-	-	-	D	4.1E-10
Halogens	HCl	E	2.1E-06	E	7.7E-07	-	-
Metals	Antimony	-	-	-	-	D	1.4E-04
	Arsenic	-	-	-	-	D	1.5E-05
	Barium	-	-	-	-	D	6.1E-05
	Beryllium	E	2.5E-06	E	2.2E-06	D	6.0E-06
	Cadmium	-	-	-	-	D	2.9E-05
	Chromium (Hex)	-	-	-	-	D	2.1E-06
	Chromium (Total)	E	3.9E-05	E	1.3E-05	D	6.9E-05
	Copper	E	4.5E-05	E	3.6E-05	D	2.9E-05
	Lead	-	-	-	-	D	1.9E-04
	Manganese	E	1.2E-04	E	1.9E-04	D	1.4E-04
	Mercury	D	8.5E-06	D	8.0E-06	D	1.5E-04
	Nickel	-	-	-	-	D	2.9E-04
	Phosphorus	-	-	-	-	D	1.5E-03

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TABLE ES-4. ASPHALT BLOWING AND COKE CALCINING EMISSION FACTORS
(lb/MMBtu)

Category	Substance	Asphalt, Blow Cycle		Asphalt, No Blow Cycle		Coke Calcining	
		EPA Rating	Emission Factor	EPA Rating	Emission Factor	EPA Rating	Emission Factor
Metals (Cont'd.)	Selenium	-	-	-	-	D	1.5E-05
	Silver	-	-	-	-	D	5.1E-05
	Thallium	-	-	-	-	D	2.2E-04
	Zinc	E	7.9E-04	E	5.0E-04	D	3.7E-04
PAH	Acenaphthene	-	-	-	-	D	4.4E-08
	Acenaphthylene	-	-	-	-	D	5.6E-08
	Anthracene	-	-	-	-	D	5.4E-08
	Benzo(a)anthracene	-	-	-	-	D	2.6E-08
	Benzo(a)pyrene	-	-	-	-	D	2.4E-08
	Benzo(b)fluoranthene	-	-	-	-	D	2.4E-08
	Benzo(g,h,i)perylene	-	-	-	-	D	2.4E-08
	Benzo(k)fluoranthene	-	-	-	-	D	2.4E-08
	Chrysene	-	-	-	-	D	3.7E-08
	Dibenz(a,h)anthracene	-	-	-	-	D	2.4E-08
	Fluoranthene	-	-	-	-	D	1.1E-07
	Fluorene	-	-	-	-	D	1.7E-07
	Indeno(1,2,3-cd)pyrene	-	-	-	-	D	2.4E-08
	Naphthalene	-	-	-	-	D	7.3E-06
	PAH Total	-	-	-	-	D	8.6E-06
	Phenanthrene	-	-	-	-	D	5.7E-07
	Pyrene	-	-	-	-	D	7.9E-08
SVOC	Ethylbenzene	E	8.1E-04	E	7.2E-04	-	-
	Phenol	D	7.1E-05	D	4.4E-05	-	-
VOC	Acetaldehyde	E	1.7E-06	E	4.1E-06	D	3.1E-03
	Formaldehyde	E	3.3E-06	E	1.2E-05	D	1.0E-03
	Aldehyde Total	E	5.0E-06	E	1.6E-05	D	4.2E-03
	Benzene	-	-	-	-	D	1.0E-03
	Toluene	-	-	-	-	D	1.6E-04
	Xylene (m,p)	-	-	-	-	D	8.9E-05
	Xylene (o)	-	-	-	-	D	1.3E-04
	Xylene (Total)	E	8.1E-04	E	7.2E-04	-	-
	BTX Total	-	-	-	-	D	1.4E-03
	Acrolein	-	-	-	-	D	1.0E-03
	Hydrogen Sulfide	D	1.9E-03	D	1.7E-03	-	-

Section 1

INTRODUCTION

This report presents the results of a project to develop air emission factors for combustion devices using petroleum-based fuels. The project was performed by Energy and Environmental Research Corporation (EER) with funding from the American Petroleum Institute (API) and the Western States Petroleum Association (WSPA). The goal was to provide scientifically sound emission factors using procedures recognized by state and federal regulatory agencies for the purposes of developing air emission inventories. These emission factors can be utilized by environmental health and safety engineers to develop more accurate and complete air emission inventories to comply with state and federal requirements. They also can be used to support scientifically-sound technical and policy decision-making related to development of National Emission Standards for Hazardous Air Pollutants (NESHAPs) for petroleum industry sources.

In 1987, the California state legislature passed Assembly Bill 2588 (AB2588), entitled the "Air Toxics Hot Spots Information and Assessment Act of 1987." This California law required industry to inventory air emissions of more than 300 substances (later expanded to more than 700) to assess the potential human health risk to communities surrounding emission sources. Substances include known and potential carcinogens and acutely toxic substances, collectively known as air toxics. Source testing to characterize air toxics emissions was required when recognized emission factors or reliable engineering estimating techniques did not exist. AB2588 allowed source test results for representative sources to be applied to other similar sources through the use of emission factors, or "pooled" source testing. In 1989, the Western States Petroleum Association (WSPA) initiated development of air toxics emission factors specific to petroleum industry combustion sources with a pooled testing program. Two rounds of testing were performed in 1990 and 1992. All source testing was performed under strict guidelines for test methodology specified by the California Air Resources Board (CARB). The results of this testing program were organized into a common database of air toxics emission factors. This database, which has become known as the WSPA database, provides common and consistent

emission factors for petroleum industry combustion devices [Hansell *et al.*, 1992]. The source types included in the database are

- Boilers, process heaters, steam generators, internal combustion engines (gas turbines and reciprocating) with and without NO_x and other air emissions controls; and
- Asphalt blowers and coke calciners.

The database includes sources fired with a variety of gaseous and liquid fuels, including natural gas and petroleum industry process gases (e.g., refinery gas, field gas, casing vapor recovery gas). The database includes information on sources located in California only. The data may not be representative of emission factors for sources outside of California. Since California generally has more stringent air pollutant emission regulations than other states, California sources probably have more controls for criteria pollutants (e.g., NO_x, SO₂, particulate, etc.) than those in the rest of the nation.

A key feature of this database is the emphasis placed on the evaluation of data quality. Significant variations in test and quality assurance/quality control procedures were observed among the various tests, particularly in the first round of pooled source testing. Recognizing the need for more reliable emission factors, WSPA developed a guidance manual for performing air toxics tests to ensure high quality data in the second round of pooled source tests as well as any subsequent tests performed by its individual member companies (Soelberg *et al.*, 1994). As additional tests were performed by industry over the ensuing years, the database has been periodically updated to provide more reliable and representative emission factors.

CARB recently completed a project to compile air toxics emission factors from source test data generated in response to AB2588. Through surveys and visits to local air quality management districts throughout the state, source test reports describing 799 air toxics emissions tests for a wide variety of combustion and non-combustion sources were assembled and used to develop air toxics emission factors (Hansell, 1996). CARB did not develop air toxics emission factors for

petroleum industry combustion sources under this effort. Instead, CARB agreed to provide the American Petroleum Institute (API) and WSPA access to results from 161 petroleum industry air toxics source tests for derivation of combustion device emission factors. Many of these source tests had already been evaluated and incorporated into the WSPA database described above. In return for the additional source test data, API and WSPA agreed to use the CARB data validation procedures and provide the validated information to CARB for inclusion in the California Air Toxics Emission Factors (CATEF) database. In response to this agreement, API and WSPA agreed to use the same rigorous data validation and emission factor development procedures described in the CATEF report (Hansell, 1996) to develop petroleum industry emission factors. The results of this effort are described in Volume 2 of this report. The information in Volume 2 will be submitted to CARB for inclusion in the next version of the CATEF report and database.

In addition to developing emission factors for CATEF, API and WSPA conducted a separate analysis which is described in this volume. The data review and validation procedures are identical to those used for CATEF. To improve the quality of emission factors specific to petroleum industry combustion sources, the CATEF emission factor derivation procedure was modified:

- Emission factors from selected CATEF source categories were pooled together to increase the robustness of the emission factors for selected petroleum industry sources;
- Statistical comparisons were conducted assuming the data are log-normally distributed; and
- Undetected test results collected using low sensitivity analytical techniques were excluded.