EMISSION FACTOR DOCUMENTATION
FOR AP-42 SECTION 3.1 STATIONARY GAS TURBINES

Prepared for:

Office of Air Quality Planning and Standards
U.S. Environmental Protection Agency
Research Triangle Park, NC

Prepared by:

Alpha-Gamma Technologies, Inc.
4700 Falls of Neuse Road
Raleigh, North Carolina

April 2000

TABLE OF CONTENTS

TABLES

Emission Factor Documentation for AP-42 Section 3.1
Stationary Gas Turbines

1.0 Introduction[1]

The revised AP-42 section described in this report replaces the section published in September 1996 as Supplement B to the Fifth Edition. This background report replaces the Emission Factor (EMF) Documentation for AP-42 section 3.1, Stationary Gas Turbines For Electricity Generation, issued February 1993 and amended in 1996 to support Supplement B of the Fifth Edition. The purpose of this background report is to provide technical documentation supporting the Supplement E revisions to AP-42 section 3.1.

The EPA publishes emission factors in its Compilation of Air Pollutant Emission Factors, Volume I Stationary Point and Area Sources, EPA Publication No. AP-42 (AP-42). The document has been published since 1968 as the primary compilation of EPA's emission factor information. Federal, state, and local agencies, consultants, and industry use the document to identify major contributors of atmospheric pollutants, develop emission control strategies, determine applicability of permitting programs, and compile emission inventories for ambient air impact analyses and State Implementation Plans (SIPs). Volume I is published by Emission Factor Inventory Group (EFIG) in EPA's Office of Air Quality Planning and Standards (OAQPS). The OAQPS is located in Research Triangle Park, NC.

1.1 Reasons For Updating

The Clean Air Act Amendments of 1990 added greatly to the number of air pollution sources for which emission factor development was required, and also called for the improvement of existing factors. There are several reasons for updating or revising AP-42 sections and emission factors.

- Contractor Expertise. A contractor or consultant may have gained expertise on a source category during previous work, either for EPA or for other clients, and may warrant consideration by EPA for a relatively low-expense update and expansion of available information.

- New Standard. After the proposal of a standard, the contractor reviews the available material to determine if sufficient information has been gathered to support the development of emission factors for the industry or process being studied. Oftentimes, the proposal or development of a new standard for a source or source category will trigger a re-evaluation of emission factors for a particular source. In the proposal of a standard, the proposal team gathers tremendous amounts of data to support the standard, much more data than is typically gathered for AP-42. The proposal team may compare their new data with existing information used to develop AP-42 emission factors. If, in the comparison, the team discovers a deficiency in the existing information, they may turn their data over to EFIG, who in turn may use the information to improve emission factors.

- Outside Requests. EPA receives requests for better source and emission factor information. Requests may come from other Office of Air Quality Planning and Standards (OAQPS) branches, EPA laboratories and regional offices, state agencies, trade

associations, special interest groups, or private individuals. The requests may take the form of directives, letters, oral inquiries, or comments on published emission factors.

- Improvement of the National Inventory. The EPA may determine that a particular source category is a significant contributor to the National Inventory and that EPA should develop or improve emission factors.

- New Information. New information will be useful that may have been developed initially for Emission Standards Division (ESD) background documents involving New Source Performance Standards, Maximum Achievable Control Technologies (MACT), National Emission Standards For Hazardous Air Pollutants (NESHAP), and Control Techniques Guidelines (CTG), and reports by various EPA laboratories.

Section 3.1 has been updated to incorporate new available data on this source category. New information has been used to better characterize this source category and to develop improved criteria pollutant emission factors. In response to upcoming MACT standards for this source category, an expanded hazardous air pollutant (HAP) emission factor list has also been provided.

This background report consists of four sections. Section 1 provides information on AP-42 documents such as this one that are issued to update sections of AP-42. Section 2 presents the data search and screening steps, discusses the references used to revise AP-42 Section 3.1, and defines the emissions data quality rating system. Section 3 discusses overall revisions to AP-42 Section 3.1, provides details about the data base built for storing the available data, presents the calculations used to calculate emission factors, and defines the emission factor quality rating system. Section 4 presents the revised AP-42 Section 3.1.

1.2 REFERENCES FOR SECTION 1

1. *Procedures For Preparing Emission Factor Documents*, EPA-454/R-95-015, Office of Air Quality Planning and Standards, U.S. EPA, Research Triangle Park, NC 27711, May 1997.

2.0 Literature Search and Screening

Data used in this section were obtained from a number of sources within the OAQPS and from outside organizations. The AP-42 background files were reviewed for information on stationary gas turbines, applicable pollution control technologies, and emissions data. The Factor Information Retrieval System (FIRE) was searched for emissions data on natural gas-fired gas turbines. The Source Test Information Retrieval System (STIRS) data set, compiled by EFIG, was also reviewed. The STIRS data set is a collection of emission test reports which were scanned and stored on CD-ROM. The Combustion Turbine Workgroup of the former EPA Industrial Combustion Coordinated Rulemaking (ICCR) submitted test reports for natural gas, No. 2 fuel oil, digester gas, and landfill gas-fired gas turbines. Test reports were also gathered from the state of Wisconsin and the state of California.

In the review of available references, emissions data were accepted if:

- sufficient information about the turbine and any pollution control devices was given,
- the test report identified if the emission tests were conducted before or after a pollution control device,
- emissions levels were measured by a current test method,
- emission test results were reported in units which could be converted into the reporting units selected for this section, and
- sufficient data existed to characterize operating conditions during testing.

Several test reports were not used in the emission factor development due to missing information regarding the turbine operating parameters. However, these reports are included in the data base provided for this section and are identified by an "x" in their ID numbers. Also appropriate comments are given in the corresponding "Comment" field.

2.1 Review of Data Sets

Since Supplement B was published, EPA has initiated several efforts towards gathering emissions data for combustion sources, including gas turbines. These efforts include the STIRS and the former EPA ICCR efforts.

A total of 119 source test reports containing 369 tests were obtained for gas turbines. In most cases, the test reports included pooled testing efforts for different gas turbines. For NO_X and CO emissions, the data included test reports and test summary data submitted by the San Diego Air Pollution Control District. Out of the gathered 119 test reports, 88 reports containing 267 tests provided sufficient information for emission classification and categorization.

A summary of the references used to develop emission factors and their associated data base identification numbers is presented in Table 2.2-1. A summary review of the references which were not used to develop emission factors is presented in Table 2.2-2.

Detailed information for each test report used for developing the presented emission factors in Section 3.1 of the AP-42 Document is provided in the emissions data base for the section. Refer to Section 3.2.1 of this background report for instructions on how to obtain, use, and review the gathered emissions data for stationary gas turbines.

Table 2.2-1, References Used to Develop Emission Factors

Nearly all of the emission test data contained in these references were assigned a rating of "A" due to the detailed information provided, with the exception of the summary reports provided by the San Diego Air Pollution Control District which were assigned a rating of "B". These references are source test reports for natural gas, landfill gas, digester gas, and oil-fired gas turbines used for electric generation, gas transmission, and industrial uses. A total of 200 tests are for natural gas-fired gas turbines, 43 tests are for distillate oil-fired gas turbines, 20 tests are for landfill gas-fired gas turbines, 3 tests are for digester gas-fired gas turbines, and 1 test is for a field gas-fired combustion turbine. The data extracted from these reports include both criteria and HAP emission data and are available in Microsoft Access on the web at "www.epa.gov/ttn/chief". Several of these test reports contained HAP emission data resulting from the AB 2588 reporting requirements in California.

Table 2.2-2, References Not Used to Develop Emission Factors

Test reports identified with an "x" in the ID number were not used to determine emission factors for Section 3.1 due to the absence of essential turbine operating parameters for the calculation or categorization of emission factors. Other reasons for the exclusion of test reports include indications of poor operating conditions or sample contamination.

2.2 Emission Data Quality Rating System[1]

As part of the emissions data analysis, the quality of the information contained in the set of referenced documents were evaluated. Source test reports were considered to have sound methodology and adequate detail if they met the following criteria:

1. Source operation. The manner in which the source was operated is well documented in the report. The source was operating within typical parameters during the test.

2. Sampling procedures. The sampling procedures conformed to a generally acceptable methodology. The emission tests were conducted using an up to date measurement method. If actual procedures deviated from accepted methods, the deviations are well documented. When this occurred, an evaluation was made of the extent to which such alternative procedures could influence the test results.

3. Sampling and process data. Adequate sampling and process data are documented in the report, and any variations in the sampling and process operation are noted. If a difference between test results cannot be explained by information contained in the test report, the data are suspect and are given a lower rating.

4. Analysis and calculations. The test reports contain original raw data sheets. The nomenclature and equations used were compared to those (if any) specified by EPA to establish equivalency. The depth of review of the calculations was dictated by the reviewer's confidence in the ability and conscientiousness of the tester, which in turn was

based on factors such as consistency of results and completeness of other areas of the test report.

After the source test reports were deemed acceptable based on the aforementioned criteria, data contained in these reports that were used to calculate emission factors were assigned a quality rating. The rating system used was that specified by OAQPS for preparing AP-42 sections.[12] The data were rated as follows:

A - Multiple tests that were performed on the same source using sound methodology and reported in enough detail for adequate validation. These tests do not necessarily conform exactly to the methodology specified in EPA referenced test methods, but at least follow EPA methods in form and function.

B - Tests that were performed by a generally sound methodology, but lack enough detail for adequate validation.

C - Tests that were based on an untested or new methodology or that lacked a significant amount of background data.

D - Tests that were based on a generally unacceptable method but may provide an order-of-magnitude value for the source.

Table 2.2-1. SUMMARY OF REFERENCES USED IN THE REVISION OF SECTION 3.1

Reference Number[a]	General Information Concerning Document	Pollutants Tested	Data Quality	Data Base I.D.
3	Source test on a natural turbine firing both natural gas and oil	Formaldehyde, acetaldehyde	A	2
4	AB 2588 test on a turbine firing both natural gas and oil	Benzene, formaldehyde	A	3
5	AB 2588 test on a turbine firing both natural gas and oil	Speciated HAPs	A	4
6	AB 2588 test on a turbine firing both natural gas and oil	Speciated HAPs, metals	A	6
7	AB 2588 test on a natural gas-fired turbine	Speciated HAPs	A	7
9	Source test on a natural gas-fired turbine	Speciated HAPs	A	9
12	Source test on a turbine firing both natural gas and oil	Speciated HAPs	A	12
13	AB 2588 test on a turbine firing both natural gas and oil	Speciated HAPs	A	13
15	Source test on a turbine firing both natural gas and oil	Speciated HAPs, NO_X, CO	A	15
16	AB 2588 test on a natural gas-fired turbine	Formaldehyde	A	16
17	Source test on a natural gas-fired turbine	Benzene	A	17
18	Source test on a natural gas-fired turbine	Speciated HAPs	A	18
19	Source test on an oil-fired turbine	Speciated HAPs	A	19
20	AB 2588 test on a natural gas-fired turbine	Benzene, formaldehyde	A	20
21	AB 2588 test on a natural gas-fired turbine	Speciated HAPs	A	21
22	AB 2588 test on a natural gas-fired turbine	Speciated HAPs	A	22

Table 2.2-1. SUMMARY OF REFERENCES USED IN THE REVISION OF SECTION 3.1 (Continued)

Reference Number[a]	General Information Concerning Document	Pollutants Tested	Data Quality	Data Base I.D.
24	AB 2588 test on a natural gas-fired turbine	Speciated HAPs	A	27
26	Source test on a natural gas-fired turbine.	Formaldehyde	A	26
27	Compliance test on a natural gas-fired turbine	Speciated HAPs	A	28
28	Source test on a natural gas-fired turbine	NO_X, CO	A	243
29	Source tests on nine natural gas-fired gas turbines	NO_X, CO, THC	A	244
30	Source test on two oil-fired gas turbines with water injection	NO_X, CO, THC, VOC	C	225
31	Source test on a natural gas-fired turbine	NO_X, CO	A	245
33	Source tests on eight natural gas and oil fired gas turbines with water injection	NO_X	A	246
34	Compliance test on two natural gas-fired gas turbines	NO_X, CO, THC	A	202
36	Source test report on one natural gas lean-premix turbine and one natural gas diffusion turbine.	NO_X, CO	A	203
37	Source test report for a natural gas lean-premix turbine.	NO_X, CO, VOC	A	204
38	Compliance test for a natural gas-fired turbine	CO, SO_2	A	205
39	Source test report for a natural gas-fired lean-premix turbine	NO_X, CO	A	206
40	Source test report for four natural gas-fired gas turbines	NO_X, CO, SO_2	A	207
41	Compliance test for a natural gas-fired turbine	NO_X	A	208

Table 2.2-1. SUMMARY OF REFERENCES USED IN THE REVISION OF SECTION 3.1 (Continued)

Reference Number[a]	General Information Concerning Document	Pollutants Tested	Data Quality	Data Base I.D.
42	Source test report for two natural gas-fired turbine	NO_X, CO, SO_2	A	209
43	Source test report for four natural gas-fired gas turbines with water injection	NO_X, CO	A	210
44	Source test report for a natural gas-fired turbine	NO_X	A	211
45	Source test report for four natural gas-fired gas turbines with water injection	NO_X, CO	A	214
46	Compliance test for a natural gas-fired turbine	NO_X, CO	A	219
47	Source test report for a natural gas-fired turbine with water injection	NO_X, CO	A	221
48	Source test report for an oil-fired turbine with water injection	NO_X, CO	A	223
49	Source test report for a natural gas-fired turbine	NMHC	A	224
50	Source test report for five natural gas-fired lean-premix gas turbines	NO_X, CO	A	226
51	Source test report for three oil-fired gas turbines	NO_X, CO	A	227
52	Source test report for two natural gas-fired gas turbines with water injection	NO_X	A	228
54	Source test report for a natural gas-fired turbine	NO_X, CO	A	231
55	Source test report for two natural gas-fired gas turbines	CO, SO_2	A	232
56	Source test report for a natural gas-fired turbine	NO_X, CO	A	234

Table 2.2-1. SUMMARY OF REFERENCES USED IN THE REVISION OF SECTION 3.1 (Continued)

Reference Number[a]	General Information Concerning Document	Pollutants Tested	Data Quality	Data Base I.D.
57	Source test report for a natural gas-fired turbine	NO_X, CO	A	237
59	Source test report for a natural gas-fired turbine with ammonia injection and SCR	NO_X, CO, and NMHC	A	216
60	Source test report for two oil-fired and two digester gas-fired gas turbines	Speciated HAPs, metals, NO_X, CO, NMHC, SO_2, CO_2	A	300
61	Source test report for one oil-fired and one digester gas-fired turbine	Speciated HAPs, metals	A	301
62	Source test report for a landfill gas-fired turbine	Speciated HAPs, NO_X, CO, NMHC, CO_2	A	302
63	Source test report for a landfill gas-fired turbine	Speciated HAPs, NO_X, CO, NMHC	A	303
64	Source test report for a landfill gas-fired turbine	Speciated HAPs, NO_X, CO, NMHC, CO_2	A	304
65	Source test report for a landfill gas-fired turbine	Speciated HAPs, NO_X, CO, NMHC, SO_2, CO_2	A	305
66	Source test report for a landfill gas-fired turbine	Speciated HAPs, NO_X, CO, NMHC	A	306
67	Source test report for a landfill gas-fired turbine	Speciated HAPs, NO_X, CO, NMHC, SO_2	A	307
68	Source test report for a landfill-gas fired turbine	Speciated HAPs, NO_X, CO, NMHC, SO_2	A	308
69	Source test report for a landfill gas-fired turbine	Speciated HAPs, NO_X, CO, NMHC, SO_2	A	309
70	Source test report for a landfill gas-fired turbine	Speciated HAPs, NO_X, CO, NMHC	A	310
71	Source test report for a landfill gas-fired turbine	Speciated HAPs, NO_X, CO, NMHC	A	311
72	Source test report for a landfill gas-fired turbine	Speciated HAPs, NO_X, CO, NMHC, SO_2	A	312

Table 2.2-1. SUMMARY OF REFERENCES USED IN THE REVISION OF SECTION 3.1 (Continued)

Reference Number[a]	General Information Concerning Document	Pollutants Tested	Data Quality	Data Base I.D.
73	Source test report for two natural gas-fired gas turbines	Benzene, formaldehyde, NO_X, CO	A	313
74	Source test report for a natural gas-fired turbine	Benzene, formaldehyde, NO_X, CO	A	315
75	Source test report for a natural gas-fired and an oil-fired gas turbines with water injection	PM-condensables, PM-filterable	C	WDNR-0098
76	Source test report for a natural gas-fired and an oil-fired gas turbines with water injection	PM-condensables, PM-filterable	C	WDNR-0099
77	Source test report for a natural gas-fired and a oil-fired gas turbines with water injection	PM-condensables, PM-filterable	C	WDNR-0102
81	Source test report for a natural gas-fired turbine	NO_X, CO, NMHC	D	212
87	Source test report for a natural gas-fired turbine with steam injection and SCR	NO_X, CO, THC	A	241
96	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	B	406
97	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	B	407
98	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	B	408
99	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	B	409
100	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	B	410

Table 2.2-1. SUMMARY OF REFERENCES USED IN THE REVISION OF SECTION 3.1 (Continued)

Reference Number[a]	General Information Concerning Document	Pollutants Tested	Data Quality	Data Base I.D.
102	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	B	412
104	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	B	425
105	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	B	428
106	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	B	430
107	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	B	432
108	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	B	435
109	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	B	441
110	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	B	444
111	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	B	446
112	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	B	447
113	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	B	448
114	Source test report for natural gas-fired gas turbines with steam injection and SCONOX.	Benzene, formaldehyde, and acetaldehyde	A	318

Table 2.2-1. SUMMARY OF REFERENCES USED IN THE REVISION OF SECTION 3.1
(Concluded)

Reference Number[a]	General Information Concerning Document	Pollutants Tested	Data Quality	Data Base I.D.
117	Compliance test report for a natural gas-fired turbine with lean pre-mix.	Speciated HAPs, NO_X, and CO	A	314
118	Compliance test report for a natural gas-fired turbine.	Speciated HAPs, NO_X, and CO	A	316
119	Compliance test report for a natural gas-fired turbine.	Speciated HAPs, NO_X, and CO	A	317

Table 2.2-2. SUMMARY OF REFERENCES NOT USED IN THE REVISION OF SECTION 3.1

Reference Number[a]	General Information Concerning Document	Pollutants Tested	Data Quality	Data Base I.D.
2	AB 2588 test on a refinery gas-fired turbine	Speciated HAPs, metals	C	1
8	Source test on a natural gas-fired turbine	Speciated HAPs	C	8
10	Source test on a natural gas-fired turbine	Metals	C	10
11	Source test on a natural gas-fired turbine	Speciated HAPs	B	11
14	AB 2588 test on an oil-fired turbine	Speciated HAPs, metals	C	14
23	AB 2588 test on a natural gas-fired turbine	Speciated HAPs	C	23
25	Source test on a natural gas-fired turbine.	Formaldehyde	C	25
32	Source test on a natural gas-fired turbine with steam injection	NO_X, CO	C	200
35	Compliance test on a turbine firing both natural gas and oil	NO_X	C	201
53	Source test report for two natural gas-fired lean-premix gas turbines with water injection	SO_2, PM-condensables, PM-filterable	C	229
58	Source test report for two natural gas-fired lean-premix gas turbines with water injection	SO_2, PM-condensables, PM-filterable	C	240
78	Source test report for gas turbines used for gas transmission	Speciated HAPs	B	29
79	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	C	PEDP-0004
80	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	C	TNRC-0077
82	Compliance test report for a natural gas-fired turbine	NO_X, CO	C	215

Table 2.2-2. SUMMARY OF REFERENCES NOT USED IN THE REVISION OF SECTION 3.1
(Continued)

Reference Number[a]	General Information Concerning Document	Pollutants Tested	Data Quality	Data Base I.D.
83	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	C	217
84	Source test report for a landfill gas-fired turbine	NO_X, CO	C	218
85	Source test report for two natural gas-fired gas turbines with steam injection, SCR and CO catalyst	NO_X, CO	C	220
86	Compliance test report for four natural gas-fired gas turbines with water injection	NO_X, CO	C	222
88	Source test report for a natural gas-fired turbine with steam injection and SCR	NO_X, CO	C	236
89	Source test report for two natural gas-fired gas turbines with steam injection and SCR	NO_X, CO	C	238
90	Source test report for two natural gas-fired gas turbines with steam injection, SCR and CO catalyst	NO_X, CO	C	239
91	Source test report for three natural gas-fired gas turbines with water injection, SCR and CO catalyst	NO_X, CO	C	242
92	Compliance test report for two natural gas-fired gas turbines with steam injection, SCR and CO catalyst	NO_X, CO	C	230
93	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	C	402
94	Source test report for natural gas-fired gas turbines.	NO_X, CO, and SO_2	C	403

Table 2.2-2. SUMMARY OF REFERENCES NOT USED IN THE REVISION OF SECTION 3.1
(Concluded)

Reference Number[a]	General Information Concerning Document	Pollutants Tested	Data Quality	Data Base I.D.
95	Source test report for natural gas-fired gas turbines with water injection.	NO_X	C	404
101	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	C	411
103	Compliance test report for a natural gas-fired turbine with water injection	NO_X, CO	C	417
115	Source test report for natural gas-fired gas turbines.	NO_X, CO, and SO_2	C	235
116	Source test report for natural gas-fired gas turbines with NH_3 injection	Naphthalene, toluene, xylene, benzene, and formaldehyde	C	213
120	Source test report for a natural gas-fired turbine	NO_X, CO, and NMHC	C	233

[a]Reference number corresponds to the reference listing at the end of this section.

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3. Source Emission Test Report regarding Formaldehyde Emissions from the Agnews Cogeneration Facility, San Jose, California. Prepared by Best Environmental, Inc. San Leandro, California for Calpine, San Jose, California. October 2, 1992.

4. Bell. A.C. Emissions Inventory Testing at Long Beach Combustion Turbine No. 3 for Inclusion in Air Toxins Hot Spots Inventory required under AB 2588. Prepared by Carnot, Tustin, California for Southern California Edison Company, Rosemead, California. May, 1989.

5. McDannel, M.D. Air Toxins Emissions Inventory Testing at Coolwater Generating Station Combustion Turbine No. 42 for Inclusion in Air Toxins Hot Spots Inventory Required under AB 2588. Prepared by Carnot, Tustin, California for Southern California Edison Company, Rosemead, California. May, 1990.

6. Source Test Report AB 2588 for Turbine No. 1 at Choachella Power Plant. Prepared by South Coast Environmental Company, La Verne, California for Imperial Irrigation District, Imperial, California. February 25, 1991.

7. Vacherot, R.J. Emissions Testing of a Gas-Fired Cogeneration Facility to Satisfy AB 2588 Requirement. Prepared by Horizon Air Measurement Services, Newbury Park, California for Reese Chamber Systems Consultants, Inc., Somis, California. June 25, 1991.

8. Emission Measurements for Speciated PAH's and BETX Compounds on Gas Fired Turbine and Steam Generator. Prepared by the Almega Corporation (Project # C6823) for Shell Western E&P, Bakersfield, California. August 1, 1991.

9. Source Test Report for the Texaco Heater Treater, the Mobil Steam Generator, and the SWEPI Gas Turbine in the San Joaquin Valley Unified Air Pollution District, California. Prepared by Radian Corporation for Western States Petroleum Association, Bakersfield, California. September, 1992.

10. State of California Air Resources Board, Engineering Evaluation Branch Monitoring and Laboratory Division, Project # C-88-014. Evaluation Test on a Natural Gas Fired Turbine Cogeneration Facility, University Technical Services Inc., Taft, California. January 1989.

11. Emission Testing at Gilroy Energy Company. Prepared by Pape & Steiner Environmental Services, Bakersfield, California for Gilroy Energy Company, Gilroy, California. August, 1990.

12. Rooney, T. Emission Performance Testing of One Cogeneration Turbine at 32nd Street Naval Station, San Diego, California. Prepared by Western Environmental Services, Redondo Beach, California for Sithe Energies, U.S.A. Inc., San Diego, California. May 1991, Revised November 1991.

13. Reel, T. Test Report: AB 2588 Testing for South Bay Unit 2 and Kearny GT-1. Prepared by Carnot, Tustin, California for San Diego Gas & Electric Company, San Diego, California. October, 1991.

14. Report of Air Pollution Source Testing for California AB 2588 at the Kern River Cogen Company, Bakersfield, California. Prepared by Engineering-Science, Inc., Pasadena, California for Kern River Cogen Company, Bakersfield, California. March 28, 1990.

15. LeBarron, D. Determination of Polycyclic Aromatic Hydrocarbons, Formaldehyde, CO, and NO_x Emissions from Turbine Unit #2 at the Modesto Irrigation District McClure Road Generation Station, Modesto, California. Prepared by Ecoserve, Inc. Environmental Services, Pittsburgh, California for Modesto Irrigation District, Modesto California. November 28, 1990.

16. AB 2588 Toxic Emission Testing LM2500 Cogen. Prepared by BTC Environmental, Inc. Ventura, California for Willamette Industries, Inc. Port Hueneme, California. October 21, 1991.

17. Pecaut, A.D. Emissions Testing from a Gas-Fired Cogeneration Facility to Determine Benzene Concentration. Prepared by Horizon Air Measurement Services, Inc. for Willamette Industries, Oxnard, California. January 7, 1992.

18. McRae, G. Air Toxic Emissions Testing of Natural Gas Fired Turbine at Sycamore Cogeneration Company, Bakersfield, California. Prepared by Engineering-Science, Inc. Bakersfield, California for Sycamore Cogeneration Company, Bakersfield, California. June 30, 1992.

19. Gas Turbine Emission Testing for McClure Generating Station. Prepared by Acurex Corporation, Mountain View, California for Modesto Irrigation District, Modesto, California. December 18, 1989.

20. AB 2588 Testing at University Technical Services Petro-Lewis Cogeneration Plant, Taft, California. Prepared by Pape & Steiner Environmental Services, Bakersfield, California for University Technical Services, San Diego, California. August, 1990.

21. Vacherot, R.J. AB 2588 Toxic Emissions Test Results on Gas-Fired Cogeneration Facility, Dexzel Combined Cycle Facility Authority to Operate Permit No. 488001 (A). Prepared by Horizon, Air Measurement Services, Inc. for Diamond (Dexzel) Energy, Inc., Los Angeles, California. July 8, 1992.

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3.0 AP-42 Section Development

3.1 Revisions To Section Narrative

The main change to Section 3.1 of AP-42 was to incorporate gas turbines used for natural gas distribution, which were previously addressed in Section 3.2 of AP-42. The EPA decided that it was more effective to present emission factors for gas turbines in a single section, independent of industrial application, since emission levels from these gas turbines were determined to be similar.

Gas turbines using staged (lean-premix) combustors were also added to the section. A brief discussion of the combustion differences between diffusion flame and lean-premix combustors was added. Other technical discussion updated in this section includes a detailed discussion of the gas turbine operating configurations (operating cycles), identification of the existing industries utilizing gas turbines, and information regarding new control technologies for NO_X and CO emissions reduction. These control technologies include the SCONOX and the XONON technologies for gas turbines.

As for emissions information, the most significant change to the previous section is the inclusion of emission factors for landfill gas and digester gas turbines. In addition, emission factors for natural gas turbines and distillate oil gas turbines were updated. EPA has gathered 119 source test reports for HAPs and criteria pollutants for gas turbines, of which 88 test reports were used in the development of the emission factors presented in Section 3.1. The remaining test reports were not used due to lack of essential information regarding the gas turbine operating parameters during testing. A further discussion of the emissions data is presented in Section 3.2.2.

3.2 Pollutant Emission Factor Development

3.2.1 Data Base Design

The emission data assembled for the development of stationary combustion turbine emission factors was stored in an electronic relational data base formatted in Microsoft® Access 97 data base. A data base approach was chosen in order to easily access and manipulate the large amount of data collected for this section and to facilitate data transfer to and from other concurrent projects at EPA. The design of this data base was accomplished in conjunction with the former Industrial Combustion Coordinated Rulemaking (ICCR) effort of the Emission Standards Division (ESD). Data entered under either of these projects are easily transferred between data bases. Furthermore, the common design of the data base will allow for simple future additions to the data base and simple recalculation of turbine emission factors.

Test reports containing HAP emissions were assigned ID numbers of less than 200. Test containing criteria emissions were assigned ID numbers between 200 and 300. Tests containing both HAP and criteria emissions were assigned ID numbers between 300 and 400, and the summary tests submitted by San Diego Air Pollution Control District were assigned ID numbers greater than 400. Within the data base, data was stored in two tables to reduce repetitive entry of data. These tables, and the data fields associated with each table are described below:

The Facilities Table includes the following data fields:

- Facility Name,
- Location,
- Testing Company,

- Date of Test,
- Turbine Manufacturer,
- Turbine Model Number,
- Operating Load (percent of Capacity),
- Rating (MW),
- Rating (HP),
- Test HP,
- Fuel Type,
- Application Type, and
- Emission Controls.

The Test Data Table includes the following data fields:

- Pollutant,
- Test Method,
- Pollutant Concentration (as reported),
- Detection Limit,
- Exhaust Oxygen Percentage,
- Data Rating,
- Fuel Exhaust Factor (F-Factor),
- Exhaust Flow Rate,
- Fuel Heating Value,
- Standard Temperature of F-Factor,
- Fuel Flow Rate,
- Exhaust Moisture Content (percent by Volume), and
- Molecular Weight of Pollutant.

The data base was programmed to relate the data in the two tables and calculate emission factors for the available pollutants in units of pounds per million standard cubic feet (lb/MMscf) and pounds per million British thermal units (lb/MMBtu) for gaseous fuels and pounds per one thousand gallons (lb/1000 gal) and pounds per million British thermal units (lb/MMBtu) for liquid fuels. The data base also provides emissions concentrations in parts per billion (ppb) corrected to 15 percent oxygen, and emission rates in pounds per hour (lb/hr) and pounds per megawatt-hour (lb/MW-hr) for all fuel types. To ensure consistent calculation of emission factors, the data base was programmed to use the emission concentration data and process data taken during the testing period to calculate the emission factors. Emission factors provided in test reports were not used. The EPA concluded that this method of calculation would provide the highest quality emission factors, since different methods of calculating emission factors were used in some of the references, and in some cases, the method of calculating emission factors was not given. Equations used to calculate emission factors were dependent on the pollutant concentration units and on the desired emission factor.

For concentration in micrograins per dry standard cubic meter, the following equation was used:

$$EF_{MMBtu} = \frac{(C_{ugrm} * F * 1.43 * 10^{-4})}{(35.31)} * \text{oxygen correction}$$

For concentration in parts per billion by volume - dry, the following equation was used:

$$EF_{MMBtu} = \frac{(Cppbvd * F * MW)}{(10^9 * 385.5)} * \text{temperature correction} * \text{oxygen correction}$$

For concentration in grains/dscf, the following equation was used:

$$EF_{MMBtu} = (C_{grf} * F * 1.43 * 10^{-4}) * \text{oxygen correction}$$

For concentration in micrograms per dry standard cubic meter, the following equation was used:

$$EF_{MMBtu} = \frac{(C_{ugm} * F)}{(10^6 * 453.6 * 35.31)} * \text{oxygen correction}$$

Where:

EF_{MMBtu}	=	Emission factor (pounds per million British thermal units of heat input)
C_{ugrm}	=	Concentration (micrograins per dry standard cubic meter)
C_{ppbvd}	=	Concentration (parts per billion by volume, dry)
C_{grf}	=	Concentration (grains per dry standard cubic foot)
C_{ugm}	=	Concentration (micrograms per dry standard cubic meter)
F	=	F-Factor (dry standard cubic feet per million Btu, default values used from 40 CFR Part 60, App. A, Table 19-1)
MW	=	Molecular weight (pounds per pound-mole)
T_{std}	=	Standard temperature (°F)
% O_2	=	Percent of oxygen is exhaust, by volume
1020	=	Natural gas heating value (MMBtu per MMscf)
139	=	Distillate oil heating value (MMBtu per Mgal)
400	=	Landfill gas heating value (MMBtu per MMscf)
600	=	Digester gas heating value (MMBtu per MMscf)
385.5	=	Volume occupied by 1 lb-mole at 68^{O}F and 1 atm (standard cubic feet per lb-mole)
60	=	Conversion factor (minutes per hour)
453.6	=	Conversion factor (grams per pound)
$1.43*10^{-4}$	=	Conversion factor (pounds per grain)
35.31	=	Conversion factor (dry standard cubic feet per dry standard cubic meter)

$$\text{Temperature correction (to } 68^\circ\text{F)} = \left(\frac{528^\circ\text{R}}{460^\circ\text{R}_t + \text{T}_{std}\ ^\circ\text{F}} \right)$$

$$\text{Oxygen correction (to } 0\%\ \text{O}_2\text{)} = \left(\frac{20.9}{20.9\ -\ \%\text{O}_2} \right)$$

The emission factors are based on gas turbines operating on both gaseous and liquid fuels. For consistency in comparing control options, the emission factors are presented in units of lb/MMBtu. A method to convert units from lb/MMBtu to lb/MMscf for natural gas-fired, landfill gas-fired, and digester gas-fired gas turbines is provided below. Also, a method of conversion is provided to obtain lb/1,000 gallons for distillate fired gas turbines.

For gas turbines that burn natural gas, the conversion of lb/MMBtu to lb/10^6 scf can be made using an assumed natural gas heating value of 1020 MMBtu/10^6 scf. This conversion can be done through the following equation:

lb/10^6 scf = lb/MMBtu * 1020 (MMBtu/10^6 scf)

For gas turbines that burn landfill gas, the conversion of lb/MMBtu to lb/10^6 scf can be made using an assumed natural gas heating value of 400 MMBtu/10^6 scf. This conversion can be done through the following equation:

lb/10^6 scf = lb/MMBtu * 400 (MMBtu/10^6 scf)

For gas turbines that burn digester gas, the conversion of lb/MMBtu to lb/10^6 scf can be made using an assumed natural gas heating value of 600 MMBtu/10^6 scf. This conversion can be done through the following equation:

lb/10^6 scf = lb/MMBtu * 600 (MMBtu/10^6 scf)

For gas turbines that burn distillate oil, the conversion of lb/MMBtu to lb/10^3 gallons can be made using an assumed distillate oil heating value of 139 MMBtu/10^3 gallon. This conversion can be done through the following equation:

lb/10^3 gallon = lb/MMBtu * 139 (MMBtu/10^3 gallon)

Detection Limits

For cases where the concentration of a specific pollutant was below the test method detection limit and a detection limit was provided, then half of the detection limit was used to calculate an emission factor. If no detection limit was provided, then the results from that test were not used. Furthermore, if an emission factor for an individual engine was developed from a detection limit and the resulting emission factor was higher than the emission factors generated from detected concentrations, then the emission factor based on a detection limit was removed from the average. The goal of this decision was to prevent

unusually high detection limits from artificially increasing an average emission factor. If an average emission factor was generated entirely from detection limits and not on measured values, it is noted as an emission factor based on detection limits and that expected emissions are lower than the emission factor. These methods for addressing detection level issues were provided in the Procedures For Preparing Emission Factor Documents.[1]

Calculation of Average Emission Factors

To provide average emission factors for these sources, the emission factors from all tests in a specific group were averaged to generate an emission factor. The averaging method used in the data base was an arithmetic average. For tests that consisted of multiple runs, the arithmetic average of the runs was used to develop the emission factor of that test. Individual tests were given equal weight in the calculation of average emission factors for each turbine group. If the majority of data used to generate an emission factor were from non-detect results where the detection limit was used, then the average emission factor was noted to be made up of mostly detection limit estimates. The EPA intends for average emission factors generated from mostly detection levels to provide order of magnitude estimates of emissions levels, and these data are given a low quality rating.

Presentation of Data

Due to the size of the data base, a printout of all the test data used to generate the engine emission factors in Section 3.1 is not presented. Instead, EPA is providing an electronic copy of the data base in Microsoft Access format on the Technology Transfer Network (TTN). This decision has resulted in a substantial decrease in paper needed for this background information document and will provide users with a more detailed background data set for this section. Furthermore, by providing the data base to the public, anyone may use or augment the data base for their individual needs, providing a substantial building block for anyone interested in compiling an extensive data base on natural gas-fired combustion sources. An electronic copy of the data base can be downloaded from the TTN at http://www.epa.gov/ttn/chief. In this website, follow the main menu options to locate the file and then download it.

To view the tests used to calculate the emission factors calculated for theses sources, open the data base file which will automatically open the MAIN FORM view (in cases where the MAIN FORM does not open, open the file and choose the FORMS selection on the main data base screen, then under the FORMS selection, choose MAIN FORM). This will activate a macro which will provide a pollutant list, fuel type, and control device type available for these sources. This provides the option to view the input data, source information, or the emission tests used to calculate the emission factor for a specific pollutant (based on fuel type and control information) by simply clicking on the desired button: To view the data used to calculate the average emission factor for each test, click the EF INPUTS button; to view the individual source information, click the VIEW FACILITIES button; to view the data used for calculating the emission factor, click the EF REPORT button.

To view the tests that were not used to determine the emission factors, close the MAIN FORM and select the Report Menu. Under the Report Menu, select the “Report for not used tests”. This report provides a brief summary of the test information, fuel type, and the corresponding emissions.

3.2.2 Results of Data Analysis

Source Category Selection

An important step in emission factor development is the determination of emission sources which are similar enough to be grouped together and represented by a single emission factor. This is accomplished by investigating which parameters influence emissions, and which should be used to establish distinct groups within the stationary combustion turbine source category. The emission factors for each test contained in the data base were analyzed to determine appropriate groupings.

Available emissions data indicate that the turbine's operating load has a considerable effect on the resulting emission levels. Gas turbines are typically operated at high loads (greater than or equal to 80 percent of rated capacity) to achieve maximum thermal efficiency and peak combustor zone flame temperatures. With reduced loads, or during periods of frequent load changes, the combustor zone flame temperatures are expected to be lower than the high load temperatures, yielding lower thermal efficiencies and more incomplete combustion. The emission factors presented in the background information document are categorized for gas turbines operating under high load conditions and for gas turbines operating under all load condition. Emission factors presented in Section 3.1 are for gas turbines operating at high load conditions only.

NO_X and CO Emission Factors

Based on the analysis of available NO_X and CO data, this category was separated into four main groups: natural gas-fired gas turbines, distillate oil-fired gas turbines, landfill gas-fired gas turbines, and digester gas-fired gas turbines. For natural gas-fired gas turbines, NO_X and CO data were further separated into uncontrolled, water-steam injection, lean-premix combustion, and selected catalytic reduction (SCR). It should be noted that either water-steam injection or lean-premix combustors can reduce NO_X emissions by over 50 percent, when compared to uncontrolled emissions. Based on the presented data, CO emissions also decrease with water-steam injection which is contrary to that which is expected. The EPA could not identify the reason for this behavior, except that the data sets used for developing these factors are different. It is important to note that the presented emission factors are based on a wide range of calculated emission levels (1 to 500 $lb/10^6$ scf with O_2 levels ranging from 15 percent to 17.5 percent).

For distillate oil-fired gas turbines, NO_X and CO data were separated into uncontrolled and water-steam injection categories. Water-steam injection for distillate oil-fired gas turbines reduces NO_X by 50 percent or more and increases CO emissions. No subcategorization was possible for landfill gas and digester gas-fired gas turbines due to the limited available data.

It is noticed that the turbine load conditions have a considerable effect on the measured NO_X and CO emissions. Typically, NO_X and CO emissions are reduced with increasing turbine load conditions.

Organic and Metallic Compound Emission Factors

Emission factors for organic compounds (methane, formaldehyde, benzene, etc.) were not grouped as extensively as the NO_X and CO emission factors. Analysis of this data showed that fuel type had an effect on organic emission levels, but NO_X controls such as water-steam injection did not show an observable effect within the data scatter. Therefore, organic compound emission factors were grouped by fuel type for the stationary combustion turbine category.

Within the organic compound category, one test (test ID # 316.1.1) for methane emissions from a natural gas-fired turbine was eliminated to make the data more applicable. Prior to eliminating this test report, the methane emission factors were higher than the total hydrocarbon (THC) emission factors. This is an unrealistic scenario, as the methane emission factors is a component of the THC emission factor. The elimination of this test report corrects this unrealistic condition.

For HAP emissions, the emissions data also indicate that formaldehyde is the most significant HAP emitted from gas turbines. For natural gas fired gas turbines, formaldehyde accounts for about two-thirds of the total HAP emission. Polycyclic aromatic hydrocarbons (PAH), benzene, toluene, xylenes, and others account for the remaining one-third of HAP emissions. For No. 2 distillate oil-fired gas turbines, small amount of metallic HAP are present in the turbine's exhaust in addition to the gaseous HAP identified under gas fired gas turbines. These metallic HAP are carried over from the fuel constituents. The formation of carbon monoxide during the combustion process is a good indication of the expected levels of HAP emissions. Similar to CO emissions, HAP emissions increase with reduced operating loads. Typically, gas turbines operate under full loads for greater fuel efficiency, thereby minimizing the amount of CO and HAP emissions.

Similar to organic compound emission factors, metallic compound emission factors were determined to be affected by fuel type, and no effect of NO_X control was observed. Therefore, metallic compound emission factors were also grouped by fuel type for the stationary combustion turbine category.

PM Emission Factors

PM emissions data for uncontrolled gas turbines were not available. Therefore, emission factors for condensable and filterable PM were developed for natural gas-fired gas turbines using water-steam injection control and distillate oil-fired gas turbines using water-steam injection control. Water-steam injection is not expected to have a large effect on PM emissions for gas turbines. For both natural gas and distillate oil-fired gas turbines, the emission factors were determined based on source test reports from Wisconsin. There were 5 tests done on one gas turbine for the condensible and filterable for both the natural gas and the oil (for details, see database). Each test was for 3 runs and each test is rated "C". All of these tests indicated sampling times of 2 hours or more per run. No indication of N_2 purging was provided for the tests gathered from the State of Wisconsin. However, the resulting emission levels compared well with the tests that indicated N_2 purging.

Condensable PM is the particulate matter collected using EPA Method 202 (or equivalent). Filterable PM is the particulate matter collected on, or prior to, the filter of an EPA Method 5 (or equivalent). Total PM is the sum of the condensable PM and filterable PM. PM emissions from combustion turbines are considered PM-10 emissions.

For landfill gas and digester gas-fired gas turbines, only PM-10 emission factors based on EPA Method 5 were determined from source test reports gathered from the EPA ICCR effort.

CO_2 Emission Factors

As outlined in the Procedures for Preparing Emission Factor Document,[1] emission factors for CO_2 were calculated by mass balance for natural gas and distillate oil-fired gas turbines. This approach was taken because the carbon content in pipeline-quality natural gas in fairly consistent. It was assumed that 99.5 percent and 99 percent of the fuel carbon is converted to CO_2, for natural gas and distillate oil-fired gas turbines, respectively. The carbon weight percent for natural gas was assumed at 75 percent, and for

distillate oil, it was assumed at 70 percent.

For landfill gas and digester gas-fired gas turbines, CO_2 content in the exhaust stream (volume percent) was provided for several tests. For landfill gas-fired gas turbines, CO_2 emission factors were determined from three test reports; report ID 302, 304, and 305. The average CO_2 emission factor from these reports was 50 lb/MMBtu. The corresponding CO_2 percent in the exhaust stream ranged from 4 percent to 4.5 percent. For digester gas, the CO_2 emission factor was determined from two tests included in report ID 300. The average CO_2 emission factor from these tests was 27 lb/MMBtu. The CO_2 percent in the exhaust stream was measured at 4 percent for both tests.

3.3 Emission Factor Quality Rating System

The quality of the emission factors developed from analysis of the test data was rated using the following general criteria:

A - Excellent: Developed only from A-rated test data taken from many randomly chosen facilities in the industry population. The source category is specific enough that variability within the source category population may be minimized.

B - Above Average: Developed only from A-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry population. The source category is specific enough that variability within the source category population may be minimized.

C - Average: Developed only from A- and B-rated test data from a reasonable number of facilities. Although no specific bias is evident, it is not clear if the facilities tested represent a random sample of the industry population. The source category is specific enough that variability within the source category population may be minimized.

D - Below Average: The emission factor was developed only from A- and B-rated test data from a small number of facilities, and there is reason to suspect that these facilities do not represent a random sample of the industry. There may also be evidence of variability within the source category population. Limitations on the use of the emission factor are always noted in the emission factor table.

E - Poor: The emission factor was developed from C- and D-rated test data, and there is reason to suspect that the facilities tested do not represent a random sample of the industry. There also may be evidence of variability within the source category population.

The above criteria for emission factor ratings are defined in the OAQPS document which provided guidance for preparing emission factor documents. The use of these criteria is somewhat subjective and depends to an extent upon the individual reviewer. As these criteria were applied to the emission factors, the term “number of facilities” was interpreted to mean “number of different turbine models”. This criteria prevented emission factors generated from multiple tests on a single turbine model type from receiving higher emission factor ratings. Emission factors for this section were rated in the following manner:

A-Rated	Emission factor average based on results of A or B-rated data from fifteen or more emissions tests.
B-Rated	Emission factor average based on results of A or B-rated data from ten to fourteen

different emissions tests.

C-Rated — Emission factor average based on results of A or B-rated data from three to nine different emissions tests.

D-Rated — Emission factor average based on results of A or B-rated data from two or less emissions tests.

E-Rated — Emission factor average based on engineering judgement or tests rated at C or below.

3.4 Emission Factors

The emission factors for the sources covered in Section 3.1 of the AP-42 document are presented in Tables 3.4-1, 3.4-2, 3.4-3, and 3.4-4. These tables provide the number of tests used in calculating the various emission factors as well as the relative standard deviation (in percent) associated with each emission factor. This additional information is intended to provide greater insight to the reader about the background of each emission factor. For further detail on each emission factor, the complete data base used to generate these factors is provided on the web at "www.epa.gov/ttn/chief" (See Section 3.2.1 of this document for more details on the data base).

Table 3.4-1. SUMMARY OF EMISSION FACTORS FOR NATURAL GAS-FIRED GAS TURBINES

Natural Gas-Fired Gas Turbine HAP Emissions

			All Loads				**High Loads: Greater Than or Equal to 80 Percent**			
Pollutant	CAS No.	Control Method	Emission Factor (lb/MMBtu)	Emission Factor (lb/MMscf)	RSD Percent	Count	Emission Factor (lb/MMBtu)	Emission Factor (lb/MMscf)	RSD Percent	Count
1,3-Butadiene	106-99-0	Uncontrolled	< 4.29 E-07	< 4.38 E-04	121.5	2	< 4.29 E-07	< 4.38 E-04	121.5	2
Acetaldehyde	75-07-0	Uncontrolled	4.45 E-05	4.54 E-02	64.3	9	4.02 E-05	4.10 E-02	68.0	8
Acetaldehyde	75-07-0	CO Catalyst	1.76 E-04	1.80 E-01	139.5	2	1.76 E-04	1.80 E-01	139.5	2
Acrolein	107-02-8	Uncontrolled	8.31 E-06	8.48 E-03	71.5	7	6.36 E-06	6.49 E-03	50.9	6
Acrolein	107-02-8	CO Catalyst	3.62 E-06	3.69 E-03	NA	1	3.62 E-06	3.69 E-03	NA	1
Benzene	71-43-2	Uncontrolled	1.03 E-04	1.05 E-01	440.0	27	1.18 E-05	1.20 E-02	136.1	17
Benzene	71-43-2	CO Catalyst	3.26 E-06	3.33 E-03	101.9	2	3.26 E-06	3.33 E-03	101.9	2
Ethylbenzene	100-41-4	Uncontrolled	2.58 E-05	2.63 E-02	130.4	5	3.20 E-05	3.27 E-02	110.2	4
Formaldehyde	50-00-0	Uncontrolled	3.12 E-03	3.18 E+00	204.0	33	7.09 E-04	7.23 E-01	206.1	22
Formaldehyde	50-00-0	CO Catalyst	3.60 E-04	3.67 E-01	133.5	2	3.60 E-04	3.67 E-01	133.5	2
Naphthalene	91-20-3	Uncontrolled	1.37 E-06	1.40 E-03	87.6	5	1.27 E-06	1.30 E-03	107.3	4
PAH	NA	Uncontrolled	2.25 E-06	2.30 E-03	131.1	5	2.23 E-06	2.27 E-03	152.9	4
Propylene Oxide	75-56-9	Uncontrolled	< 2.86 E-05	< 2.92 E-03	NA	1	< 2.86 E-05	< 2.92 E-03	NA	1
Toluene	108-88-3	Uncontrolled	9.37 E-05	9.56 E-02	220.6	11	1.34 E-04	1.37 E-01	191.0	7
Xylenes	1330-20-7	Uncontrolled	5.48 E-05	5.59 E-02	108.1	7	6.38 E-05	6.50 E-02	93.2	6

Table 3.4-1. SUMMARY OF EMISSION FACTORS FOR NATURAL GAS-FIRED GAS TURBINES
(Continued)

Natural Gas-Fired Gas Turbine Criteria Emissions

		All Loads				**High Loads: Greater Than or Equal to 80 Percent**			
Pollutant	Control Method	Emission Factor (lb/MMBtu)	Emission Factor (lb/MMscf)	RSD Percent	Count	Emission Factor (lb/MMBtu)	Emission Factor (lb/MMscf)	RSD Percent	Count
CO	Uncontrolled	1.77 E-01	1.80 E+02	267.5	76	8.23 E-02	8.39 E+01	171.4	53
CO	Water-Steam Injection	3.34 E-02	3.41 E+01	106.3	18	2.95 E-02	3.01 E+01	117.0	16
CO	Lean Pre-Mix	1.27 E+00	1.30 E+03	189.5	4	1.51 E-02	1.54 E+01	NA	1
Methane	Uncontrolled	8.64 E-03	8.81 E+00	142.2	5	8.64 E-03	8.81 E+00	142.2	5
NO_X	Uncontrolled	2.95 E-01	3.01 E+02	75.0	80	3.23 E-01	3.29 E+02	69.8	56
NO_X	Water-Steam Injection	1.26 E-01	1.28 E+02	29.8	75	1.28 E-01	1.30 E+02	29.8	46
NO_X	Lean Pre-Mix	1.11 E-01	1.13 E+02	23.6	4	9.91 E-02	1.01 E+02	NA	1
NO_X	SCR	1.28 E-02	1.31 E+01	13.1	4	1.28 E-02	1.31 E+01	13.1	4
PM Condensable	Water-Steam Injection	4.73 E-03	4.82 E+00	90.9	1	4.73 E-03	4.82 E+00	90.9	1
PM Filterable	Water-Steam Injection	1.90 E-03	1.93 E+00	49.5	1	1.90 E-03	1.93 E+00	49.5	1

Table 3.4-1. SUMMARY OF EMISSION FACTORS FOR NATURAL GAS-FIRED GAS TURBINES
(Concluded)

Natural Gas-Fired Turbine Criteria Emissions

		All Loads				**High Loads: Greater Than or Equal to 80 Percent**			
Pollutant	Control Method	Emission Factor (lb/MMBtu)	Emission Factor (lb/MMscf)	RSD Percent	Count	Emission Factor (lb/MMBtu)	Emission Factor (lb/MMscf)	RSD Percent	Count
PM total[a]	Water-Steam Injection	6.63 E-03	6.76 E+00	NA	1	6.63 E-03	6.76 E+00	NA	1
SO_2	Uncontrolled	3.38 E-03	3.45 E+00	45.5	6	3.38 E-03	3.45 E+00	45.5	6
TOC[b]	Uncontrolled	1.07 E-02	1.09 E+01	141.1	10	1.07 E-02	1.09 E+01	141.1	10
VOC[c]	Uncontrolled	2.06 E-03	2.09 E+00	NA	5	2.06 E-03	2.09 E+00	NA	5

[a] Calculated value: PM total = PM (condensable) + PM (filterable).
[b] Pollutant referenced as THC in the gathered emission tests. It is assumed as TOC, because it is based on EPA Test Method 25A.
[c] Calculated value: VOC = THC - Methane.

Table 3.4-2. SUMMARY OF EMISSION FACTORS FOR DISTILLATE OIL-FIRED GAS TURBINES

Distillate Oil-Fired Gas Turbines HAP Emissions

Pollutant	CAS No.	Control Method	All Loads				High Loads: Greater Than or Equal to 80 Percent			
			Emission Factor		RSD Percent	Count	Emission Factor		RSD Percent	Count
			(Lb/MMBtu)	(lb/1,000 gal)			(Lb/MMBtu)	(lb/1,000 gal)		
1,3-Butadiene	106-99-0	Uncontrolled	< 1.65 E-05	< 2.30 E-03	47.5	4	< 1.58 E-05	< 2.20 E-03	NA	1
1,4-Dichlorobenzene	106-46-7	Uncontrolled	< 2.97 E-05	< 4.12 E-03	5.8	3	NA	NA	NA	NA
Acetaldehyde	75-07-0	Uncontrolled	3.03 E-05	4.21 E-03	36.9	2	NA	NA	NA	NA
Arsenic	NA	Uncontrolled	< 1.10 E-05	< 1.53 E-03	72	4	< 1.06 E-05	< 1.47 E-03	NA	1
Benzene	71-43-2	Uncontrolled	5.48 E-05	7.62 E-03	104.9	5	5.48 E-05	7.62 E-03	104.9	5
Beryllium	NA	Uncontrolled	< 3.07 E-07	< 4.27 E-05	NA	1	< 3.07 E-07	< 4.27 E-05	NA	1
Cadmium	NA	Uncontrolled	3.75 E-06	5.21 E-04	78.3	4	4.80 E-06	6.67 E-04	NA	1
Carbon Tetrachloride	56-23-5	Uncontrolled	< 3.06 E-05	< 4.25 E-03	8.2	3	NA	NA	NA	NA
Chlorobenzene	108-90-7	Uncontrolled	< 2.49 E-05	< 3.46 E-03	10.2	3	NA	NA	NA	NA
Chloroform	67-66-3	Uncontrolled	< 2.55 E-05	< 3.55 E-03	4.4	3	NA	NA	NA	NA
Chromium	NA	Uncontrolled	8.43 E-06	1.17 E-03	64.6	5	1.08 E-05	1.51 E-03	8.5	2
Ethylene Dichloride	107-06-2	Uncontrolled	2.02 E-05	2.81 E-03	1.4	2	NA	NA	NA	NA
Formaldehyde	50-00-0	Uncontrolled	2.45 E-04	3.41 E-02	120.6	10	2.82 E-04	3.92 E-02	115.0	8
Lead	NA	Uncontrolled	1.34 E-05	1.87 E-03	50.6	5	1.42 E-05	1.97 E-03	51.2	2
Manganese	NA	Uncontrolled	7.89 E-04	1.10 E-01	NA	1	7.89 E-04	1.10 E-01	NA	1
Methylene Chloride	74-87-3	Uncontrolled	< 2.13 E-05	< 2.97 E-03	29.5	3	NA	NA	NA	NA
Mercury	NA	Uncontrolled	1.20 E-06	1.67 E-04	NA	1	1.20E-06	1.67E-04	NA	1
Naphthalene	91-20-3	Uncontrolled	3.52 E-05	4.89 E-03	187.9	5	3.52 E-05	4.89 E-03	187.9	5

Table 3.4-2. SUMMARY OF EMISSION FACTORS FOR DISTILLATE OIL-FIRED GAS TURBINES
(Continued)

Distillate Oil-Fired Gas Turbines HAP Emissions

			All Loads				**High Loads: Greater Than or Equal to 80 Percent**			
Pollutant	CAS No.	Control Method	Emission Factor (lb/MMBtu)	Emission Factor (lb/1,000 gal)	RSD Percent	Count	Emission Factor (lb/MMBtu)	Emission Factor (lb/1,000 gal)	RSD Percent	Count
Nickel	NA	Uncontrolled	1.62 E-05	2.26 E-03	146.9	4	< 4.61 E-06	< 6.41 E-04	NA	1
PAH	NA	Uncontrolled	4.03 E-05	5.61 E-03	182.0	6	4.03 E-05	5.61 E-03	163.9	5
Selenium	NA	Uncontrolled	< 2.88 E-05	< 4.00 E-03	110.5	4	< 2.52 E-05	< 3.50 E-03	NA	1
Tetrachloroethylene	127-18-4	Uncontrolled	< 3.24 E-05	< 4.50 E-03	12.0	3	NA	NA	NA	NA
Trichloroethylene	79-01-6	Uncontrolled	< 2.75 E-05	< 3.82 E-03	1.0	3	NA	NA	NA	NA
Vinyl Chloride	75-01-4	Uncontrolled	< 5.27 E-05	< 7.33 E-03	40.5	3	NA	NA	NA	NA
Vinylidene Chloride	75-35-4	Uncontrolled	< 2.02 E-05	< 2.81 E-03	1.4	2	NA	NA	NA	NA

Table 3.4-2. SUMMARY OF EMISSION FACTORS FOR DISTILLATE OIL-FIRED GAS TURBINES
(Concluded)

Distillate Oil-Fired Gas Turbines Criteria Emissions

		All Loads				High Loads: Greater Than or Equal to 80 Percent			
Pollutant	Fuel Source	Emission Factor (lb/MMBtu)	Emission Factor (lb/1,000 gal)	RSD Percent	Count	Emission Factor (lb/MMBtu)	Emission Factor (lb/1,000 gal)	RSD Percent	Count
CO	Uncontrolled	1.24 E-02	1.72 E+00	125.7	5	3.29 E-03	4.57 E-01	23.3	3
CO	Water-Steam Injection	1.03 E-01	1.43 E+01	44.1	8	7.61 E-02	1.05 E+01	43.2	5
NMHC	Uncontrolled	8.03 E-03	1.22 E+00	34.8	2	NA	NA	NA	NA
NO_X	Uncontrolled	6.37 E-01	8.85 E+01	55.1	6	8.82 E-01	1.23 E+02	36.0	3
NO_X	Water-Steam Injection	2.34 E-01	3.25 E+01	22.0	23	2.44 E-01	3.39 E+01	21.9	13
PM Condensable	Water-Steam Injection	7.18 E-03	9.98 E-01	NA	1	7.18 E-03	9.98 E-01	65.3	1
PM Filterable	Water-Steam Injection	4.32 E-03	6.00 E-01	NA	1	4.32 E-03	6.00 E-01	55.3	1
PM total[a]	Water-Steam Injection	1.15 E-02	1.60 E+00	NA	1	1.15 E-02	1.60 E+00	NA	1
PM-10	Uncontrolled	2.03 E-02	2.82 E+00	76.4	2	NA	NA	NA	NA
PM-10	Water-Steam Injection	4.40 E-02	6.12 E+00	141.4	2	4.40 E-02	6.12 E+00	141.4	2
SO_2	Uncontrolled	3.30 E-02	4.58 E+00	69.1	2	NA	NA	NA	NA
TOC[b]	Water-Steam injection	4.64 E-03	6.46 E-01	28.6	6	4.01 E-03	5.58 E-01	21.9	3

[a] Calculated value: PM (total) = PM (condensable) + PM (filterable)

[b] Pollutant referenced as THC in the gathered emission tests. It is assumed as TOC, because it is based on EPA Test Method 25A.

Table 3.4-3. SUMMARY OF EMISSION FACTORS FOR LANDFILL GAS- FIRED GAS TURBINES

Landfill Gas-Fired Gas Turbine HAP Emissions

			All Loads				**High Loads Greater Than or Equal to 80 Percent**			
Pollutant	CAS No.	Control Method	Emission Factor (lb/MMBtu)	Emission Factor (lb/SCF)	RSD Percent	Count	Emission Factor (lb/MMBtu)	Emission Factor (lb/SCF)	RSD Percent	Count
Acetonitrile	107-13-1	Uncontrolled	< 1.18 E-05	< 4.72 E-03	85.8	11	< 1.18 E-05	< 4.72 E-03	85.8	11
Benzene	71-43-2	Uncontrolled	2.07 E-05	8.28 E-03	95.8	11	2.07 E-05	8.28 E-03	95.8	11
Benzyl Chloride	100-44-7	Uncontrolled	< 1.18 E-05	< 4.71 E-03	82.5	11	< 1.18 E-05	< 4.71 E-03	82.5	11
Carbon Tetrachloride	56-23-5	Uncontrolled	< 1.75 E-06	< 7.01 E-04	60.6	11	< 1.75 E-06	< 7.01 E-04	60.6	11
Chlorobenzene	108-90-7	Uncontrolled	< 2.91 E-06	< 1.16 E-04	79.4	11	< 2.91 E-06	< 1.16 E-04	79.4	11
Chloroform	67-66-3	Uncontrolled	< 1.36 E-06	< 5.45 E-04	60.5	11	< 1.36 E-06	< 5.45 E-04	60.5	11
Methylene Chloride	74-87-3	Uncontrolled	2.29 E-06	9.14 E-04	133.1	11	2.29 E-06	9.14 E-04	133.1	11
Tetrachloroethylene	127-18-4	Uncontrolled	< 2.44 E-06	< 9.78 E-04	61.1	11	< 2.44 E-06	< 9.78 E-04	61.1	11
Toluene	108-88-3	Uncontrolled	1.10 E-04	4.39 E-02	254.8	11	1.10 E-04	4.39 E-02	254.8	11
Trichloroethylene	79-01-6	Uncontrolled	< 1.91 E-06	< 7.62 E-04	113.4	11	< 1.91 E-06	< 7.62 E-04	113.4	11
Vinyl Chloride	75-01-4	Uncontrolled	< 1.55 E-06	< 6.20 E-04	63.5	11	< 1.55 E-06	< 6.20 E-04	63.5	11
Xylenes	1330-20-7	Uncontrolled	3.12 E-05	1.25 E-02	236.8	10	3.12 E-05	1.25 E-02	236.8	10

Table 3.4-3. SUMMARY OF EMISSION FACTORS FOR LANDFILL GAS- FIRED GAS TURBINES
(Concluded)

Landfill Gas-Fired Combustion Turbine Criteria Emission

		All Loads				**High Loads: Greater Than or Equal to 80 Percent**			
Pollutant	Fuel Source	Emission Factor (lb/MMBtu)	Emission Factor (lb/MMscf)	RSD Percent	Count	Emission Factor (lb/MMBtu)	Emission Factor (lb/MMscf)	RSD Percent	Count
CO	Uncontrolled	3.34 E-01	1.34 E+01	172.0	20	4.37 E-01	1.75 E+02	145.1	15
VOC[a]	Uncontrolled	1.34 E-02	5.36 E+00	93.9	11	1.34 E-02	5.36 E+00	93.9	11
NO_X	Uncontrolled	1.87 E-01	7.48 E+01	66.9	20	1.41 E-01	5.63 E+01	67.5	15
PM-10	Uncontrolled	2.32 E-02	9.28 E+00	52.4	11	2.32 E-02	9.28 E+00	52.4	11
SO_2	Uncontrolled	4.49 E-02	1.79 E+01	38.4	5	4.49 E-02	1.79 E+01	38.4	5

[a] Based on adding the formaldehyde emissions to the NMHC.

Table 3.4-4. SUMMARY OF EMISSION FACTORS FOR DIGESTER GAS FIRED GAS TURBINES

Digester Gas-Fired Gas Turbine HAP Emissions			**All Loads**				**High Loads: Greater Than or Equal to 80 Percent**			
Pollutant	CAS No.	Fuel Source	Emission Factor		RSD %	Count	Emission Factor		RSD %	Count
			(lb/MMBtu)	(lb/MMscf)			(lb/MMBtu)	(lb/MMscf)		
1,3-Butadiene	106-99-0	Uncontrolled	< 9.80 E-06	< 5.88 E-03	26.9	3	< 9.80 E-06	< 5.88 E-03	26.9	3
1,4-Dichlorobenzene	106-46-7	Uncontrolled	< 1.95 E-05	< 1.17 E-02	28.7	3	< 1.95 E-05	< 1.17 E-02	28.7	3
Acetaldehyde	75-07-0	Uncontrolled	5.27 E-05	3.16 E-02	25.0	2	5.27 E-05	3.16 E-02	25.0	2
Arsenic	NA	Uncontrolled	< 2.28 E-06	< 1.37 E-03	NA	3	< 2.28 E-06	< 1.37 E-03	NA	3
Cadmium	NA	Uncontrolled	< 5.79 E-07	< 3.47 E-04	68	3	< 5.79 E-07	< 3.47 E-04	68	3
Carbon Tetrachloride	56-23-5	Uncontrolled	< 1.99 E-05	< 1.20 E-02	33.0	3	< 1.99 E-05	< 1.20 E-02	33.0	3
Chlorobenzene	108-90-7	Uncontrolled	<1.58 E-05	< 9.48 E-03	17.6	3	< 1.58 E-05	< 9.48 E-03	17.6	3
Chloroform	67-66-3	Uncontrolled	< 1.65 E-05	< 9.88 E-03	20.8	3	< 1.65 E-05	< 9.88 E-03	20.8	3
Chromium	NA	Uncontrolled	< 1.16 E-06	< 6.95 E-04	67.8	3	< 1.16 E-06	< 6.95 E-04	67.8	3
Ethylene Dichloride	107-06-2	Uncontrolled	< 1.50 E-05	< 8.97 E-03	8	2	< 1.50 E-05	< 8.97 E-03	8	2
Formaldehyde	50-00-0	Uncontrolled	1.89 E-04	1.13 E-01	19.9	2	1.89 E-04	1.13 E-01	19.9	2
Lead	NA	Uncontrolled	< 3.35 E-06	< 2.01 E-03	77	3	< 3.35 E-06	< 2.01 E-03	77	3
Methylene Chloride	74-87-3	Uncontrolled	< 1.29 E-05	< 7.72 E-03	6.3	3	< 1.29 E-05	< 7.72 E-03	6.3	3
Nickel	NA	Uncontrolled	1.97 E-06	1.18 E-03	40.3	3	1.97 E-06	1.18 E-03	40.3	3
Selenium	NA	Uncontrolled	1.13 E-05	6.79 E-03	99.2	3	1.13 E-05	6.79 E-03	99.2	3
Tetrachloroethylene	127-18-4	Uncontrolled	< 2.13 E-05	< 1.28 E-02	35.5	3	< 2.13 E-05	< 1.28 E-02	35.5	3
Trichloroethylene	79-01-6	Uncontrolled	< 1.78 E-05	< 1.07 E-02	24.7	3	< 1.78 E-05	<1.07 E-02	24.7	3
Vinyl Chloride	75-01-4	Uncontrolled	< 3.63 E-05	< 2.80 E-02	56.8	3	< 3.63 E-05	< 2.80 E-02	56.8	3
Vinylidene Chloride	75-35-4	Uncontrolled	< 1.50 E-05	< 8.97 E-03	8.0	2	< 1 .50 E-05	< 8.97 E-03	8.0	2

Table 3.4-4. SUMMARY OF EMISSION FACTORS FOR DIGESTER GAS FIRED GAS TURBINES
(Concluded)

Digester Gas-Fired Gas Turbine Criteria Emissions

		All Loads				**High Loads: Greater Than or Equal to 80 Percent**			
Pollutant	Fuel Source	Emission Factor (lb/MMBtu)	Emission Factor (lb/MMscf)	RSD Percent	Count	Emission Factor (lb/MMBtu)	Emission Factor (lb/MMscf)	RSD Percent	Count
CO	Uncontrolled	1.70 E-02	1.02 E+01	7.1	2	1.70 E-02	1.02 E+01	7.1	2
VOC[a]	Uncontrolled	5.82 E-03	3.48 E+00	16.9	2	5.82 E-03	3.48 E+00	16.9	2
NO_X	Uncontrolled	1.63 E-01	9.78 E+01	5.2	2	1.63 E-01	9.78 E+01	5.2	2
PM-10	Uncontrolled	1.20 E-02	7.21 E+00	63.1	3	1.20 E-02	7.21 E+00	63.1	3
SO_2	Uncontrolled	6.53 E-03	3.92 E+00	7.4	2	6.53 E-03	3.92 E+00	7.4	2

[a] Based on adding the formaldehyde emissions to the NMHC.

3.5 REFERENCES FOR SECTION 3

1. Procedures for Preparing Emission Factor Documents, Third Revised Draft Version, Office of Air Quality Planning and Standards, U.S. EPA, Research Triangle Park, NC 27711, November 1996.