Prepared for
Canadian Energy Partnership for Environmental Innovation
Petroleum Technology Alliance Canada
BC Oil and Gas Research and Innovation Society

Prepared by
Ramboll Environ,
Irvine, California

Document type
Final (Revision 0.2)

Date
8 July, 2016 (revised September 15, 2016)

CEPEI PM2.5 EMISSION FACTOR DEVELOPMENT

UPDATE: ALTERNATIVE PM2.5 EMISSION FACTORS FOR NATURAL GAS-FIRED ENGINES

RAMBOLL ENVIRON

REVISION HISTORY

Revision No.	Date	Approved By	Comment
Draft A	16 February 2016	Glenn England	For review
Draft B	4 March 2016	Glenn England	Revised – for review
Revision 0	8 July 2016	Glenn England	Final. Revised in response to CEPEI comments and final test data. Misc. corrections and revisions.
Revision 0.2	15 September 2016	Glenn England	Updated cover page

Distribution

Jasmine Urisk (CEPEI)

Glenn England (Ramboll Environ)

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

T5EmissionFactorReport-R0.docx

ACRONYMS AND ABBREVIATIONS

%	percent
%vol	percent volume
°C	degrees Centigrade
°F	degrees Fahrenheit
°R	degrees Rankine
µg	microgram
2SLB	two-stroke lean burn
4SLB	four-stroke lean burn
4SRB	four-stroke rich burn
A/F	air-fuel ratio controller
Ag	silver
Al	aluminum
API	American Petroleum Institute
Au	gold
Ba	barium
BC	British Columbia
Br	bromine
Btu	British thermal unit
Btu/scf	British thermal units per standard cubic foot
Ca	calcium
Cd	cadmium
Ce	cerium
CEPEI	Canadian Energy Partnership for Environmental Innovation
cfm	cubic feet per minute
Cl	chlorine
Cl^-	chloride ion
CO Cat	CO oxidation catalyst
CO	carbon monoxide
Co	cobalt
CO_2	carbon dioxide
cPM	condensable particulate matter
Cr	chromium

Cs	cesium
CTM 39	U.S. EPA Conditional Test Method 039
Cu	copper
DB	duct burner
DR	dilution ratio
dscf	dry standard cubic foot (unless otherwise noted, standard reference conditions are 528°R, 29.92 in. Hg)
dscfm	dry standard cubic feet per minute
dscm	dry standard cubic meter
EC	elemental carbon
Eu	europium
Fe	iron
fPM	filterable particulate matter
g	gram
GJ/hr	gigajoules per hour
gr	grain (= 1/7000 pound)
GTCC/C	gas turbine combined cycle cogeneration unit
Hg	mercury
HHV	higher (gross) heating value
hp	horsepower
hr	hour
In	indium
K	potassium
kg/GJ	kilograms per gigajoule
kg/s	kilograms per second
La	lanthanum
lb	pound
LPC	lean premix combustor
Mg	magnesium
mg	milligram
MMBtu	million British thermal units
MMBtu/hr	million British thermal units per hour
Mn	manganese
Mo	molybdenum

MW	megawatt
Na	sodium
Na^+	sodium ion
NH_4^+	ammonium ion
Ni	nickel
NO_3^-	nitrate ion
NO_X	nitrogen oxides
NSCR	non-selective catalytic reduction
O_2	oxygen (molecular)
OC	organic carbon
P	phosphorus
PAH	polycyclic aromatic hydrocarbons
Pb	lead
PCC	pre-combustion chamber
PM	particulate matter
PM10	particulate matter with aerodynamic diameter of 10 micrometers and smaller
PM2.5	particulate matter with aerodynamic diameter of 2.5 micrometers and smaller
psia	pound per square inch absolute
Q-Q	quantile-quantile (graph)
Rb	rubidium
RICE	reciprocating internal combustion engine
RPM	revolutions per minute
S	sulfur
Sb	antimony
scf	standard cubic foot
scfd	standard cubic feet per day
SCR	selective catalytic reduction
Si	silicon
Sm	samarium
Sn	tin
SO_2	sulfur dioxide
SO_4^{2-}	sulfate ion
$SO_4^{=}$	sulfate ion
Sr	strontium

STP	standard temperature and pressure
SVOC	semivolatile organic compounds
Tb	terbium
Ti	titanium
Tl	thallium
TMF	Teflon® membrane filter
U	uranium
UPL	upper prediction limit
U.S. EPA	U.S. Environmental Protection Agency
U.S.	United States
V	vanadium
W	tungsten
Y	yttrium
Zn	zinc
Zr	zirconium

1. EXECUTIVE SUMMARY

In 2012, the Canadian Energy Partnership for Environmental Innovation (CEPEI) published a technical memorandum[1] providing alternative PM2.5 (particles with aerodynamic diameter of 2.5 micrometers and smaller) air emission factors and species profiles for natural gas-fired boilers, process heaters, a diesel engine and gas turbine combined cycle/cogeneration power plants. This document provides updated emission factors for natural gas-fired gas turbines/combined cycle/cogeneration units and new emission factors for natural gas-fired spark-ignited reciprocating engines.

Previously reported PM2.5 emission factors and species profiles[2] are based on tests conducted in the United States (U.S.) from 1998 to 2003 during an industry-government collaboration led by GE Energy and Environmental Research Corporation (GE EER) using a dilution sampling methodology. Dilution sampling is thought to provide more accurate measurements of PM2.5 from gas combustion than traditional hot filter/cooled impinger test methods. The California Energy Commission, New York State Energy and Research Development Authority and U.S. Department of Energy co-sponsored the work along with the American Petroleum Institute (API) and Gas Research Institute. The U.S. Environmental Protection Agency (U.S. EPA) served as external peer reviewers during the study, contributing to the study design and results review, eventually adopting PM2.5 and PM10 emission factors for natural gas combustion derived from the results for use in its tri-annual air pollutant National Emission Inventories (NEIs). Those tests included two natural gas-fired heavy duty gas turbine combined cycle power generation units with lean premix combustors and a refinery gas-fired aeroderivative gas turbine cogeneration system, all three with supplementary firing capability and with post-combustion emission controls (oxidation catalyst and selective catalytic reduction, SCR). No natural gas-fired reciprocating engines were included in those collaborative tests. API separately sponsored tests of three natural gas-fired spark-ignited reciprocating engines operating as natural gas production compressor drives in 2003[3]. In 2008, GE Energy subsequently conducted method evaluation tests on a natural gas-fired combined cycle power generation unit with SCR using a similar dilution methodology based on modified U.S. EPA Conditional Test Method 39 (CTM 39), with external peer review participation from U.S. EPA, California Air Resources Board and the South Coast Air Quality Management District. In 2014, the Utah Department of Environmental Quality (in consultation with U.S. EPA) approved PM10 tests using modified CTM 39 to demonstrate compliance with PM10 emission limits based on U.S. EPA's NEI PM10 emission factor. Thus, modified CTM 39 has been applied with consent of regulatory agencies for PM2.5/10 emission factor development and for regulatory compliance demonstration.

In 2015, CEPEI and the Petroleum Technology Alliance of Canada (PTAC), including the British Columbia Oil and Gas Research and Innovation Society (BC OGRIS), sponsored new tests on two natural gas-fired engines in Canada: a gas turbine engine and a spark-ignited reciprocating engine, both operating as natural gas pipeline compressor drives and with no post-combustion controls. The engines are typical of Canadian natural gas pipeline engines in terms of size, configuration, emission controls and operation. The objective of the tests was to provide data for developing updated PM2.5

[1] *Fine Particulate Emissions from Natural Gas-Fired Combustion Sources: Alternative PM2.5 Emission Factors*, Technical Memorandum, Innovative Environmental Solutions Inc., for Canadian Energy Partnership for Environmental Innovation, October, 2012.

[2] England, G.C. Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas-fired Combustion Systems, Final Report, 2004, prepared for U.S. Department of Energy, Gas Research Institute, American Petroleum Institute, California Energy Commission and New York State Energy Research and Development Authority, http://www.nyserda.org/environment/emepreports.html.

[3] England, G.C., K.R. Loos, K. Ritter. Measurements of PM2.5 Mass and Species Emissions from Natural Gas-Fired Reciprocating Internal Combustion Engines, SPE-94201-PP, Exploration & Production Environmental Conference, Society of Petroleum Engineers, Galveston, TX. March 2005.

emission factors and species profiles representative of engines in Canada without post-combustion controls applicable to upstream and downstream oil and gas operations and natural gas end users. The tests were conducted using a stationary source dilution sampling method combined with ambient air sample collection and analysis methods to determine both the mass and chemical speciation of combined filterable plus condensable PM2.5 emissions. The methodology is similar to that used for the earlier GE EER test program. The chemical composition of the collected aerosols also was determined (elements, selected ions and organic and elemental carbon). Detailed test results obtained in this study are provided in a separate Test Report.

Updated PM2.5 emission factors and species profiles were derived from the CEPEI test results and data from the earlier tests noted above. PM2.5 mass emission factors for gas turbines, gas turbine combined cycle/cogeneration units and for four-stroke reciprocating internal combustion engines, expressed as kilograms of PM2.5 per gigajoule of fuel heat input (kg/GJ), are provided in Table E-1. The maximum and 95% confidence upper bound provide an indication of the upper limits of the data set. The 99% confidence upper prediction limit provides an indication of an upper limit for the average for the next unit tested.

U.S. EPA's *Compilation of Air Pollutant Emission Factors* ("AP-42") is a widely-referenced source of emission factors. The published AP-42 filterable and condensable particulate matter emission factors for natural gas-fired gas turbine and four-stroke reciprocating engines, also shown in Table E-1, are based on tests of three gas turbines[4], two four-stroke lean burn and three four-stroke rich burn reciprocating engines.

The average CEPEI PM2.5 emission factor of 0.000101 kg/GJ for gas-fired gas turbines and cogeneration/combined cycle units based on dilution sampling methods is 1/28 (3.5%) of the combined AP-42 gas turbine emission factor for filterable and condensable particulate matter (0.00285 kg/GJ).

The average emission factor of 0.00150 kg/GJ for four-stroke reciprocating engines is 1/6 (16%) of the combined filterable and condensable particulate matter emission factor for all four-stroke engines derived from the AP-42 data set (0.00673 kg/GJ). Further, there are no condensable particulate matter test data for four-stroke rich burn engines in the AP-42 data set; the condensable particulate matter emission factor reported in AP-42 for four-stroke rich burn engines is based on two four-stroke lean burn engine tests.

Although AP-42 does not report uncertainty associated with the emission factors, the total particulate matter emission factor uncertainty calculated from the underlying data is 85% for the gas turbine and 270% and 438% for four-stroke rich burn and lean burn engines, respectively. The very large uncertainties for the AP-42 four-stroke engine emission factors are due to both the wide range of emissions among the units and the small number of units tested. Although the CEPEI and AP-42 data sets are similar in size, the improved precision of measurements in CEPEI's data set results in lower uncertainties. Although the data sets are small in both cases, we consider the CEPEI emission factors more robust than the AP-42 factors because of much lower uncertainty (in terms of both relative percent and absolute magnitude).

[4] Two of the three units were tested with and without power augmentation. EPA treated each test as a separate unit for emission factor calculation. See discussion in Section 6.

Table E-1: Comparison of CEPEI and EPA AP-42 PM emission factors for gas-fired gas turbines, combined cycle/cogeneration units and four-stroke reciprocating engines

Parameter	Gas-fired gas turbines, gas turbine cogeneration & combined cycle units (kg/GJ)	Natural gas-fired spark-ignited reciprocating engines (four-stroke) (kg/GJ)
CEPEI Emission Factors (PM2.5, dilution sampling methods)		
Number of units tested	6 (5*)	3
Average	0.000101	0.00150
Uncertainty (95% confidence)	80%	116%
maximum	0.000236	0.00216
95% confidence upper bound	0.000148	0.00226
99% confidence upper prediction limit	0.000380	0.00710
U.S. EPA AP-42 Emission Factors (hot filter/cooled impinger sampling methods)		
Number of units tested	5 (3**)	3 (four-stroke rich burn) 2 (four-stroke lean burn)
Total particulate matter (filterable + condensable)	0.00285 (uncertainty 85%)	0.00835 (four-stroke rich burn) (uncertainty 270%) 0.00430 (four-stroke lean burn) (uncertainty 438%) 0.00673 (four-stroke all) (uncertainty 446%)***

*Five units were actually tested. One natural gas combined cycle unit at gas turbine was tested at full load with and without duct burners. Each test was treated as a separate unit, representing emissions for units with and without duct burner (supplementary firing) capability.

**Three units were actually tested. Two units were tested with and without power augmentation. Each test was treated as a separate unit.

***AP-42 does not report an aggregate emission factor for four-stroke engines. This value was calculated for comparison purposes by aggregating the unit average values used to calculate emission factors for rich burn and lean burn engines.

Average PM2.5 chemical species are measured primarily as organic carbon, with minor amounts of sulfate, ammonium, elemental carbon, chloride, nitrate and other elements. Iron and silica were more prevalent in PM2.5 from the reciprocating engines than the gas turbines and combined cycle/cogeneration units. Sulfate and ammonium were not detected in the samples from the CEPEI 2015 test program. This likely reflects low natural gas sulfur content and the absence of post-combustion catalysts (e.g., selective catalytic reduction[5] or CO oxidation catalysts) on this unit, as

[5] Catalysts are known to promote oxidation of SO_2 to SO_3, a precursor to particulate sulfate emissions.

compared with the refinery gas and natural gas-fired units tested previously in the U.S which did have post-combustion catalysts.

The CEPEI PM2.5 emission factor for gas turbines and combined cycle/cogeneration units is based on six tests of five units[6] including one unit firing refinery gas and four units firing natural gas. This includes simple and combined cycle/cogeneration units with and without post-combustion catalysts for NO_X and CO emissions reduction. In contrast, the AP-42 PM emission factors include data for five tests of three natural gas-fired gas turbines with water injection (for NO_X emissions control) but without post-combustion catalysts.

The CEPEI PM2.5 emission factor for four-stroke reciprocating engines is based on tests of three units: one four-stroke rich burn engine with non-selective catalytic NO_X reduction and two four-stroke lean burn engines with no post-combustion emission controls. The number of units tested is comparable with the number of units included in the AP-42 data sets. The PM2.5 emission data in the CEPEI data set for the rich burn engine is approximately four times greater than the PM2.5 emission data for the two lean burn engines. The small number of units and range of PM2.5 emissions contribute to large relative uncertainty – 186% - in the average CEPEI PM2.5 emission factor. Nevertheless, the uncertainty associated with the CEPEI PM2.5 emission factor is considerably lower than the uncertainties for the AP-42 filterable and condensable particulate matter (and by summation, total PM) emission factors, as noted above. Previous studies showed that the dilution sampling test methodology on which the CEPEI PM2.5 emission factor is based is more accurate and precise than the hot filter/cooled impinger test methods used for the AP-42 filterable and condensable particulate matter emission factors. Therefore, the CEPEI PM2.5 emission factor for natural gas-fired four-stroke engines is considered more robust than the respective AP-42 emission factors.

As a general precaution, an average or median emission factor should not be used to establish emissions limits or standards because emissions from half of the units will be higher than the average and half will be lower (assuming a normal distribution). However, an average or median emission factor is appropriate to estimate average emissions from a population of similar units. Additional testing of natural gas-fired gas turbines and/or combined cycle/cogeneration units over time could further reduce uncertainty and improve emission factor quality.

[6] One combined cycle unit was tested with and without duct burners firing. Each test was treated as a separate unit for emission factor analysis purposes.

2. INTRODUCTION

Atmospheric particles with aerodynamic diameter less than or equal to 2.5 micrometers (PM2.5) contribute to adverse human health, regional haze (visibility) and ecosystem effects. Most airborne PM2.5 derives from gaseous emissions that react slowly in the atmosphere to form fine particles ("secondary" PM2.5). The contribution of directly emitted ("primary") PM2.5 varies among different source types, but is relatively small for engines, boilers and other combustion equipment burning gaseous fuels. Nevertheless, PM2.5 emissions from natural gas-burning engines often receive exceptional scrutiny in populated urban areas.

Widely published PM2.5 emission factors, such as those given in the *Compilation of Air Pollutant Emission Factors* (AP-42)[7] published by the U.S. Environmental Protection Agency (U.S. EPA), are based on traditional emissions test methods for filterable and condensable PM2.5 use using hot filter/cooled impinger techniques. Previous studies showed that these methods lack sufficient sensitivity to accurately and precisely measure the very low PM2.5 concentrations typical of gas-fired combustion sources. Also, PM2.5 results from such methods often are biased high due to substances formed from gases in the samples after collection (a chemical measurement artifact, often in the form of sulfates). Although the degree of high bias due to insufficient sensitivity and chemical artifacts may be small relative to higher PM2.5 concentrations for other source types, typically it is significant relative the low PM2.5 concentrations characteristic of gas-fired combustion sources[8]. Current PM2.5 emission factors for natural gas-fired engines therefore exaggerate estimated human health and environmental impacts and often unnecessarily aggravate concerns during plant siting and licensing.

Dilution sampling methods offer greater sensitivity and precision than traditional hot filter/cooled impinger PM2.5 test methods, leading to more accurate PM2.5 emission factors. The Canadian Energy Partnership for Environmental Innovation (CEPEI) recently published recommended alternative PM2.5 emission factors for natural gas-fired gas turbine engines, gas turbine combined cycle or cogeneration units, boilers and process heaters that are based on tests conducted in the U.S. under a collaborative, multi-stakeholder government-industry research program. That program applied dilution sampling with proven ambient air sample collection and analysis methods. The PM2.5 emission factors resulting from that program are less than 1/10 of the combined filterable plus condensable particulate matter emission factors for natural gas external combustion (boilers and process heaters) and gas turbines published in AP-42. Subsequent tests sponsored by the American Petroleum Institute using the same test methodology produced PM2.5 emission factors for natural gas-fired reciprocating engines that are considerably lower than their respective AP-42 emission factors. More recently, the test methodology was further refined as a modification of a U.S. EPA dilution sampling test method and applied in tests of a natural gas-fired gas turbine combined cycle unit and several gas-fired refinery boilers and process heaters, yielding PM2.5 emission factor results of magnitude similar to those in the earlier tests. Thus, there is a growing body of test results useful for developing improved, more accurate PM2.5 emission factors for gas-fired combustion sources and an emerging test protocol for a standardized PM2.5 dilution sampling test methodology that is capable of reliable measurements at these low levels.

---

[7] *Compilation of Air Pollutant Emission Factors*, AP-42, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. https://www3.epa.gov/ttnchie1/ap42/.

[8] Wien, S., G.C. England, K.R. Loos, and K. Ritter. Investigation of Artifacts in Condensable Particulate Measurements for Stationary Combustion Sources, 94th Air &Waste Manage Association Annual Conference and Exhibition, Orlando, Florida. June 2001.

The gas turbine and reciprocating engines in the U.S. program employed catalytic emissions controls that are not widely used in Canada. Catalytic emission controls such as selective catalytic NO_X reduction can both reduce and contribute to PM2.5 emissions, depending on site-specific parameters. Therefore, there is a need for improved PM2.5 emission factors representative of units in Canada.

2.1 CEPEI Project Description

The primary goal of the project is to update PM2.5 emission factors and chemical speciation profiles that will be used for federal and provincial/territorial air quality permitting/licensing applicable to engines used in upstream/downstream oil and gas operations in Canada. A key objective is to gain acceptance for using the new emission factors among industry, government, consultants and the community. The project was sponsored by CEPEI and several of its member companies (ATCO Gas, Enbridge Gas Distribution Inc., FortisBC, Manitoba Hydro, SaskEnergy TransGas, TransCanada PipeLines Ltd., and Union Gas Limited) and by the Petroleum Technology Alliance Canada (PTAC), including funding from the BC Oil and Gas Research and Innovation society (OGRIS).

This project generated new test data and updated PM2.5 emission factors for natural gas-fired engines applicable to upstream and downstream oil and gas operations as well as end user engine applications. The tests were conducted using a proven dilution sampling method combined with ambient air sample collection and analysis methods to determine both the mass and chemical speciation of PM2.5 emissions. A modified version of U.S. EPA Conditional Test Method 039 (CTM 39) that has been recently applied to tests of several gas-fired sources was used. The modified method combines key elements of the scientifically proven research dilution sampling method used in the U.S. program within the general framework and equipment of the published U.S. EPA method.

The chemical composition of the collected aerosols also was determined (51 elements by x-ray fluorescence; sulfate, nitrate, chloride & other ions by ion chromatography and organic and elemental carbon by thermal optical reflectance). These results help clarify the true contribution of sulfates to PM2.5 emissions. Chemically speciated PM2.5 profiles will be applicable to source apportionment and health risk analysis.

Tests were conducted on two units: one is a natural gas-fired combustion turbine employing lean premix low-NO_X combustors; the other site is a natural gas-fired lean burn reciprocating engine. The host site units are representative of engine size and configurations for Canadian upstream and downstream oil and gas applications (such as compressor drives). Neither of the units employed post-combustion catalysts for additional emissions control, which distinguishes them from units previously tested in the U.S. They also may be representative of power generation and cogeneration applications. The goal in selecting these units is to assure that the data can be extrapolated to the widest range of gas-burning engines.

3. DATA SOURCES

3.1 CEPEI Test Program Results (2015)

The primary objectives were:

- Measure PM2.5 mass concentrations and selected species (elements, ions, organic and elemental carbon) in the stack gas using a dilution sampler combined with ambient air sample collection and analysis methods;
- Measure O_2 and CO_2 concentrations in the stack gas and fuel composition to enable calculation of PM2.5 emission factors via the use of fuel factors ("F factors") following U.S. EPA Method 19;

The secondary objectives were:

- Collect data needed to evaluate CTM 39 method performance and optimize future test protocols, including collection and analysis of replicate sample and sample train blanks and replicate reagent blanks;
- Compare samples and blanks to determine significance of differences;
- Evaluate replicate blanks to determine overall method sensitivity and reporting limits.

The tests were conducted using a version of CTM 39, a stationary source PM10/2.5 dilution sampling method, modified by adding ambient air sample collection and analysis methods to determine both the mass and chemical speciation of PM2.5 emissions. The method combines key elements of the scientifically proven dilution sampling method used in previous U.S. research programs within the general framework and equipment of a published U.S. EPA test method. The method also reflects several elements of ISO 25597-13, another more recently published stationary source PM10/2.5 dilution sampling method, with respect to splitting the diluted sample and sample collection on 47-mm Teflon® membrane filters and quartz fiber filters.

The chemical composition of the collected aerosols was determined (51 elements by x-ray fluorescence; sulfate, nitrate, chloride, ammonium & other ions by ion chromatography and colorimetry, and organic and elemental carbon by thermal optical absorbance/reflectance). These results help to clarify the contribution of sulfates to air emissions from these types of engines. PM2.5 chemical species profiles developed from the results also will be useful for source apportionment and health risk analysis.

Tests were conducted on two units at different natural gas pipeline compressor stations (Table 3-1): one is a natural gas-fired combustion (gas) turbine engine employing lean premix low-NO_X combustors; the other is a natural gas-fired four-stroke lean burn reciprocating engine. Neither site employs post-combustion emission controls. The engines are considered representative of engine sizes and configurations used in Canadian upstream and downstream oil and gas applications (such as compressor drives). They also may be representative of power generation and cogeneration applications. The tests were designed to assure that the data can be extrapolated to the widest range of gas-burning engines.

A detailed summary of the CEPEI test results is provided in Appendix A.

Table 3-1: Process and air pollution control descriptions.

Unit ID	Process Description	Air Pollution Controls
Site Alfa	Natural gas-fired reciprocating internal combustion engine, four-stroke, lean burn, turbocharged, Waukesha Model 12VAT27GL, 3130 horsepower (2.3 MW), commissioned circa 1997. The engine was nearing the end of its major scheduled maintenance cycle at the time of the tests.	Pre-combustion chambers, air/fuel ratio controller
Site Buick	Natural gas-fired gas turbine engine, Rolls Royce model RB211 24DLE, 27.5 MW mechanical power output capacity, in service as a natural gas compressor drive.	Dry low emissions (lean premix) combustion system, short can version

The engines were operated on natural gas fuel at approximately constant power output, with an engine load of 80% of rated capacity or higher. Process operating conditions for each test run indicate stable operation within the target operating range for each test (Tables 3-2 and 3-3).

Table 3-2: Site Alfa reciprocating engine average operating conditions during PM2.5 tests.

Parameter	Units	Run 1	Run 2	Run 3
Date		20 Oct 2015	20 Oct 2015	21 Oct 2015
Fuel heat input (gross)	GJ/hr	20.8	20.5	20.5
Engine speed	RPM	950	950	949

Table 3-3. Site Buick gas turbine average operating conditions during PM2.5 tests.

Parameter	Units	Run 1	Run 2	Run 3
Date		15 Oct 2015	16 Oct 2015	17 Oct 2015
Power output	kW	21,000*	23,000*	23,072
Turbine speed	RPM	*	*	4,307
Fuel gas flow rate	kg/s	1.29*	1.39*	1.39

*Data not available due to data recorder error. Power and fuel flow rates for Runs 1 and 2 estimated from Run 3 data based on measured stack gas flow rates and O_2 concentrations.

Average PM2.5 mass emission rates in kg/GJ are summarized in Table 3-4. Reconstructed mass (i.e., the sum of individual species adjusted for oxides and organic carbon artifact) and measured mass agree well (within ±6%) for the reciprocating engine tests. The measured PM2.5 mass for gas turbine engine Run 1 is very high relative to Runs 2 and 3. This is accounted for primarily by silicon (as silicon dioxide). This strongly suggests sample contamination for Run 1, which may have been introduced during sample train operation troubleshooting prior to starting the run. The measured mass is much lower than the reconstructed mass for gas turbine Runs 2 and 3. Because the reconstructed masses are more consistent from run to run when excluding silicon in Run 1, the reconstructed masses from each of the three test runs (excluding silicon in Run 1) were used to calculate the average gas turbine PM2.5 mass emission rate shown in Table 3-4. Perhaps fortuitously, the averages of the measured and reconstructed masses for all three runs are nearly the same (2.42E-04 and 2.36 E-04 kg/GJ, respectively).

Table 3-4: Average PM2.5 mass emission factors for natural gas-fired reciprocating engine and gas turbine.

Unit	PM2.5, kg/GJ
Reciprocating Engine (Site Alfa)	0.00150
Gas Turbine Engine (Site Buick)	0.000236

31 elements and ions were not detected in any runs on the reciprocating engine. Twenty species that were detected in at least one reciprocating engine run account for 99.69% of total reconstructed mass (Table 3-5). Ninety-four percent of total mass is accounted for by organic carbon (OC), followed by sulfur (S), elemental carbon (EC) and calcium (Ca) which account for 4.5 percent of total mass. Nitrate ion accounted for 0.33%.

Table 3-5: PM2.5 species profile – Site Alfa reciprocating engine (detected in at least one test run, as fraction of reconstructed mass).

Species	Mass Fraction	Species	Mass Fraction
OC	0.94	Eu	0.00064
S	0.018	Na^+	0.00050
EC	0.017	Ba	0.00031
Ca	0.011	Fe	0.00028
NO_3^-	0.0033	Ti	0.00024
Zn	0.0015	W	0.00021
Cl	0.0014	Ce	0.00022
Si	0.0013	K	0.00021
P	0.0012	Cs	0.00018
Al	0.00060	La	0.00012

36 elements and ions were not detected in any runs on the gas turbine engine. Twenty species account for 98.9 percent of reconstructed mass (Table 3-6). OC accounts for 80 percent of total reconstructed mass, followed by sodium (Na), EC and magnesium (Mg).

The trace element concentrations with mass fractions less than 0.001 generally are near to the analytical minimum reporting limits and or field blank levels (less than 5 times higher than), and Na results should be considered qualitative due to limitations of the analytical technique.

Table 3-6: PM2.5 species profile – Site Buick gas turbine engine (detected in at least one test run, as fraction of reconstructed mass).

Species	Mass Fraction	Species	Mass Fraction
OC	0.80	NO_3^-	0.0018
Na	0.089	W	0.0012
EC	0.042	Br	0.0015
Mg	0.023	Cs	0.00049
P	0.0076	Cl	0.00050
Sm	0.0053	K	0.00054
Eu	0.0046	Cd	0.00045
Si	0.0041	Ba	0.00041
Tb	0.0033	Sb	0.00033
Ce	0.0023	Sn	0.00028

A detailed test report includes a full description of the test methodology and results[9] and a detailed summary of the test results is provided in Appendix A.

3.2 U.S. Collaborative Test Program (1998-2003)

A collaboration between industry (American Petroleum Institute, Gas Research Institute) and U.S. government agencies (California Energy Commission, U.S. Department of Energy, New York Energy Research and Development Authority) from 1998 to 2004 conducted PM2.5 tests using a dilution sampling methodology on nine natural gas- and refinery gas-fired boilers, process heaters, gas turbine combined cycle/cogeneration units, one oil-fired boiler and one diesel engine. The American Petroleum Institute sponsored tests on a boiler and a process heater at U.S. refineries in 1998[10] and 1999[11] using a research dilution sampling methodology and a traditional hot filter/cooled impinger method to characterize PM2.5 mass and chemical species. A laboratory test[10] also was conducted with simulated combustion gases to evaluate "pseudoparticulate" formation in the cooled impingers, used for determining condensable particulate matter (cPM), due to conversion of sulfur dioxide (SO_2) gas to solid residues within the measurement process that contribute to reported cPM ("SO_2 artifact"). These tests first identified that traditional hot filter/cooled impinger method results for gas-fired combustion sources may be significantly biased high due to sulfate artifacts. Gas Research Institute (GRI) subsequently co-sponsored a test with API on a U.S. natural gas-fired steam generator[12] with similar findings. Subsequent tests co-sponsored by API, GRI and the U.S. government agencies listed above collected PM2.5 mass and chemical species data from six additional gas-fired sources: three gas

---

[9] England, G.C., CEPEI PM2.5 Emission Factor Development Test Report, Natural Gas-Fired Reciprocating and Gas Turbine Engines, Ramboll Environ, Irvine California, prepared for Canadian Energy Partnership for Environmental Innovation, Guelph, Ontario.

[10] England, G.C. and S. Wien. Gas Fired Boiler – Test Report Refinery Site A, Characterization of fine Particulate emission factors and Speciation Profiles from Stationary Petroleum Industry Combustion Sources. Publication 4702, GE Energy and Environmental Research Corporation, Irvine, California, prepared for American Petroleum Institute, Washington, D.C. 2001.

[11] England, G.C. and S. Wien. Gas Fired Heater – Test Report Site B – Characterization of Fine Particulate Emission Factors and Speciation Profiles from Stationary Petroleum Industry Combustion Sources. Publication 4704, GE Energy and Environmental Research Corporation, Irvine, California, prepared for American Petroleum Institute, Washington, D.C. 2001.

[12] England, G.C. and S. Wien. Gas-Fired Steam Generator – Test Report Site C: Characterization of Fine Particulate emission factors and Speciation Profiles from Stationary Combustion Sources. Publication 4712, GE Energy and Environmental Research Corporation, Irvine, California, prepared for American Petroleum Institute, Washington, D.C. 2001.

turbine combined cycle/cogeneration units[13],[14],[15] one boiler[16], and two process heaters[17],[18]. In these tests, measurements were made using both a research dilution sampler used in the earlier tests and a compact dilution sampler developed during the program. All tests used the same ambient air sample collection and analysis methods, except that the laboratory analytical protocol for semivolatile organic compounds (SVOC) was changed to focus on determination of polycyclic aromatic hydrocarbons (PAH) rather than total SVOC mass speciation after Site Bravo tests in 2001. CEPEI's 2012 technical memorandum (Appendix E to this report) summarized these tests and developed recommended PM2.5 emission factors and species profiles from the results.

3.3 API Reciprocating Engine Tests (2003)

In 2003, API sponsored tests of three natural gas-fired spark-ignited reciprocating internal combustion engines (RICE) used as compressor drives at a natural gas production facility[19,20]. A two-stroke engine, a four-stroke rich burn engine and a four-stroke lean burn engine were tested (Table 3-7). The four-stroke rich burn engine was equipped with non-selective catalytic reduction for nitrogen oxides (NO_X)

---

[13] Wien, S., England, G.C. and Chang, M.C., Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas-fired Combustion Systems, Topical Report: Test Results for a Combined Cycle Power Plant with Supplementary Firing, Oxidation Catalyst and SCR at Site Bravo, GE Energy and Environmental Research Corporation, Irvine, California, prepared for U.S. Department of Energy, Gas Research Institute, American Petroleum Institute, California Energy Commission and New York State Energy Research and Development Authority, 2004. http://www.energy.ca.gov/pier/project_reports/CEC-500-2005-032_to_44.html.

[14] England, G.C., Wien, S., McGrath, T.P., and Hernandez, D., Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas-fired Combustion Systems, Topical Report: Test Results for a Combined Cycle Power Plant with Oxidation Catalyst and SCR at Site Echo. GE Energy and Environmental Research Corporation, Irvine, California, prepared for U.S. Department of Energy, Gas Research Institute, American Petroleum Institute, California Energy Commission and New York State Energy Research and Development Authority, 2004. http://www.energy.ca.gov/pier/project_reports/CEC-500-2005-032_to_44.html.

[15] England, G.C. and T. McGrath, "Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas-fired Combustion Systems, Topical Report: Test Results for A Cogeneration Plant with Supplementary Firing, Oxidation Catalyst and SCR at Site Golf. GE Energy and Environmental Research Corporation, Irvine, California, prepared for U.S. Department of Energy, Gas Research Institute, American Petroleum Institute, California Energy Commission and New York State Energy Research and Development Authority, 2004. http://www.energy.ca.gov/pier/project_reports/CEC-500-2005-032_to_44.html.

[16] Wien, S., McGrath, T.P., England, G.C. and Chang, O.M.C., Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas-fired Combustion Systems, Topical Report: Test Results for a Dual Fuel-Fired Commercial Boiler (Site Delta). GE Energy and Environmental Research Corporation, Irvine, California, prepared for U.S. Department of Energy, Gas Research Institute, American Petroleum Institute, California Energy Commission and New York State Energy Research and Development Authority, 2004. http://www.energy.ca.gov/pier/project_reports/CEC-500-2005-032_to_44.html.

[17] Wien, S., England, G.C. and Chang, O.M.C., Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas-fired Combustion Systems, Topical Report: Test Results for a Gas-Fired Process Heater (Site Alpha), GE Energy and Environmental Research Corporation, Irvine, California, prepared for U.S. Department of Energy, Gas Research Institute, American Petroleum Institute, California Energy Commission and New York State Energy Research and Development Authority, 2003. http://www.energy.ca.gov/pier/project_reports/CEC-500-2005-032_to_44.html.

[18] Wien, S., England, G.C. and Chang, O.M.C., "Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas-fired Combustion Systems, Topical Report: Test Results for a Gas-Fired Process Heater with Selective Catalytic Reduction (Site Charlie). GE Energy and Environmental Research Corporation, Irvine, California, prepared for U.S. Department of Energy, Gas Research Institute, American Petroleum Institute, California Energy Commission and New York State Energy Research and Development Authority, 2003. http://www.energy.ca.gov/pier/project_reports/CEC-500-2005-032_to_44.html.

[19] England, G.C., K.R. Loos, K. Ritter. Measurements of PM2.5 Mass and Species Emissions from Natural Gas-Fired Reciprocating Internal Combustion Engines, SPE-94201-PP, Exploration & Production Environmental Conference, Society of Petroleum Engineers, Galveston, TX. March 2005.

[20] England, G.C., McGrath, T.P., Hernandez, D. PM2.5, PM2.5 Precursor and Hazardous Air Pollutant Emissions from Natural Gas-Fired Reciprocating Engines: Final Report (Draft). GE Energy and Environmental Research Corporation, Irvine, California, prepared for American Petroleum Institute, Washington, D.C. 2004.

emissions control. The two-stroke engine had precombustion chambers and no post-combustion emission controls and the four-stroke lean burn engine had no post-combustion emission controls.

Table 3-7: Reciprocating engines tested in 2003 API test program.

Type	Make/Model	Size	Emission Controls
four-stroke lean burn	Caterpillar G3606TA	1665 hp	None
four-stroke rich burn	Ingersoll Rand 48 KVSA (turbocharged)	1626 hp	NSCR
two-stroke lean burn	Cooper Bessemer GMVH-12C (turbocharged)	2700 hp	Precombustion chambers

PM2.5 and chemical species were measured using the GE compact dilution sampler and the same ambient air sample collection and analysis methods as used in the earlier tests discussed above. Operating conditions, PM2.5 mass, OC/EC, particulate carbon, elements and ions results for each test run and for each engine are summarized in Appendix D. Volumetric parameters are given at 20 °C reference temperature unless otherwise noted. The average PM2.5 emission factor for each engine type ranged from 0.000774 for the four-stroke rich burn engine to 0.00859 kg/GW for the two-stroke lean burn engine (Table 3-8). The species profiles for all engines are dominated by organic carbon, which accounts for 80 to 98 percent of the PM2.5 mass (Table 3-9).

Table 3-8: PM2.5 emission factors for reciprocating engines tested in 2003 API test program

Type	PM2.5 (kg/GW)
four-stroke lean burn	2.16E-03
four-stroke rich burn	7.74E-04
two-stroke lean burn	8.59E-03

Table 3-9: PM2.5 species profile for reciprocating engines tested in 2003 API test program (percent)

Species	4SRB	4SLB	2SLB
Organic Carbon (OC)	80	90	98
Si	6.0	1.4	0.18
Fe	3.9	5.8	
$SO_4^=$	3.2	0.66	0.24
Elemental Carbon (EC)	2.5		0.75
Ca	1.2	0.53	0.28
NH_4^+	0.89		0.07
Zn	0.57	0.55	0.08
NO_3^-	0.47	0.25	0.19
Cl-	0.38	0.15	0.05
Mo	0.14	0.07	0.03
P	0.14		0.03
Soluble Na^+	0.06	0.05	0.06
Cu	0.05	0.06	0.01
Co	0.03	0.02	
K	0.03	0.04	0.01
Cr	0.02	0.01	
Sn	0.02		
Ba		0.02	0.01
Ni		0.01	

3.4 GE Energy Gas Turbine Combined Cycle Unit Tests (2008)

In 2008, GE Energy developed a modified version of CTM 39 for measuring low concentrations in stack gases from natural gas-fired gas turbines and combined cycle/cogeneration units. U.S. EPA, California Air Resources Board, the South Coast Air Quality Management District, the Sacramento Metropolitan Air Quality Management District, and the San Juaquin Valley Air Pollution Control District participated in test planning and results review. The modifications to CTM 39 included addition of ambient air sample collection and analysis methods similar to those used in the U.S. collaborative program. To evaluate method performance, nine test runs with paired modified CTM 39 sampling trains were conducted on one 170 MW gas turbine unit of a 500 MW a natural gas-fired combined cycle power plant equipped with lean premix combustors and SCR[21]. The unit did not have duct burners.

CTM 39 specifies recovery of particles deposited on the sampler surfaces by quantitatively rinsing the surfaces with acetone and water after each test. The results showed that PM2.5 masses reported in the acetone and water recovery rinses for samples and for six replicate sample train field blanks are indistinguishable. This indicates that the levels measured in the samples are below the minimum reporting limit of the recovery rinse procedure; i.e., the true mass of PM2.5 in the samples is below the "noise" level of the recovery rinse procedure. Further, the reporting limit of the recovery rinse procedure is much greater than measured PM2.5 masses on the 47-mm TMFs[22]. Particles emitted from natural gas combustion are smaller than 1 micrometer and primarily smaller than 0.1 micrometers[23,24]. An earlier study of particle deposition in a dilution sampler showed that deposition of particles smaller than 1 micrometer on surfaces of the sampler prior to the filter is expected to be less than 7% and probably less than 1% for particles smaller than 0.1 micrometer[25]. Thus, there is very little, if any, PM2.5 from natural gas combustion expected to be present on the sampler surfaces.

Measured PM2.5 masses on the TMFs are greater than the minimum reporting limit for the TMFs and are thus reliable measurements. Therefore, PM2.5 emission factors derived from the 2008 GE Energy test results are based on TMF results only. PM2.5 mass (TMFs) and chemical species results (Tables 3-10 and 3-11) agree reasonably well in magnitude with results for similar units tested during the U.S. collaborative program. A detailed summary of test results is provided in Appendix C.

Table 3-10: Average PM2.5 emission factor from 2008 GE Energy natural gas-fired gas turbine combined cycle unit tests – TMF results.

	PM2.5 (kg/GJ)
Sample Train A	2.55E-05
Sample Train B	1.76E-05
Average Sample Trains A & B	2.15E-05

[21] Matis, C., England, G.C., Crosby, K., Rubenstein, G., Tong, C. Evaluation Report, Evaluation of CTM-039 Dilution Method for Measuring PM10/PM2.5 Emissions from Gas-Fired Combustion Turbines, GE Energy, Schenectady, New York, 2009.

[22] Matis, C., G.C. England, K. Crosby and G. Rubenstein. Field Demonstration of a Dilution-Based Particulate Measurement System, Symposium on Air Quality Measurement Methods and Technology, Air & Waste Management Association, Chapel Hill, NC. November 2008.

[23] Chapter 4, Section 1.4 – Natural Gas Combustion, in *Compilation of Air Pollutant Emission Factors* AP-42, U.S. Environmental Protection Agency, 2000.

[24] Spang, B., S. Yoshimura, R. Hack, V. McDonell, S. Samuelsen (2013). Evaluation of the Level of Gaseous Fuel-Bound Sulfur on Fine Particulate Emission From a Low Emission Gas Turbine Engine, *J. Eng. Gas Turbines & Power*, 135:03501.1-03501.8.

[25] Hildemann, L. M., G. R. Cass & G. R. Markowski (1989). A Dilution Stack Sampler for Collection of Organic Aerosol Emissions: Design, Characterization and Field Tests, *Aerosol Science and Technology*, 10:1, 193-204, DOI: 10.1080/02786828908959234

Table 3-11: Average PM2.5 species profile from 2008 GE Energy natural gas-fired gas turbine combined cycle unit tests – TMF results.

Species	%	Species	%
OC	85	Sr	0.018
EC	7.34	Ti	0.016
$SO_4^{=}$	1.89	Y	0.01
Cl^-	1.67	Ni	0.0066
Si	1.56	Mo	0.0056
NH_4^+	0.94	Cr	0.0052
NO_3^-	0.64	Pb	0.0049
Al	0.23	Se	0.0047
Fe	0.21	Cu	0.0041
Ca	0.18	Br	0.003
Cl	0.13	Sm	0.0023
Zn	0.041	Rb	0.0016
S	0.03	V	0.001
K	0.025		

Note, the run-to-run variability of the 47-mm TMF results is greater in the GE Energy 2008 tests than was generally observed in the U.S. collaborative program – this was attributed to defects in the filter holders which resulted in adhesive contamination and filter tearing for some of the samples. As a result, some of the TMF net weights are less than zero and there are two very high outliers in the data set. The data were examined excluding the negative values and two high outliers; however, this changed the mean emission factor by only -11%. Since the high outliers could not be attributed to a definitive measurement defect, and since the negative values and outliers provide information regarding measurement uncertainty in these tests, the mean emission factor of the full data set is considered the most representative statistic for these tests.

3.5 Refinery Boiler and Process Heater Tests (2014)

Although the primary focus of this emission factor update is on reciprocating engines and gas turbines, PM10 (expressed as total PM) tests were conducted on six refinery gas-fired boilers and process heaters in 2014[26] using a modified version of U.S. EPA CTM 39 similar to that used in the 2015 CEPEI tests. The refinery gas contained 7 to 9 ppm hydrogen sulfide. The three boilers were equipped with SCR, and one boiler also had low-NO_X burners. The three process heaters were equipped with low-NO_X burners but no post-combustion emissions controls. The results (Table 3-12) are generally consistent in magnitude with earlier results obtained during the U.S. collaborative program. Boiler A was tested

[26] Astin, M.S., Benson, E., England, G.C., Croghan, S. PM10/2.5 Emissions from Gas-Fired Refinery Boilers and Heaters: Test Methods, Results and Better Emission Factors for Air Quality Impact Assessment, 2015 Environmental Conference, American Fuels & Petrochemicals Manufacturers, Salt Lake City, Utah, 2015.

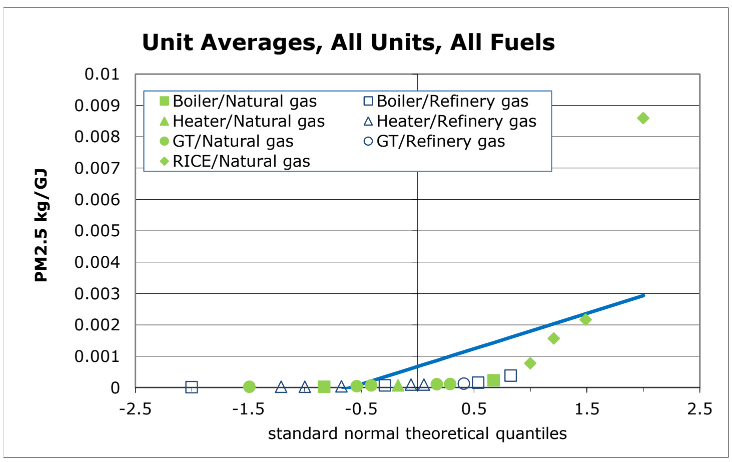
both before (Runs 1-3) and after (Runs 4-6) tuning the SCR ammonia flow rate, and the difference in results likely illustrates the contribution of ammonium sulfate/bisulfate to PM emissions.

Table 3-12: PM2.5 test results for refinery boilers and process heaters (2014).

	Run ID	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Average
Boiler A	mg/dscm	1.76E+00	1.40E+00	1.69E+00	6.53E-01	7.05E-01	5.62E-01	1.13E+00
Boiler A	kg/GJ	5.93E-04	4.73E-04	4.64E-04	2.52E-04	2.74E-04	2.15E-04	3.79E-04
Boiler B	mg/dscm	1.76E-01	1.90E-01	1.80E-01	--	--	--	1.82E-01
Boiler B	kg/GJ	6.71E-05	7.27E-05	6.88E-05	--	--	--	6.95E-05
Boiler C	mg/dscm	2.93E-02	3.62E-02	3.56E-02	--	--	--	3.37E-02
Boiler C	kg/GJ	1.20E-05	1.48E-05	1.46E-05	--	--	--	1.38E-05
Heater A	mg/dscm	2.93E-01	4.12E-01	1.60E-01	--	--	--	2.88E-01
Heater A	kg/GJ	9.24E-05	1.28E-04	4.99E-05	--	--	--	9.01E-05
Heater B	mg/dscm	2.67E-01	3.89E-01	2.44E-01	--	--	--	3.00E-01
Heater B	kg/GJ	7.35E-05	1.26E-04	7.01E-05	--	--	--	9.00E-05
Heater C	mg/dscm	1.51E-01	1.50E-01	1.48E-01	--	--	--	1.50E-01
Heater C	kg/GJ	3.97E-05	3.94E-05	3.90E-05	--	--	--	3.94E-05

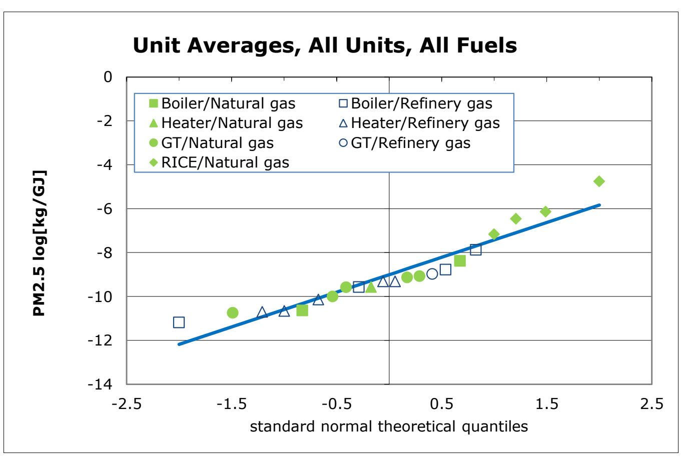
4. PM2.5 EMISSION FACTORS

The average emission factors for each unit including the U.S. collaborative program, 2015 CEPEI, 2014 refinery and 2008 GE Energy test results were compared to determine if data should be aggregated or separated by fuel, unit type or configuration. The ranked data (low to high) were examined on theoretical normal quantile-quantile (Q-Q) plots to both compare the magnitude, data trends, fit to a normal distribution and central tendency of the data (Figure 4-1). Data fitting a normal distribution will fall on a straight line on a Q-Q plot. Inflection points in the ranked data indicate subsets of data with different distributions – this may suggest natural divisions within the data where it makes sense to subdivide emission factors. Comparing the entire data set to a fitted normal distribution correlation (blue line in Figure 4-1a) shows the data do not fit a normal distribution – the RICE data which constitute the high end of the data range, particularly the two-stroke engine result, heavily skew the distribution. Environmental data often are skewed high and fit a lognormal distribution (i.e., the log-transformed data fit a normal distribution). A similar evaluation also shows the data do fit an approximate lognormal distribution with a geometric mean PM2.5 emission factor of 0.000122 kg/GJ (Figure 4-1b).



Raw Statistics	
Number of Valid Observations	22
Number of Distinct Observations	21
Minimum	0.000013814
Maximum	0.00859
Mean of Raw Data	0.0006717
Standard Deviation of Raw Data	0.00185
Khat	0.388
Theta hat	0.00173
Kstar	0.366
Theta star	0.00184
Mean of Log Transformed Data	-9.009
Standard Deviation of Log Transformed Data	1.654
Normal GOF Test Results	
Correlation Coefficient R	0.601
Shapiro Wilk Test Statistic	0.388
Shapiro Wilk Critical (0.05) Value	0.911
Approximate Shapiro Wilk P Value	6.42E-10
Lilliefors Test Statistic	0.381
Lilliefors Critical (0.05) Value	0.189
Data not Normal at (0.05) Significance Level	

(a)

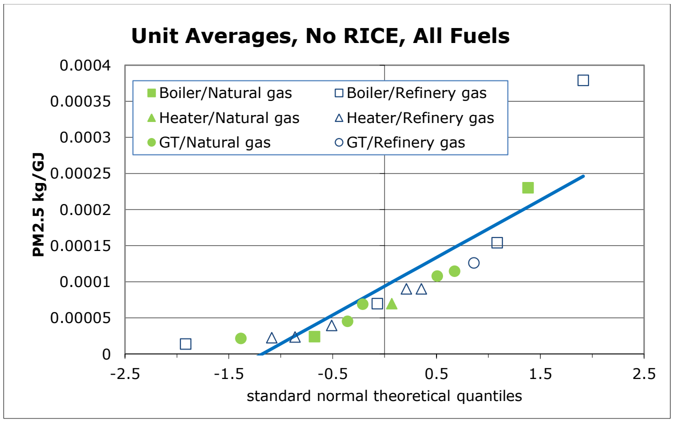


Raw Statistics	
Number of Valid Observations	22
Number of Distinct Observations	21
Minimum	0.000013814
Maximum	0.00859
Mean of Raw Data	0.0006717
Standard Deviation of Raw Data	0.00185
Khat	0.388
Theta hat	0.00173
Kstar	0.366
Theta star	0.00184
Mean of Log Transformed Data	-9.009
Geometric Mean of Raw Data	0.000122
Standard Deviation of Log Transformed Data	1.654
Lognormal GOF Test Results	
Correlation Coefficient R	0.954
Shapiro Wilk Test Statistic	0.909
Shapiro Wilk Critical (0.05) Value	0.911
Approximate Shapiro Wilk P Value	0.043
Lilliefors Test Statistic	0.174
Lilliefors Critical (0.05) Value	0.189
Data appear Approximate_Lognormal at (0.05) Significance Level	

(b)

Figure 4-1: Q-Q plot for PM2.5 emission factors from gas-fired boilers, process heaters, gas turbines and reciprocating engines, measured with dilution sampling methods.

If the RICE data are excluded, the remaining data approximately fit a normal distribution (Figure 4-2). Goodness of fit to a normal distribution was confirmed using ProUCL[27], a statistical analysis application developed by U.S. EPA for environmental data analysis. Thus, it is reasonable to consider the data set excluding RICE for an aggregate PM2.5 emission factor.



Raw Statistics	
Number of Valid Observations	18
Number of Distinct Observations	17
Minimum	0.000013814
Maximum	0.00037876
Mean of Raw Data	0.000093801
Standard Deviation of Raw Data	0.00009035
Khat	1.478
Theta hat	0.000063459
Kstar	1.269
Theta star	0.000073928
Mean of Log Transformed Data	-9.649
Standard Deviation of Log Transformed Data	0.904
Normal GOF Test Results	
Correlation Coefficient R	0.872
Shapiro Wilk Test Statistic	0.775
Shapiro Wilk Critical (0.05) Value	0.897
Approximate Shapiro Wilk P Value	0.00038199
Lilliefors Test Statistic	0.194
Lilliefors Critical (0.05) Value	0.209
Data appear Approximate Normal at (0.05) Significance Level	

Figure 4-2: Normal Q-Q plot of PM2.5 emission factors for gas-fired boilers, process heaters and gas turbines, measured with dilution sampling methods.

The average emission factor for all gas-fired units excluding the RICE data may be expressed as the mean (average) of the unit average emission factors for 16 units using refinery gas or natural gas as fuels. Tests for one gas turbine combined cycle unit, Site Echo from the U.S. collaborative tests, tested at high load with duct burners on and reduced load with duct burners off are included as separate data points to represent emissions from similar units with and without duct burners). The data are skewed high due to a single data point at the high end of the range, resulting in a mean emission factor of 0.00010 kg/GJ ±48% (mean ± uncertainty) which is 45% greater than the median (Table 4-1). However, the high data point is not a statistical outlier (Dixon's test) so there is no reason to exclude it.

The high data point is Boiler A from the 2014 refinery tests, which exhibited higher emissions attributed to ammonium sulfate/bisulfate produced by ammonia slip from the SCR. Although the data are considered valid, results for two other boilers with SCRs at the same facility are lower indicating this unit may not be representative of most such units. Removing the Boiler A data point reduces the mean and uncertainty to 0.000084 kg/GJ ±43%. Considering only the natural gas-fired units results in a mean emission factor that is the same as for the full data set but with greater uncertainty, 0.00010 kg/GJ ±72%. Because the full data set remains small in statistical terms (fewer than 25 data points), we recommend using the full data set including the Boiler A data point as a general emission factor for all gas-fired units. However, we recommend using the median emission factor rather than the mean when applying emission factors in situations where the central data characteristic is indicated. For example, the median value may be appropriate when estimating emissions from a population of many similar units such as in regional air quality analysis.

The maximum and 95% confidence upper bound (95% CUB) provide measures of the upper limits of the data set. The 99% confidence upper prediction limit (99% UPL) provides a measure of an upper limit of the mean value for the next unit that is tested. In this data set, the maximum is the highest value, followed by the 99% UPL and the 95% CUB in descending order. An upper limit or maximum may be appropriate in situations where a conservative estimate of emissions is necessary. For

[27] http://www.epa.gov/land-research/proucl-software.

example, an upper limit may be appropriate when evaluating emissions from one unit within a larger population of units or when establishing emissions limits or standards.

Table 4-1: Aggregate PM2.5 emission factor statistics for boilers, process heaters, gas turbines and gas turbine combined cycle/cogeneration units.

Parameter	Units	Value	Value	Value
Data set		NG+RG	NG+RG (exclude outlier)	NG
Number of units		17	16	6
Number of data points		18	17	8
Mean	kg/GJ	1.01E-04	8.42E-05	1.00E-04
Median	**kg/GJ**	**6.95E-05**	6.95E-05	6.91E-05
Geometric mean	kg/GJ	6.71E-05	6.06E-05	7.11E-05
Minimum	kg/GJ	1.38E-05	1.38E-05	2.15E-05
Maximum	**kg/GJ**	**3.79E-04**	2.36E-04	2.36E-04
Standard deviation	kg/GJ	9.64E-05	6.89E-05	8.66E-05
COV	%	96	82	86
Confidence level	%	95%	95%	95%
Measurement bias	%	6.5	6.5	6.5
t factor (2 tail)		2.11	2.12	2.36
t factor (1 tail)		1.33	1.34	1.41
Total uncertainty	%	48	43	72
Total uncertainty	kg/GJ	4.84E-05	3.58E-05	7.27E-05
95% confidence upper bound	**kg/GJ**	**1.32E-04**	1.07E-04	1.44E-04
Data distribution		normal	normal	normal
99% confidence upper prediction limit	**kg/GJ**	**3.55E-04**	2.67E-04	3.76E-04

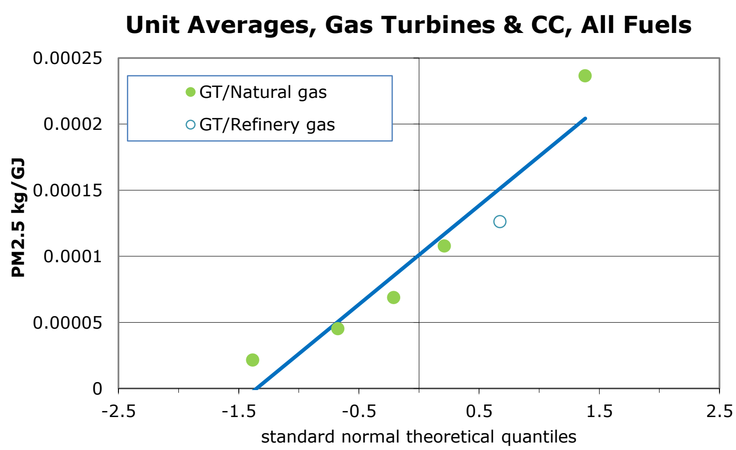
4.1 Gas Turbines and Gas Turbine Combined Cycle/Cogeneration Units

The current data set includes test results for five units utilizing gas turbines. Three units (Bravo, Echo, GE 2008) are natural gas-fired gas turbine combined cycle units (GTCC) employing large heavy-duty frame gas turbines with lean premix combustors (LPC) with SCR for NO_X emissions control. Two of these (Bravo and Echo) employ duct burners for supplementary steam generation and CO oxidation catalysts for additional emissions control. One (Golf) is a refinery cogeneration unit employing an aeroderivative gas turbine with diffusion flame combustors employing water injection (WI) and SCR for NO_X emissions control and CO oxidation catalyst. The CEPEI Buick unit is an aeroderivative gas turbine with lean premix combustors but no post-combustion controls applied as a natural gas pipeline compressor drive. One unit (Echo) was tested at base gas turbine load with duct burners on and at near base gas turbine load with duct burners off. The two conditions are treated as separate units in this analysis since the tests with duct burners off may also represent emissions from similar units without duct burner (supplementary firing) capability.

PM2.5 mass emission factors determined by dilution sampling methods are within the same order of magnitude, spanning a 11:1 range (Table 4-2) and the data are normally distributed (Figure 4-3). The 2015 CEPEI gas turbine test produced the highest PM2.5 emission factor in the data set. A natural gas-fired combined cycle unit (Site Echo, duct burners on) has the lowest PM2.5 mass emission factor. The refinery gas-fired unit has the second highest PM2.5 emission factor. The refinery gas contained an average of 27 ppm total sulfur, which is higher than the sulfur content of the natural gas-fired units and 2 to 20 times higher than typical natural gas sulfur content. The PM2.5 sulfate concentration for Site Golf is 3 to more than 10 times higher than that for the natural gas-fired units, which accounts for much of the difference in PM2.5 emission factor. Data for the natural gas-fired units only also are normally distributed (Figure 4-4).

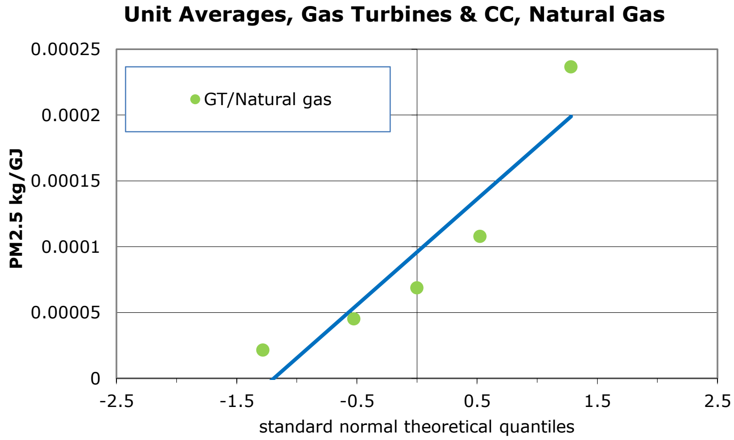
Table 4-2: PM2.5 emission factor data set for gas-fired gas turbines (dilution test methods)

Facility ID	Unit ID	Fuel	Controls	Test Date	kg/GJ
Bravo	GTCC/C (2xDB on + 1x DB off), 159 MW	Natural gas	LPC+CO Cat+SCR	2001	1.08E-04
Echo	GTCC/C (High load, DB on), 170	Natural gas	LPC+CO Cat+SCR	2003	4.51E-05
Echo	GTCC/C (Reduced load DB off), 170	Natural gas	LPC+CO Cat+SCR	2003	6.88E-05
Golf	GT-Cogen (DB on), 48 MW	Refinery gas	WI+CO Cat+SCR	2003	1.26E-04
GE 2008	GTCC (no DB), 170 MW	Natural gas	LPC+SCR	2008	2.15E-05
CEPEI Buick	Gas turbine, 27.5 MW	Natural gas	LPC	2015	2.36E-04



Raw Statistics	
Number of Valid Observations	6
Number of Distinct Observations	6
Minimum	2.15E-05
Maximum	2.36E-04
Mean of Raw Data	1.01E-04
Standard Deviation of Raw Data	7.68E-05
Khat	2.03
Theta hat	4.97E-05
Kstar	1.126
Theta star	8.97E-05
Mean of Log Transformed Data	-9.467
Standard Deviation of Log Transformed Data	0.841
Normal GOF Test Results	
Correlation Coefficient R	0.954
Shapiro Wilk Test Statistic	0.916
Shapiro Wilk Critical (0.05) Value	0.788
Approximate Shapiro Wilk P Value	N/A
Lilliefors Test Statistic	0.205
Lilliefors Critical (0.05) Value	0.362
Data appear Normal at (0.05) Significance Level	

Figure 4-3: Q-Q plot and goodness of fit statistics for gas turbine PM2.5 emission factor data set – natural gas and refinery gas fuels



Raw Statistics	
Number of Valid Observations	5
Number of Distinct Observations	5
Minimum	2.15E-05
Maximum	2.36E-04
Mean of Raw Data	9.59E-05
Standard Deviation of Raw Data	8.48E-05
Khat	1.747
Theta hat	5.49E-05
Kstar	0.832
Theta star	1.15E-04
Mean of Log Transformed Data	-9.564
Standard Deviation of Log Transformed Data	0.902
Normal GOF Test Results	
Correlation Coefficient R	0.928
Shapiro Wilk Test Statistic	0.868
Shapiro Wilk Critical (0.05) Value	0.762
Approximate Shapiro Wilk P Value	N/A
Lilliefors Test Statistic	0.245
Lilliefors Critical (0.05) Value	0.396
Data appear Normal at (0.05) Significance Level	

Figure 4-4: Q-Q plot and goodness of fit statistics for gas turbine PM2.5 emission factor data set – natural gas fuel only

The mean and median for both data sets are similar, reflecting a good data fit to a normal distribution (Table 4-3). The mean PM2.5 emission factor and uncertainty are 0.000096 kg/GJ ±110% for natural gas-fired units alone and 0.00010 kg/GJ ±80% for all units firing natural gas or refinery gas. Because the uncertainty is lower for the emission factor including the refinery gas-fired unit, we recommend the latter emission factors for estimating emissions from gas-fired gas turbines and combined cycle units.

4.2 RICE Data Set

The PM2.5 emission factor data set (Table 4-4) includes results for four natural gas-fired engines encompassing three different engine types and different emission controls ranging from pre-combustion chambers (PCC) and air/fuel ratio controllers (A/F) to non-selective catalytic reduction (NSCR). The data set includes one four-stroke rich burn (4SRB) engine and two four-stroke lean burn (4SLB) engines. PM2.5 emission factor for the two-stroke lean burn (2SLB) engine is 4 to 11 times higher than the other units. Since two-stroke engines are different in many respects from four-stroke engines and generally exhibit higher emissions of organic combustion byproducts from fuel gas and lubrication oil blow-by, PM2.5 emission factors are evaluated for the four-stroke engines alone in this analysis. The four-stroke engine data set fit a normal distribution (Figure 4-5).

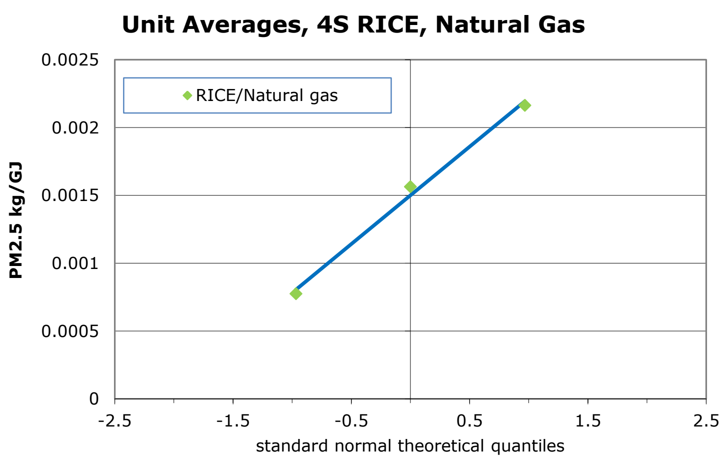
Because the data set is very small – 3 units - an aggregate PM2.5 emission factor for both lean burn and rich burn four-stroke engines combined, so that it can be expressed with an associated uncertainty. The mean PM2.5 emission factor and uncertainty is 0.00150 kg/GJ ±116% (Table 4-5). The mean and the median are nearly the same. Therefore, the mean is an appropriate statistic for emission factor use.

Table 4-3: PM2.5 emission factor statistics for gas-fired gas turbine and gas turbine combined cycle/cogeneration units.

Parameter	Units	Value	Value
Fuel		Natural gas	Natural gas & refinery gas
Number of units tested		4	5
Number of unit averages		5	6
Mean	**kg/GJ**	9.59E-05	1.01E-04
Median	kg/GJ	6.88E-05	8.83E-05
Geometric mean	kg/GJ	7.02E-05	7.74E-05
Minimum	kg/GJ	2.15E-05	2.15E-05
Maximum	**kg/GJ**	2.36E-04	**2.36E-04**
Standard deviation	kg/GJ	8.48E-05	7.68E-05
Coefficient of variation	%	88	76
Confidence level	%	95%	95%
Measurement bias	%	6.5	6.5
t factor (2 tail)		2.78	2.57
t factor (1 tail)		1.53	1.48
Total uncertainty	%	110	80
Total uncertainty	kg/GJ	1.05E-04	8.09E-05
95% confidence upper bound	**kg/GJ**	1.54E-04	**1.48E-04**
Data distribution		normal	normal
99% confidence upper prediction limit	**kg/GJ**	4.44E-04	**3.80E-04**

Table 4-4: PM2.5 emission factor data set for natural gas-fired reciprocating engines.

Source	Unit ID	Fuel	Controls	Test Date	PM2.5 kg/GJ
API RICE	RICE 2SLB	Natural gas	PCC	2004	0.00859
API RICE	RICE 4SRB	Natural gas	NSCR	2004	0.000774
API RICE	RICE 4SLB	Natural gas	None	2004	0.00216
CEPEI RICE	Alfa 4SLB	Natural gas	PCC, A/F	2015	0.00156



Raw Statistics	
Number of Valid Observations	3
Number of Distinct Observations	3
Minimum	7.74E-04
Maximum	0.00216
Mean of Raw Data	0.0015
Standard Deviation of Raw Data	6.97E-04
Khat	6.059
Theta hat	2.48E-04
Kstar	N/A
Theta star	N/A
Mean of Log Transformed Data	-6.587
Standard Deviation of Log Transformed Data	0.525
Normal GOF Test Results	
Correlation Coefficient R	0.997
Shapiro Wilk Test Statistic	0.994
Shapiro Wilk Critical (0.05) Value	0.767
Approximate Shapiro Wilk P Value	N/A
Lilliefors Test Statistic	0.203
Lilliefors Critical (0.05) Value	0.512
Data appear Normal at (0.05) Significance Level	

Figure 4-5: Q-Q plot and goodness of fit statistics for four-stroke reciprocating engine PM2.5 emission factor data set – natural gas fuel

Table 4-5: PM2.5 emission factor statistics for four-stroke reciprocating engines.

Parameter	Units	Value
Number of units tested		3
Mean	kg/GJ	1.50E-03
Median	kg/GJ	1.56E-03
Geometric mean	kg/GJ	1.38E-03
Minimum	kg/GJ	7.74E-04
Maximum	kg/GJ	2.16E-03
Standard deviation	kg/GJ	6.97E-04
Coefficient of variation	%	46
Confidence level	%	95%
Measurement bias	%	6.5
t factor (2 tail)		4.30
t factor (1 tail)		1.89
Total uncertainty	%	116
Total uncertainty	kg/GJ	1.73E-03
95% confidence upper bound	kg/GJ	2.26E-03
Data distribution		normal
99% confidence upper prediction limit	kg/GJ	7.10E-03

5. PM2.5 SPECIES PROFILES

Species profiles were calculated as a percentage of reconstructed mass concentration. Reconstructed mass concentration is the sum of species concentrations assuming that ions and anions are balanced and excess ions and elements are present as higher stable oxides.

It is important to note that these species profiles should be applied only to PM2.5 mass measured by dilution methods similar to those used in the underlying data. They should not be applied to PM2.5 mass measured by hot filter/cooled impinger or other test methods because of measurement artifacts that may alter mass and species in those results.

5.1 Gas Turbine PM2.5 Species

Organic carbon (OC) is the predominant component of PM2.5 for the gas-fired gas turbine and combined cycle/cogeneration units (Table 5-1) regardless of fuel. Sulfate and ammonium ions comprise a minor fraction of PM2.5, except for the gas turbine ("Site Buick") tested in the CEPEI 2015 test program where none was detected. This may be a reflection of low natural gas sulfur content and absence of post-combustion catalysts at Site Buick, as post-combustion catalysts used at the other sites are known to partially oxidize sulfur dioxide gas (SO_2) to sulfur trioxide (SO_3), a particulate sulfate precursor. Ammonium likely results from ammonia used in the SCR systems present on all of the units tested except for Buick. Elemental carbon (EC), chloride and nitrate comprise the majority of the remaining mass.

5.2 Reciprocating Engine PM2.5 Species

Organic carbon is the predominant component of PM2.5 mass from reciprocating engines, accounting for 88% of PM2.5 mass for four-stroke engines on average and 98% of PM2.5 mass for the two-stroke engine (Table 5-2).

Table 5-1: PM2.5 species profiles for gas-fired gas turbines and combined cycle/cogeneration units (% of reconstructed mass)

	CEPEI 2015 Buick	Bravo	Echo Hi	Echo Lo	GE 2008	Golf	Average all	Average Nat. Gas
OC	80	73	68	73	83	50	72	76
$SO_4^{=}$		4.4	13	8.7	1.8	27	9.2	5.6
NH_4^+			7.0	5.9	0.92	9.6	3.9	2.8
EC	4.2	2.9	1.8		7.2	5.4	3.6	3.3
Cl^-		3.8	2.1	5.1	1.6	0.74	2.2	2.5
NO_3^-	0.18	5.2	2.1	1.2	0.62	2.4	2.0	1.9
Si	0.41	3.5	1.2	0.72	2.3	2.0	1.7	1.6
Na^+	0.57		2.9	2.7		1.3	1.3	1.2
Fe	0.023	2.7	0.25	0.16	0.29	0.57	0.67	0.69
Ca	0.029	1.0	0.23	0.22	0.35	0.30	0.36	0.37
Al		0.78	0.41		0.53	0.22	0.33	0.35
K	0.054	0.45	0.35	0.23	0.11	0.30	0.25	0.24
Zn	0.019	0.27	0.078	0.018	0.096	0.055	0.090	0.097
Cl	0.050				0.28		0.055	0.067
Cu	0.022	0.18				0.038	0.040	0.041
Br	0.15	0.014		0.059		0.015	0.040	0.045
Ti	0.022	0.14			0.04	0.014	0.036	0.041
Ni	0.0040	0.10			0.023	0.013	0.024	0.026
Ba	0.041					0.059	0.017	0.0083
Mn	0.056	0.073				0.017	0.025	0.026
V	0.0082	0.059			0.0061	0.0086	0.014	0.015
Sr	0.0036				0.063	0.0023	0.012	0.013
Cr	0.016				0.046	0.0031	0.011	0.013
Y	0.007				0.046		0.0089	0.011
Pb	0.017	0.027					0.0074	0.0089
Co		0.018				0.0012	0.0032	0.0036
Na	8.9						1.5	1.8
Mg	2.3						0.39	0.46
P	0.76						0.13	0.15
Sm	0.53						0.089	0.11
Eu	0.46						0.077	0.093
Tb	0.33						0.055	0.067
Ce	0.23						0.039	0.046
W	0.12						0.020	0.024
La						0.086	0.014	
Cd	0.045						0.0076	0.0091
Cs	0.049						0.0082	0.0099
Mo						0.038	0.0064	
Sb	0.033						0.0055	0.0067
Sn	0.028						0.0047	0.0057
Hg	0.016						0.0027	0.0032
U	0.015						0.0025	0.003
Se	0.010						0.0017	0.0020
Zr	0.0097						0.0016	0.0020
Tl	0.0080						0.0013	0.0016
In	0.0052						0.00087	0.0011
Rb	0.0013						0.00022	0.00026

Shaded area indicates species detected only for one unit. Results may not be representative of other units.

Table 5-2: PM2.5 species profiles for natural gas-fired reciprocating engines

	CEPEI 2015 Alfa 4SLB	API 4SRB	API 4SLB	Average 4S*	API 2SLB
OC	94	80	90	88	98
Fe	0.028	3.9	5.8	3.2	0.0041
Si	0.13	6.0	1.4	2.5	0.18
EC	1.7	2.5	0.16	1.5	0.75
SO42-	1.0	3.2	0.66	1.6	0.24
Ca	1.1	1.2	0.53	0.94	0.28
Zn	0.15	0.57	0.55	0.42	0.076
NO3-	0.33	0.47	0.25	0.35	0.19
NH4+		0.89	0.090	0.33	0.068
Cl-		0.38	0.15	0.18	0.049
P	0.12	0.14	0.032	0.097	0.03
Al	0.06	0.03	0.13	0.073	0.0014
Mo		0.14	0.073	0.071	0.028
Na+	0.050	0.057	0.049	0.052	0.063
Cu	0.00094	0.051	0.057	0.036	0.010
K	0.021	0.029	0.036	0.029	0.0078
Ba	0.031	0.022	0.020	0.024	0.0057
Co		0.029	0.021	0.017	
Mn	0.0033	0.018	0.022	0.014	
Cr	0.0060	0.022	0.0099	0.013	0.00080
La	0.012	0.010	0.011	0.011	
Sn	0.0081	0.015	0.0019	0.0083	
Ni	0.00060	0.0042	0.0061	0.0036	
Br	0.0042	0.00092	0.0013	0.0021	0.0010
V		0.0026	0.0032	0.0019	
Cd	0.0045		0.00086	0.0018	
Sr	0.0024	0.00034	0.00064	0.0011	0.00018
Ag	0.0022		0.00060	0.00093	
Y	0.0017		0.00044	0.00071	0.00019
Rb	0.0014	0.00020	0.00048	0.00069	0.00016
Se		0.0011	0.00060	0.00057	
S	1.8			0.60	
Cl	0.14			0.047	
Eu	0.064			0.021	
Ti	0.024			0.0080	
Ce	0.022			0.0073	
W	0.021			0.0070	
Cs	0.018			0.0060	
Sm	0.0084			0.0028	
Sb	0.0047			0.0016	
U	0.0043			0.0014	0.00013
Pb	0.0042			0.0014	
Au	0.0033			0.0011	
Zr			0.00024	0.000080	0.00026

Shaded area indicates species detected for only one unit. Results may not be representative of other units.
*Some species were not detected in all tests. To calculate the average species profile, the species percentage for undetected results is treated as zero. This results in an average species profile that sums to 100%.

6. DISCUSSION

6.1 PM2.5 Emission Factor Comparison – EPA AP-42

AP-42 is a widely referenced resource for emission factors when site- or industry-specific emission factors are not available. AP-42 Chapters 3.1 and 3.2 include emission factors for filterable particulate matter (fPM) - total and/or PM10 - and cPM for natural gas-fired gas turbines and natural gas-fired reciprocating internal combustion engines (RICE), respectively. The data sets on which the emission factors are based are available as Microsoft Access files that can be downloaded from U.S. EPA's website[7]. Summaries of the data sets used for these published AP-42 emission factors are provided in Appendix B.

6.1.1 AP-42: Gas Turbines

The AP-42 gas turbine data set for fPM and cPM consists of five tests on three different 86 MW units of the same make and model between 1994 and 1996. Two of the units were tested with and without water injection for gas turbine power augmentation and NO_X control (Table 6-1). The emission factors are based on U.S. EPA hot filter/cooled impinger PM test methods (U.S. EPA Methods 201, 201A or 5 for fPM and EPA Method 202 or modified Method 5 back half for cPM). EPA rates the data quality as high, but the quality of the emission factor is rated only "C" (on EPA's scale of "A" to "E", "A" being the highest quality and "E" being the lowest – refer to Appendix E for definition of EPA's quality rating system).

The limited nature of the AP-42 gas turbine data set and large degree of variability are striking for both fPM and cPM (Figure 6-1). Variability among the data sets contributes to large uncertainty in the reported emission factor, especially for cPM.

The CEPEI PM2.5 emission factor based on dilution sampling test methods, which includes fPM and cPM together from six tests of five different units, is far lower than either the AP-42 fPM or cPM emission factors alone and the uncertainty in the average emission factor is very small in comparison to that for either the fPM or cPM AP-42 factor. The large difference in the average emission factor is believed to be due to bias in the hot filter/cooled impinger measurement methods used in the AP-42 data set, related to sensitivity limitations of the gravimetric procedures used for both fPM and cPM and SO_2 artifacts in the cPM measurement procedure[8].

6.1.2 AP-42: Reciprocating Engines

The AP-42 four-stroke reciprocating engine PM emission factors (Table 6-2) are based on very limited data sets:

- Three four-stroke rich burn engine tests: fPM was measured in tests conducted in 1993 of three engines equipped with pre-combustion chambers (no post-combustion catalysts) using hot filter methods. cPM was not measured in any of these tests;
- Two four-stroke lean burn engine tests: Both fPM and cPM were measured in tests conducted in 1994 of two engines with no emission controls using hot filter/cooled impinger methods.

Although the actual measurements are of total fPM (without any size classification), AP-42 provides emission factors for filterable PM10 and filterable PM2.5 assuming that all particles are smaller than 2.5 micrometers (a reasonable assumption). The wide range of values among the data sets

Table 6-1: Average PM emission factors for natural gas-fired gas turbines.

Engine Type	Emission Controls	Pollutant	Emission Factor	Emission Factor Quality	Number of Units Tested (Test Dates)
U.S. EPA AP-42 emission factors (hot filter/cooled impinger test methods)					
Gas turbine (natural gas-fired)	None (water-steam injection for power augmentation)[28]	PM (filterable)	1.9 E-03 lb/MMBtu (8.17 E-04 kg/GJ)	C	3 (1994-1996)
		PM (condensable)	4.7 E-03 lb/MMBtu (2.03 E-03 kg/GJ)	C	
		PM (total)	6.6 E-03 lb/MMBtu (2.85 E-03 kg/GJ)	C	
CEPEI Emission Factor (dilution test methods)					
Gas turbine simple cycle and combined cycle/cogeneration units	Lean premixed combustors, with and without post-combustion catalysts	PM2.5 (filterable + condensable)	1.01 E-04 kg/GJ	--	5 (2002-2015)

[28] EPA cites water-steam injection as emission controls; however, comments in EPA database suggest this was for turbine power augmentation. This may be co-beneficial in reducing NO_X emissions. Some runs were conducted with power augmentation on and some with power augmentation off.

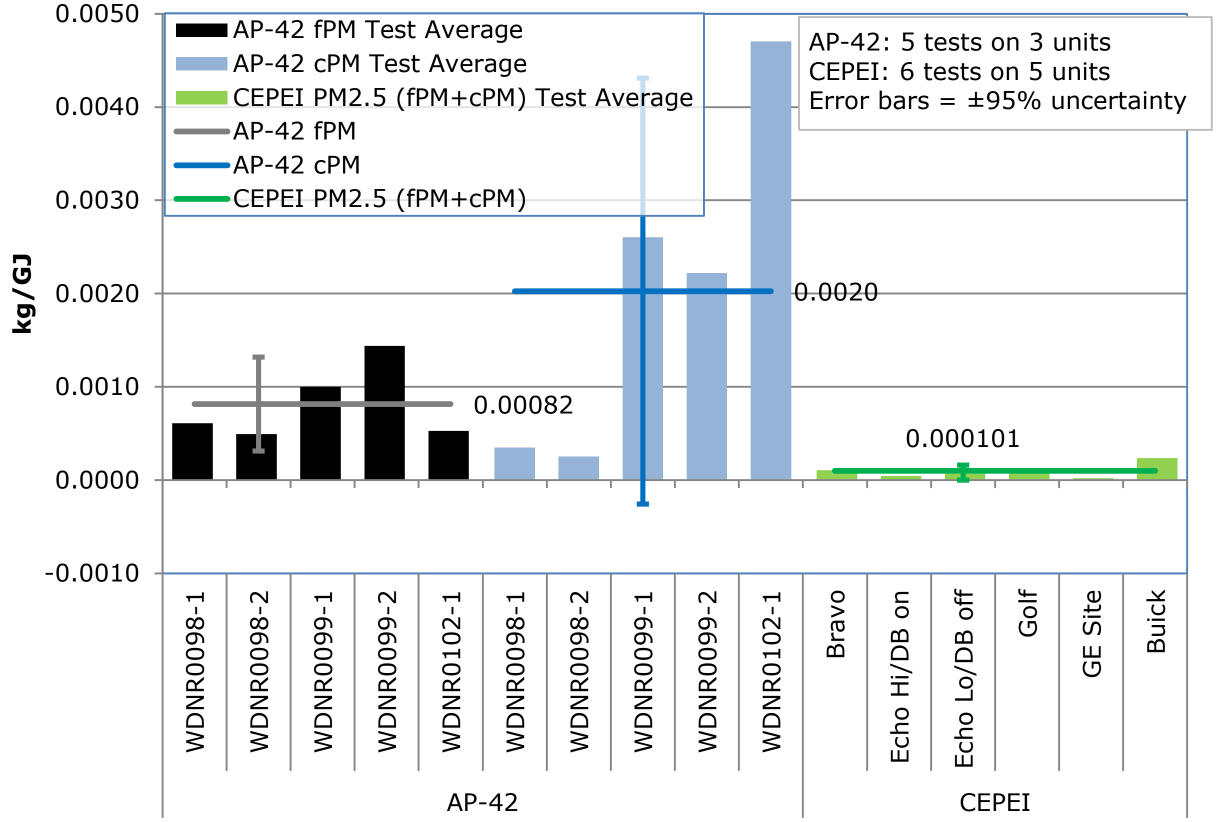


Figure 6-1: Comparison of EPA AP-42 and CEPEI emission factor data sets for filterable and condensable particulate matter – gas-fired gas turbines and combined cycle/cogeneration units.

contributing to large uncertainty in the average values for rich burn engine fPM and lean burn engine cPM is apparent, (Figure 6-2). AP-42 reports the same cPM emission factor for both 4SLB and 4SRB engines, although cPM measurements were made only for the 4SLB engines. The AP-42 lean burn engine fPM emission factor is much lower than the fPM emission factor for rich burn engines. The CEPEI PM2.5 emission factor for all four-stroke reciprocating engines is lower than the average fPM emission factor for rich burn engines and higher than the fPM emission factor for lean burn engines, and much lower than the cPM emission factor for all engines; thus, the CEPEI PM2.5 emission factor is much lower than the combined fPM + cPM AP-42 emission factors for either type of engine.

6.2 PM2.5 Emission Factor Uses and Implications

The emission factors used in this study will be useful for a variety of applications. Regional air quality models are often used to assess emissions management strategies to achieve an air quality goal. Estimated PM10/2.5 emissions from natural gas-fired combustion equipment typically comprise a very minor part of emission inventories in areas with a mix of stationary and mobile sources burning a variety of fuels and other sources of PM2.5 and PM2.5 precursor emissions. For example, PM2.5 from commercial fuel combustion (some of which is natural gas), natural gas use in power generation, natural gas transmission and natural gas distribution is reported to be less than 0.2% of total PM2.5 emissions in Canada[29]. PM2.5 emissions from natural gas combustion in power generation,

[29] Air Pollutant Emission Inventory Report 1990-2014, Environment and Climate Change Canada, Gatineau, Quebec, 2016.

Table 6-2: Average PM emission factors for natural gas-fired four-stroke reciprocating engines.

Engine Type	Emission Controls	Pollutant	Emission Factor	Emission Factor Quality	Number of Units Tested (Test Dates)
U.S. EPA AP-42 emission factors (as published, hot filter/cooled impinger test methods)					
Four-Stroke Rich Burn RICE	Pre-combustion chambers --	PM10 & PM2.5 (filterable)	9.50 E-03 lb/MMBtu (4.08 E-03 kg/GJ)	E	3 (1993)
		PM (condensable)	9.91 E-03 lb/MMBtu (4.26 E-03 kg/GJ)	E	none (cPM factor for 4SLB engines)
		PM 10 & PM2.5 (total)	19.41 E-03 lb/MMBtu (8.35 E-03 kg/GJ)	--	Sum
Four-Stroke Lean Burn RICE	No controls	PM10 & PM2.5 (filterable)	7.71 E-05 lb/MMBtu (3.31 E-05 kg/GJ)	D	2 (1994)
		PM (condensable)	9.91 E-03 lb/MMBtu (4.26 E-03 kg/GJ)	D	
		PM10 & PM2.5 (total)	9.99 E-03 lb/MMBtu (4.30 E-03 kg/GJ)	--	Sum
Four-Stroke RICE*	All	PM10 & PM2.5 (filterable)	2.46 E-03 kg/GJ uncertainty=124%	--	5
		PM (condensable)	4.26 E-03 kg/GJ uncertainty=428%	--	2
		PM10 & PM2.5 (total)	6.73 E-03 kg/GJ uncertainty=446%	--	Sum
CEPEI emission factors (dilution test methods)					
four-stroke rich burn and lean burn engines	Lean burn: no controls Rich burn: non-selective catalytic reduction	PM2.5 (filterable + condensable)	1.50 E-03 kg/GJ	--	3 (2003-2015)

*AP-42 does not report aggregate emission factors for four-stroke engines. Mean values derived from unit average test results used for AP-42 rich burn and lean burn reciprocating engine emission factors.

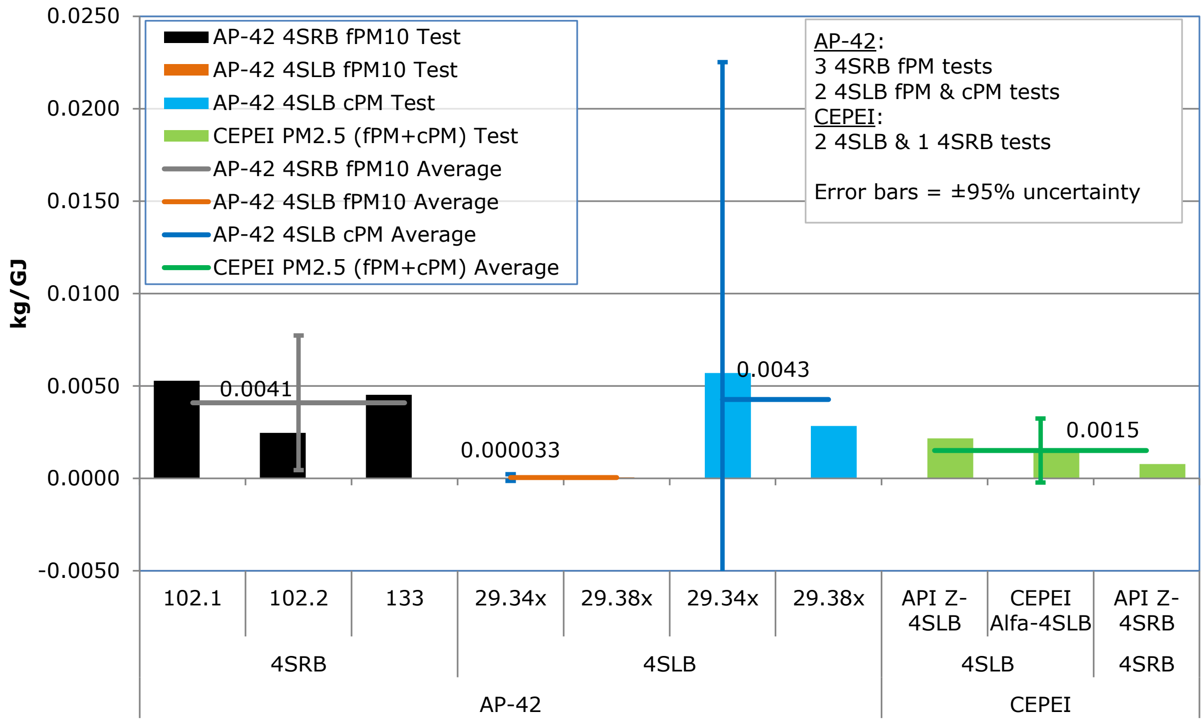


Figure 6-2: Comparison of EPA AP-42 and CEPEI PM2.5 emission factor data sets for filterable and condensable particulate matter– four-stroke reciprocating engines.

commercial, institutional and industrial boilers, internal combustion engines and residential sources comprise approximately 1% of PM2.5 emissions from all sources across the U.S. according to U.S. EPA's 2011 National Emissions Inventory[30]. Nonetheless, estimated PM2.5 emissions impacts from specific sources can generate apparent air quality impacts and human health risk concerns when using AP-42 and similar emission factors. Estimated PM2.5 emissions using the CEPEI emission factors will likely reduce the projected air quality impact of natural gas-fired engines, boilers and process heaters even further and perhaps to "de minimus" levels compared with other sources that have higher air quality impact. With application of appropriate caution considering the uncertainty and variability of the data and the small size of the data sets, the results may be used to evaluate the impact of potential PM2.5 emission limits on air quality. An average emission factor should not be used as an emission limit for a specific unit since emissions from some units are above the average and some are below. Other statistics such as the maximum, 95% confidence upper bound or 99% confidence upper prediction limit may be more appropriate metrics to consider as potential emissions limits.

As an example, using the AP-42 total particulate matter emission factor of 0.0032 kg/GJ, estimated annual PM10/2.5 emissions total 80 metric tons per year for a typical 500-MW natural gas-fired combined cycle plant with two large heavy duty gas turbines and one steam turbine operating at full load for 8760 hours. This would decrease to just 2 metric tons per year using the average CEPEI PM2.5 emission factor.

A lower estimate of PM2.5 emissions and updated PM2.5 chemical species profiles also have implications for evaluating human health risk impacts surrounding new or existing natural gas-fired

[30] 2011 National Emission Inventory Data, U.S. Environmental Protection Agency, 2016. https://www.epa.gov/air-emissions-inventories/2011-national-emissions-inventory-nei-data.

combustion equipment. For example, estimated PM2.5 emissions from a 20 MW gas turbine pipeline compressor drive operating 8760 hours per year at full load are 0.5 metric tons/year using the AP-42 emission factor and 0.02 metric tons per year using the CEPEI 99% UPL PM2.5 emission factor, a 28-fold decrease. Health risk associated with particulate matter is often based on diesel engine studies. CEPEI PM2.5 species profiles show that PM2.5 emissions from natural gas-fired engines at these very low levels is primarily organic carbon with very low levels of elemental carbon and only very minor amounts of sulfate, nitrate and other ions and elements. The chemical species profiles along with lower PM2.5 emission factors provide useful information for estimating the health risk associated from natural gas PM2.5 emissions.

It should be noted that PM2.5 measurements made during short operating periods represent a snapshot of emissions and may not represent emissions at all times. The emission factors derived in this study may not represent emissions from all similar units due to differences in unit design, fuels, operating conditions, emission controls, seasonal influences, and many other factors that influence emissions. Emission factors do not necessarily represent emissions from any particular unit. An average emission factor should not be used to establish emissions limits or standards because the emissions from half of the units will be higher than the average and half will be lower (assuming a normal distribution). The particular statistic (mean, median, maximum, etc.) associated with each emission factor data set should be carefully chosen as appropriate for a specific end use.

APPENDIX A
CEPEI PM2.5 EMISSION TEST SUMMARY

	A	B	C	D E F	G	H I J	K	L M N	O	P Q R	S
1	**Modified CTM 39, Site Alfa**				Run 1		Run 2		Run 3		Average
2	Parameter	Type	Units		Value		Value		Value		Value
3	k1	Calibration			0.8517		0.8517		0.8517		0.8517
4	n1	Calibration			0.5		0.5		0.5		0.5
5	k2	Calibration			10.545		10.545		10.545		10.545
6	n2	Calibration			0.5		0.5		0.5		0.5
7	Cdmfm1	Calibration			1.018		1.018		1.018		1.018
8	Csmfm1	Calibration			1.01		1.01		1.01		1.01
9	Csmfm2	Calibration			1.012		1.012		1.012		1.012
10	T1m	Measured	F		308.26		302.18		319.26		309.90
11	T1	Calculated	R		768.26		762.18		779.26		769.90
12	T2m	Measured	F		69.61		76.61		66.01		70.74
13	T2	Calculated	R		529.61		536.61		526.01		530.74
14	Stack T	Measured	F		749		751		751		750
15	Filter T	Measured	F		77.75		73.72		85.29		78.92
16	T3m	Measured	F		54.18		54.88		**56.47**		**55.17**
17	T3	Calculated	R		514.18		514.88		516.47		515.17
18	Pbar	Measured	in. Hg		27.83		27.83		27.69		27.78
19	Ps	Measured	iwc		1.690		1.637		1.689		1.672
20	Pst	Calculated	in. Hg		27.96		27.95		27.81		27.90
21	Cyclone dP	Measured	iwc		-5.59		-3.16		-5.74		-4.83
22	P1	Calculated	in. Hg		27.54		27.71		27.39		27.55
23	Sample venturi dP	Measured	iwc		0.538		0.539		0.537		0.538
24	Dil venturi dP	Measured	iwc		0.76		1.05		0.70		0.84
25	P2	Calculated	in. Hg		27.59		27.77		27.43		27.59
26	Exhaust Vac	Measured	iwc		29.78		30.07		27.97		29.27
27	P3	Calculated	in. Hg		25.64		25.61		25.63		25.63
28	%O2	Measured	%vd		11.31		11.22		11.09		11.21
29	%CO2	Measured	%vd		5.53		5.74		5.56		5.61
30	Ms	Calculated	lb/lb-mole		29.34		29.37		29.33		29.35
31	Mws	Calculated	lb/lb-mole		28.66		28.69		28.65		28.67
32	Mwdil	Calculated	lb/lb-mole		28.92		28.92		28.91		28.91
33	Q1	Calculated	wacf/min		0.616		0.612		0.622		0.617
34	Q2	Calculated	wacf/min		7.49		8.83		7.18		7.84
35	RHdil	Measured	%		18.88		14.10		23.25		18.74
36	RH mix	Measured	%		47.55		42.40		47.80		45.92
37	**Bwdil**	**Calculated**	**v/v**		**0.00500**		**0.00469**		**0.00546**		**0.00505**
38	**Bwds**	**Calculated**	**v/v**		**0.00785**		**0.00719**		**0.00858**		**0.00787**
39	Qmix,std	Calculated	wacf/min		7.28		8.46		7.00		7.58
40	**Bws**	**Calculated**	**v/v**		**0.0595**		**0.0594**		**0.0602**		**0.0597**
42	**PM2.5 Concentration**										
43	Run duration	Measured	minutes		238.89		239.40		239.40		239.23
44	mf47ds	Measured	mg	ADL	0.700	ADL	0.604	ADL	0.746	ADL	0.683
45	mf47dab	Measured	mg	ADL	0.008	ADL	0.011	ADL	0.013	ADL	0.011
46	mf47ds-stfb1	Measured	mg	ADL	0.004	ADL	0.004	ADL	0.004	ADL	0.004
47	mf47dab-stfb1	Measured	mg	ADL	0.022	ADL	0.022	ADL	0.022	ADL	0.022
48	mf47ds-stfb2	Measured	mg	ADL	0.003	ADL	0.003	ADL	0.003	ADL	0.003
49	mf47dab-stfb2	Measured	mg	ADL	0.008	ADL	0.008	ADL	0.008	ADL	0.008
50	qf47ds,tq	Calculated	wacm/min		0.03707		0.03666		0.03706		0.03693
51	Vf47ds,tq(std)	Calculated	dscm		8.79		8.71		8.80		8.77
52	qf47ds,q	Calculated	wacm/min		0.03715		0.03702		0.03705		0.03707
53	Vf47ds,q(std)	Calculated	dscm		8.80		8.80		8.79		8.80
54	qf47dab	Calculated	wacm/min		0.03738		0.03727		0.03732		0.03732
55	Vf47dab(std)	Calculated	dscm		8.89		8.88		8.89		8.88
57	Vdv(std)	Calculated	dscm		45.84		54.10		44.11		48.02
58	Vd(std)	Calculated	dscm		36.95		45.22		35.23		39.13
59	Vs(std)	Calculated	dscm		2.51		2.51		2.45		2.49
60	Vds(std)	Calculated	dscm		39.46		47.73		37.68		41.62
61	DR	Calculated	v/v		15.74		19.05		15.36		16.72
62	**Cpm2.5**	**Calculated**	**mg/dscm**	ADL	**1.24**	ADL	**1.30**	ADL	**1.28**	ADL	**1.273**
64											

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Alfa**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
65	**PM2.5 Emission Factor**																		
66	Fd	Input	dscf/MMBtu				8618.8				8618.8				8618.8				8618.8
67	**Epm2.5**	**Calculated**	**lb/MMBtu**			ADL	**1.46E-03**			ADL	**1.51E-03**			ADL	**1.47E-03**				**1.48E-03**
68	**Epm2.5**	**Calculated**	**kg/GJ**			ADL	6.26E-04			ADL	6.49E-04			ADL	6.31E-04				6.35E-04
69																			
70	**Stack gas flow rate**																		
71	Qfuel(15C)	Input	lb/hr				9.11E+02				8.97E+02				8.92E+02				9.00E+02
72	HHV(15C)	Input	Btu/lb				2.17E+04				2.17E+04				2.18E+04				2.17E+04
73	Qstk,dry(25C)	Calculated	dscf/hr				3.77E+05				3.68E+05				3.63E+05				3.69E+05
74	Qstk,dry(25C)	Calculated	dscfm				6.28E+03				6.13E+03				6.05E+03				6.16E+03
75	**PM2.5 Mass Flow Rate**																		
76	Mpm2.5	Calculated	lb/hr			ADL	2.92E+01			ADL	2.98E+01			ADL	2.90E+01			ADL	2.94E+01
78																			

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Alfa**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
79	**Species Lab Results - Samples**																		
80	Carbon																		
81	OC	Measured	µg			ADL	6.36E+02			ADL	6.27E+02			ADL	7.07E+02			ADL	6.57E+02
82	EC	Measured	µg			ADL	6.65E+00			ADL	1.30E+01			ADL	1.21E+01			ADL	1.06E+01
83	Total C	Measured	µg			ADL	6.43E+02			ADL	6.40E+02			ADL	7.19E+02			ADL	6.67E+02
84	OC Backup	Measured	µg			ADL	1.22E+02			ADL	1.24E+02			ADL	1.13E+02			ADL	1.19E+02
85	EC Backup	Measured	µg			ADL	3.21E+00			BDL	7.63E-01			ADL	1.43E+00			DLL	1.80E+00
86	Total C Backup	Measured	µg			ADL	1.25E+02			ADL	1.24E+02			ADL	1.14E+02			ADL	1.21E+02
88	Elements																		
89	Ag	Measured	µg			ADL	3.24E-02			BDL	3.34E-02			BDL	3.34E-02			DLL	3.31E-02
90	Al	Measured	µg			BDL	4.61E-01			ADL	6.50E-03			BDL	4.61E-01			DLL	3.09E-01
91	As	Measured	µg			BDL	1.33E-02			BDL	1.33E-02			BDL	1.33E-02			BDL	1.33E-02
92	Au	Measured	µg			BDL	3.66E-02			ADL	2.71E-02			ADL	2.24E-02			DLL	2.87E-02
93	Ba	Measured	µg			BDL	1.21E-01			ADL	5.21E-01			BDL	1.22E-01			DLL	2.55E-01
94	Br	Measured	µg			ADL	3.24E-02			ADL	1.95E-02			ADL	8.90E-03			ADL	2.03E-02
95	Ca	Measured	µg			ADL	4.46E+00			ADL	4.10E+00			ADL	3.44E+00			ADL	4.00E+00
96	Cd	Measured	µg			BDL	6.66E-02			ADL	5.07E-02			BDL	6.66E-02			DLL	6.13E-02
97	Ce	Measured	µg			ADL	1.87E-01			BDL	4.66E-01			BDL	4.69E-01			DLL	3.74E-01
98	Cl	Measured	µg			ADL	3.23E-01			ADL	6.51E-01			ADL	3.95E-02			ADL	3.38E-01
99	Co	Measured	µg			BDL	3.40E-03			BDL	3.40E-03			BDL	3.40E-03			BDL	3.40E-03
100	Cr	Measured	µg			ADL	4.84E-02			BDL	1.33E-02			ADL	6.00E-03			DLL	2.26E-02
101	Cs	Measured	µg			ADL	4.24E-02			ADL	1.65E-01			BDL	1.69E-01			DLL	1.25E-01
102	Cu	Measured	µg			ADL	4.80E-03			BDL	1.16E-02			BDL	1.16E-02			DLL	9.33E-03
103	Eu	Measured	µg			BDL	9.80E-01			ADL	8.72E-01			BDL	9.88E-01			DLL	9.47E-01
104	Fe	Measured	µg			ADL	2.57E-01			ADL	7.42E-02			ADL	1.04E-01			ADL	1.45E-01
105	Ga	Measured	µg			BDL	1.16E-02			BDL	1.16E-02			BDL	1.16E-02			BDL	1.16E-02
106	Hf	Measured	µg			BDL	1.67E-01			BDL	1.67E-01			BDL	1.67E-01			BDL	1.67E-01
107	Hg	Measured	µg			BDL	2.50E-02			BDL	2.50E-02			BDL	2.50E-02			BDL	2.50E-02
108	In	Measured	µg			BDL	3.17E-02			BDL	3.17E-02			BDL	3.17E-02			BDL	3.17E-02
109	Ir	Measured	µg			BDL	3.66E-02			BDL	3.66E-02			BDL	3.66E-02			BDL	3.66E-02
110	K	Measured	µg			ADL	1.59E-01			ADL	8.13E-02			ADL	3.30E-02			ADL	9.11E-02
111	La	Measured	µg			ADL	3.54E-02			ADL	1.45E-01			BDL	1.99E-01			DLL	1.27E-01
112	Mg	Measured	µg			BDL	1.86E+00			BDL	1.85E+00			BDL	1.85E+00			BDL	1.85E+00
113	Mn	Measured	µg			BDL	3.34E-02			BDL	3.34E-02			ADL	5.90E-03			DLL	2.42E-02
114	Mo	Measured	µg			BDL	1.84E-02			BDL	1.84E-02			BDL	1.84E-02			BDL	1.84E-02
115	Na	Measured	µg			BDL	7.79E+00			BDL	7.60E+00			BDL	7.94E+00			BDL	7.78E+00
116	Nb	Measured	µg			BDL	1.00E-02			BDL	1.00E-02			BDL	1.00E-02			BDL	1.00E-02
117	Ni	Measured	µg			ADL	1.42E-02			BDL	6.60E-03			BDL	6.60E-03			DLL	9.13E-03
118	Pb	Measured	µg			ADL	1.77E-02			ADL	4.13E-02			ADL	2.12E-02			ADL	2.67E-02
119	Pd	Measured	µg			BDL	6.00E-02			BDL	6.00E-02			BDL	6.00E-02			BDL	6.00E-02
120	P	Measured	µg			ADL	2.56E-01			ADL	3.23E-01			ADL	4.95E-01			ADL	3.58E-01
121	Rb	Measured	µg			BDL	3.40E-03			ADL	5.90E-03			ADL	1.20E-03			DLL	3.50E-03
122	S	Measured	µg			ADL	6.08E+00			ADL	2.92E+00			ADL	2.76E+00			ADL	3.92E+00
123	Sb	Measured	µg			BDL	8.33E-02			ADL	3.71E-02			ADL	3.13E-02			DLL	5.06E-02
124	Sc	Measured	µg			BDL	3.57E-01			BDL	3.58E-01			BDL	3.57E-01			BDL	3.57E-01
125	Se	Measured	µg			BDL	1.50E-02			BDL	1.50E-02			BDL	1.50E-02			BDL	1.50E-02
126	Si	Measured	µg			ADL	4.61E-01			ADL	1.96E-01			ADL	9.75E-01			ADL	5.44E-01
127	Sm	Measured	µg			ADL	2.44E-01			BDL	6.61E-01			BDL	6.60E-01			DLL	5.21E-01
128	Sn	Measured	µg			ADL	4.95E-02			ADL	1.30E-03			BDL	6.00E-02			DLL	3.69E-02
129	Sr	Measured	µg			ADL	2.00E-02			ADL	1.88E-02			ADL	2.00E-02			ADL	1.96E-02
130	Ta	Measured	µg			BDL	1.67E-01			BDL	1.67E-01			BDL	1.67E-01			BDL	1.67E-01
131	Tb	Measured	µg			BDL	4.76E-01			BDL	4.83E-01			BDL	4.79E-01			BDL	4.79E-01
132	Ti	Measured	µg			ADL	1.18E-01			ADL	1.21E-01			ADL	4.54E-02			ADL	9.49E-02
133	Tl	Measured	µg			ADL	1.01E-02			ADL	1.01E-02			ADL	5.40E-03			ADL	8.53E-03
134	U	Measured	µg			BDL	3.49E-02			ADL	2.13E-02			ADL	1.00E-04			DLL	1.88E-02
135	V	Measured	µg			BDL	3.40E-03			BDL	3.40E-03			BDL	3.40E-03			BDL	3.40E-03
136	W	Measured	µg			ADL	1.21E-01			ADL	9.31E-02			ADL	2.13E-02			ADL	7.86E-02
137	Y	Measured	µg			ADL	2.13E-02			ADL	2.40E-03			BDL	1.16E-02			DLL	1.18E-02
138	Zn	Measured	µg			ADL	7.33E-01			ADL	6.75E-01			ADL	5.12E-01			ADL	6.40E-01
139	Zr	Measured	µg			BDL	1.50E-02			BDL	1.50E-02			BDL	1.50E-02			BDL	1.50E-02
140																			

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Alfa**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
141	Ions																		
142	NH4+	Measured	µg			BDL	1.67E-02			BDL	1.67E-02			BDL	1.67E-02			BDL	1.67E-02
143	Cl-	Measured	µg			BDL	1.67E-02			BDL	1.67E-02			BDL	1.67E-02			BDL	1.67E-02
144	NO3-	Measured	µg			ADL	2.05E+00			ADL	2.78E+00			ADL	1.26E+00			ADL	2.03E+00
145	K+	Measured	µg			BDL	5.01E-01			BDL	5.01E-01			BDL	5.01E-01			BDL	5.01E-01
146	Na+	Measured	µg			ADL	3.42E-01			ADL	6.19E-02			BDL	1.67E-02			DLL	1.40E-01
147	SO42-	Measured	µg			ADL	3.99E+00			ADL	3.93E+00			ADL	3.56E+00			ADL	3.82E+00

	A	B	C	D E F	G	H I J	K	L M N	O	P Q R	S
1	**Modified CTM 39, Site Alfa**				Run 1		Run 2		Run 3		Average
2	Parameter	Type	Units		Value		Value		Value		Value
149	**Species Lab Results - Run Dilution Air**										
150	Carbon										
151	OC	Measured	μg								
152	EC	Measured	μg								
153	Total C	Measured	μg								
154	OC Backup	Measured	μg	ADL	2.42E+01	ADL	1.91E+01	ADL	1.28E+01	ADL	1.87E+01
155	EC Backup	Measured	μg	ADL	3.21E+00	BDL	7.63E-01	ADL	1.43E+00	DLL	1.80E+00
156	Total C Backup	Measured	μg	ADL	1.25E+02	ADL	1.24E+02	ADL	1.14E+02	ADL	1.21E+02
157											
158	Elements										
159	Ag	Measured	μg	BDL	3.34E-02	BDL	3.34E-02	BDL	3.34E-02	BDL	3.34E-02
160	Al	Measured	μg	ADL	2.81E-01	BDL	4.62E-01	BDL	4.62E-01	DLL	4.02E-01
161	As	Measured	μg	BDL	1.33E-02	BDL	1.33E-02	BDL	1.33E-02	BDL	1.33E-02
162	Au	Measured	μg	BDL	3.66E-02	BDL	3.66E-02	ADL	5.90E-03	DLL	2.64E-02
163	Ba	Measured	μg	BDL	1.18E-01	BDL	1.18E-01	BDL	1.19E-01	BDL	1.18E-01
164	Br	Measured	μg	ADL	1.80E-03	BDL	1.16E-02	ADL	2.18E-02	DLL	1.17E-02
165	Ca	Measured	μg	BDL	1.33E-02	BDL	1.25E-02	BDL	1.33E-02	BDL	1.30E-02
166	Cd	Measured	μg	BDL	6.66E-02	BDL	6.66E-02	BDL	6.66E-02	BDL	6.66E-02
167	Ce	Measured	μg	ADL	2.10E-01	ADL	2.50E-01	BDL	4.66E-01	DLL	3.09E-01
168	Cl	Measured	μg	ADL	2.54E-02	ADL	1.24E-02	ADL	1.36E-02	ADL	1.71E-02
169	Co	Measured	μg	BDL	3.40E-03	BDL	3.40E-03	BDL	3.40E-03	BDL	3.40E-03
170	Cr	Measured	μg	ADL	8.30E-03	ADL	9.50E-03	ADL	2.13E-02	ADL	1.30E-02
171	Cs	Measured	μg	BDL	1.68E-01	ADL	4.59E-02	ADL	1.07E-01	DLL	1.07E-01
172	Cu	Measured	μg	ADL	1.54E-02	BDL	1.16E-02	BDL	1.16E-02	DLL	1.29E-02
173	Eu	Measured	μg	ADL	4.89E-01	ADL	2.23E-01	BDL	9.79E-01	DLL	5.63E-01
174	Fe	Measured	μg	ADL	1.20E-03	ADL	7.77E-02	BDL	5.50E-02	DLL	4.46E-02
175	Ga	Measured	μg	BDL	1.16E-02	BDL	1.16E-02	BDL	1.16E-02	BDL	1.16E-02
176	Hf	Measured	μg	BDL	1.67E-01	BDL	1.67E-01	BDL	1.67E-01	BDL	1.67E-01
177	Hg	Measured	μg	ADL	1.00E-04	BDL	2.58E-02	BDL	2.50E-02	DLL	1.70E-02
178	In	Measured	μg	BDL	3.17E-02	ADL	4.20E-03	BDL	3.17E-02	DLL	2.25E-02
179	Ir	Measured	μg	BDL	3.66E-02	BDL	3.66E-02	BDL	3.66E-02	BDL	3.66E-02
180	K	Measured	μg	ADL	2.71E-02	BDL	2.16E-02	ADL	7.10E-03	DLL	1.86E-02
181	La	Measured	μg	ADL	3.66E-02	ADL	3.60E-03	BDL	1.97E-01	DLL	7.92E-02
182	Mg	Measured	μg	ADL	1.69E-01	BDL	1.86E+00	BDL	1.86E+00	DLL	1.30E+00
183	Mn	Measured	μg	BDL	3.34E-02	BDL	3.34E-02	BDL	3.34E-02	BDL	3.34E-02
184	Mo	Measured	μg	BDL	1.84E-02	BDL	1.84E-02	BDL	1.84E-02	BDL	1.84E-02
185	Na	Measured	μg	BDL	7.47E+00	BDL	7.60E+00	BDL	7.56E+00	BDL	7.55E+00
186	Nb	Measured	μg	ADL	4.80E-03	BDL	1.00E-02	ADL	2.40E-03	DLL	5.73E-03
187	Ni	Measured	μg	BDL	6.60E-03	BDL	6.60E-03	BDL	6.60E-03	BDL	6.60E-03
188	Pb	Measured	μg	ADL	1.53E-02	BDL	1.99E-02	ADL	4.71E-02	DLL	2.74E-02
189	Pd	Measured	μg	BDL	6.00E-02	BDL	6.00E-02	BDL	6.00E-02	BDL	6.00E-02
190	P	Measured	μg	ADL	1.24E-02	ADL	4.65E-02	BDL	2.66E-02	DLL	2.85E-02
191	Rb	Measured	μg	ADL	3.60E-03	ADL	9.50E-03	ADL	8.30E-03	ADL	7.13E-03
192	S	Measured	μg	BDL	1.67E-02	BDL	1.67E-02	BDL	1.67E-02	BDL	1.67E-02
193	Sb	Measured	μg	ADL	1.12E-02	ADL	1.59E-02	ADL	2.54E-02	ADL	1.75E-02
194	Sc	Measured	μg	ADL	9.50E-03	BDL	3.57E-01	ADL	7.55E-02	DLL	1.47E-01
195	Se	Measured	μg	BDL	1.50E-02	ADL	6.50E-03	BDL	1.50E-02	DLL	1.22E-02
196	Si	Measured	μg	ADL	2.49E-01	ADL	3.24E-02	ADL	1.86E-01	ADL	1.56E-01
197	Sm	Measured	μg	ADL	1.64E-01	BDL	6.59E-01	BDL	6.59E-01	DLL	4.94E-01
198	Sn	Measured	μg	BDL	6.00E-02	BDL	6.00E-02	ADL	5.43E-02	DLL	5.81E-02
199	Sr	Measured	μg	BDL	1.16E-02	BDL	1.16E-02	ADL	3.50E-03	DLL	8.90E-03
200	Ta	Measured	μg	BDL	1.67E-01	BDL	1.67E-01	BDL	1.67E-01	BDL	1.67E-01
201	Tb	Measured	μg	BDL	4.75E-01	ADL	3.20E-01	BDL	4.80E-01	DLL	4.25E-01
202	Ti	Measured	μg	ADL	4.20E-03	BDL	8.30E-03	BDL	8.30E-03	DLL	6.93E-03
203	Tl	Measured	μg	BDL	1.33E-02	BDL	1.33E-02	ADL	7.70E-03	DLL	1.14E-02
204	U	Measured	μg	BDL	3.49E-02	BDL	3.49E-02	BDL	3.49E-02	BDL	3.49E-02
205	V	Measured	μg	ADL	2.40E-03	BDL	3.40E-03	BDL	3.40E-03	DLL	3.07E-03
206	W	Measured	μg	ADL	1.66E-02	BDL	1.67E-01	ADL	5.42E-02	DLL	7.91E-02
207	Y	Measured	μg	BDL	1.16E-02	ADL	4.80E-03	ADL	2.36E-02	DLL	1.33E-02
208	Zn	Measured	μg	ADL	1.06E-02	ADL	8.20E-03	ADL	8.20E-03	ADL	9.00E-03
209	Zr	Measured	μg	ADL	2.77E-02	BDL	1.50E-02	ADL	6.50E-03	DLL	1.64E-02

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Alfa**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
211	Ions																		
212	NH4+	Measured	μg																
213	Cl-	Measured	μg																
214	NO3-	Measured	μg																
215	K+	Measured	μg																
216	Na+	Measured	μg																
217	SO42-	Measured	μg																
219																			

	A	B	C	F	G	J	K	O	R	S
1	**Modified CTM 39, Site Alfa**				Run 1		Run 2	Run 3		Average
2	Parameter	Type	Units		Value		Value	Value		Value
220	**Species Lab Results - STFB Samples**									
221	Carbon									
222	OC	Measured	µg	ADL	2.50E+00	ADL	3.63E+00		DLL	3.07E+00
223	EC	Measured	µg	BDL	7.63E-01	BDL	7.63E-01		DLL	7.63E-01
224	Total C	Measured	µg	ADL	2.50E+00	ADL	3.63E+00		DLL	3.07E+00
225	OC Backup	Measured	µg	ADL	4.03E+00	ADL	1.49E+01		DLL	9.47E+00
226	EC Backup	Measured	µg	BDL	7.63E-01	ADL	2.70E-01		DLL	5.17E-01
227	Total C Backup	Measured	µg	ADL	4.03E+00	ADL	1.52E+01		DLL	9.61E+00
228										
229	Elements									
230	Ag	Measured	µg	BDL	3.34E-02	BDL	3.34E-02		DLL	3.34E-02
231	Al	Measured	µg	ADL	2.17E-01	BDL	4.62E-01		DLL	3.40E-01
232	As	Measured	µg	BDL	1.33E-02	BDL	1.33E-02		DLL	1.33E-02
233	Au	Measured	µg	BDL	3.66E-02	ADL	2.00E-02		DLL	2.83E-02
234	Ba	Measured	µg	ADL	6.54E-02	BDL	1.19E-01		DLL	9.23E-02
235	Br	Measured	µg	ADL	6.50E-03	BDL	1.16E-02		DLL	9.05E-03
236	Ca	Measured	µg	BDL	1.33E-02	BDL	1.33E-02		DLL	1.33E-02
237	Cd	Measured	µg	BDL	6.66E-02	ADL	5.90E-03		DLL	3.63E-02
238	Ce	Measured	µg	BDL	4.67E-01	ADL	4.01E-01		DLL	4.34E-01
239	Cl	Measured	µg	ADL	8.90E-03	ADL	1.48E-02		DLL	1.19E-02
240	Co	Measured	µg	BDL	3.40E-03	BDL	3.40E-03		DLL	3.40E-03
241	Cr	Measured	µg	ADL	2.84E-02	BDL	1.33E-02		DLL	2.09E-02
242	Cs	Measured	µg	ADL	9.42E-02	ADL	9.89E-02		DLL	9.66E-02
243	Cu	Measured	µg	BDL	1.16E-02	BDL	1.16E-02		DLL	1.16E-02
244	Eu	Measured	µg	BDL	9.82E-01	BDL	9.83E-01		DLL	9.82E-01
245	Fe	Measured	µg	ADL	2.83E-02	ADL	1.30E-02		DLL	2.07E-02
246	Ga	Measured	µg	BDL	1.16E-02	BDL	1.16E-02		DLL	1.16E-02
247	Hf	Measured	µg	BDL	1.67E-01	BDL	1.67E-01		DLL	1.67E-01
248	Hg	Measured	µg	BDL	2.50E-02	BDL	2.50E-02		DLL	2.50E-02
249	In	Measured	µg	BDL	3.17E-02	BDL	3.17E-02		DLL	3.17E-02
250	Ir	Measured	µg	BDL	3.66E-02	BDL	3.66E-02		DLL	3.66E-02
251	K	Measured	µg	BDL	2.16E-02	BDL	2.16E-02		DLL	2.16E-02
252	La	Measured	µg	ADL	7.66E-02	ADL	1.94E-01		DLL	1.36E-01
253	Mg	Measured	µg	BDL	1.85E+00	BDL	1.85E+00		DLL	1.85E+00
254	Mn	Measured	µg	ADL	3.60E-03	BDL	3.34E-02		DLL	1.85E-02
255	Mo	Measured	µg	BDL	1.84E-02	ADL	6.00E-04		DLL	9.50E-03
256	Na	Measured	µg	BDL	7.70E+00	BDL	7.70E+00		DLL	7.70E+00
257	Nb	Measured	µg	ADL	3.60E-03	BDL	1.00E-02		DLL	6.80E-03
258	Ni	Measured	µg	ADL	1.20E-03	BDL	6.60E-03		DLL	3.90E-03
259	Pb	Measured	µg	ADL	2.36E-02	BDL	1.99E-02		DLL	2.18E-02
260	Pd	Measured	µg	BDL	6.00E-02	ADL	5.54E-02		DLL	5.77E-02
261	P	Measured	µg	BDL	2.66E-02	ADL	5.01E-02		DLL	3.84E-02
262	Rb	Measured	µg	ADL	9.50E-03	ADL	8.30E-03		DLL	8.90E-03
263	S	Measured	µg	BDL	1.67E-02	BDL	1.67E-02		DLL	1.67E-02
264	Sb	Measured	µg	ADL	3.01E-02	ADL	3.01E-02		DLL	3.01E-02
265	Sc	Measured	µg	ADL	8.49E-02	BDL	3.57E-01		DLL	2.21E-01
266	Se	Measured	µg	BDL	1.50E-02	ADL	1.36E-02		DLL	1.43E-02
267	Si	Measured	µg	ADL	1.35E-01	ADL	1.43E-01		DLL	1.39E-01
268	Sm	Measured	µg	ADL	4.84E-01	BDL	6.61E-01		DLL	5.72E-01
269	Sn	Measured	µg	BDL	6.00E-02	ADL	1.30E-02		DLL	3.65E-02
270	Sr	Measured	µg	BDL	1.16E-02	BDL	1.16E-02		DLL	1.16E-02
271	Ta	Measured	µg	BDL	1.67E-01	BDL	1.67E-01		DLL	1.67E-01
272	Tb	Measured	µg	BDL	4.76E-01	BDL	4.74E-01		DLL	4.75E-01
273	Ti	Measured	µg	ADL	1.01E-02	BDL	8.30E-03		DLL	9.20E-03
274	Tl	Measured	µg	ADL	6.50E-03	BDL	1.33E-02		DLL	9.90E-03
275	U	Measured	µg	BDL	3.49E-02	BDL	3.49E-02		DLL	3.49E-02
276	V	Measured	µg	BDL	3.40E-03	ADL	5.90E-03		DLL	4.65E-03
277	W	Measured	µg	ADL	8.30E-03	BDL	1.67E-01		DLL	8.75E-02
278	Y	Measured	µg	ADL	7.10E-03	ADL	1.00E-04		DLL	3.60E-03
279	Zn	Measured	µg	BDL	1.99E-02	ADL	8.20E-03		DLL	1.41E-02
280	Zr	Measured	µg	ADL	1.83E-02	ADL	1.80E-03		DLL	1.01E-02

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Alfa**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
282	Ions																		
283	NH4+	Measured	µg			BDL	1.67E-02			BDL	1.67E-02							DLL	1.67E-02
284	Cl-	Measured	µg			BDL	1.67E-02			BDL	1.67E-02							DLL	1.67E-02
285	NO3-	Measured	µg			ADL	1.95E-01			ADL	7.57E-02							DLL	1.35E-01
286	K+	Measured	µg			BDL	5.01E-01			BDL	5.01E-01							DLL	5.01E-01
287	Na+	Measured	µg			BDL	5.82E-01			BDL	1.67E-02							DLL	2.99E-01
288	SO42-	Measured	µg			BDL	1.67E-02			BDL	1.67E-02							DLL	1.67E-02
289																			

	A	B	C	F	G	J	K	N	O	R	S
1	**Modified CTM 39, Site Alfa**				Run 1		Run 2		Run 3		Average
2	Parameter	Type	Units		Value		Value		Value		Value
291	**Species Lab Results - STFB Dilution Air**										
292	Carbon										
293	OC	Measured	µg								
294	EC	Measured	µg								
295	Total C	Measured	µg								
296	OC Backup	Measured	µg	ADL	7.14E+00	ADL	4.58E+00			DLL	5.86E+00
297	EC Backup	Measured	µg	BDL	7.63E-01	BDL	7.63E-01			DLL	7.63E-01
298	Total C Backup	Measured	µg	ADL	7.14E+00	ADL	4.58E+00			DLL	5.86E+00
300	Elements										
301	Ag	Measured	µg	BDL	3.34E-02	BDL	3.34E-02			DLL	3.34E-02
302	Al	Measured	µg	BDL	4.63E-01	BDL	4.61E-01			DLL	4.62E-01
303	As	Measured	µg	BDL	1.33E-02	BDL	1.33E-02			DLL	1.33E-02
304	Au	Measured	µg	BDL	3.66E-02	ADL	4.70E-03			DLL	2.07E-02
305	Ba	Measured	µg	BDL	1.18E-01	BDL	1.18E-01			DLL	1.18E-01
306	Br	Measured	µg	ADL	1.12E-02	ADL	5.30E-03			DLL	8.25E-03
307	Ca	Measured	µg	BDL	1.33E-02	BDL	1.25E-02			DLL	1.29E-02
308	Cd	Measured	µg	BDL	6.66E-02	BDL	6.66E-02			DLL	6.66E-02
309	Ce	Measured	µg	ADL	1.87E-01	ADL	3.55E-01			DLL	2.71E-01
310	Cl	Measured	µg	BDL	1.16E-02	BDL	1.16E-02			DLL	1.16E-02
311	Co	Measured	µg	BDL	3.40E-03	BDL	3.40E-03			DLL	3.40E-03
312	Cr	Measured	µg	ADL	3.60E-03	ADL	2.40E-03			DLL	3.00E-03
313	Cs	Measured	µg	ADL	1.45E-01	ADL	8.72E-02			DLL	1.16E-01
314	Cu	Measured	µg	ADL	2.40E-03	ADL	1.54E-02			DLL	8.90E-03
315	Eu	Measured	µg	BDL	9.81E-01	ADL	7.50E-01			DLL	8.66E-01
316	Fe	Measured	µg	BDL	5.50E-02	BDL	5.50E-02			DLL	5.50E-02
317	Ga	Measured	µg	BDL	1.16E-02	BDL	1.16E-02			DLL	1.16E-02
318	Hf	Measured	µg	BDL	1.67E-01	BDL	1.67E-01			DLL	1.67E-01
319	Hg	Measured	µg	BDL	2.50E-02	BDL	2.50E-02			DLL	2.50E-02
320	In	Measured	µg	BDL	3.17E-02	BDL	3.17E-02			DLL	3.17E-02
321	Ir	Measured	µg	BDL	3.66E-02	BDL	3.66E-02			DLL	3.66E-02
322	K	Measured	µg	ADL	1.41E-02	BDL	2.16E-02			DLL	1.79E-02
323	La	Measured	µg	BDL	1.98E-01	BDL	1.98E-01			DLL	1.98E-01
324	Mg	Measured	µg	BDL	1.86E+00	BDL	1.86E+00			DLL	1.86E+00
325	Mn	Measured	µg	BDL	3.34E-02	ADL	1.07E-02			DLL	2.21E-02
326	Mo	Measured	µg	BDL	1.84E-02	ADL	2.90E-03			DLL	1.07E-02
327	Na	Measured	µg	BDL	7.78E+00	BDL	7.42E+00			DLL	7.60E+00
328	Nb	Measured	µg	ADL	7.10E-03	ADL	4.80E-03			DLL	5.95E-03
329	Ni	Measured	µg	BDL	6.60E-03	BDL	6.60E-03			DLL	6.60E-03
330	Pb	Measured	µg	ADL	1.53E-02	ADL	2.01E-02			DLL	1.77E-02
331	Pd	Measured	µg	BDL	6.00E-02	BDL	6.00E-02			DLL	6.00E-02
332	P	Measured	µg	BDL	2.66E-02	ADL	1.00E-02			DLL	1.83E-02
333	Rb	Measured	µg	BDL	3.40E-03	ADL	3.60E-03			DLL	3.50E-03
334	S	Measured	µg	BDL	1.67E-02	BDL	1.67E-02			DLL	1.67E-02
335	Sb	Measured	µg	ADL	6.89E-02	BDL	8.33E-02			DLL	7.61E-02
336	Sc	Measured	µg	BDL	3.58E-01	BDL	3.57E-01			DLL	3.57E-01
337	Se	Measured	µg	BDL	1.50E-02	BDL	1.50E-02			DLL	1.50E-02
338	Si	Measured	µg	BDL	5.12E-02	ADL	1.02E-01			DLL	7.66E-02
339	Sm	Measured	µg	BDL	6.59E-01	ADL	4.71E-02			DLL	3.53E-01
340	Sn	Measured	µg	ADL	3.66E-02	BDL	6.00E-02			DLL	4.83E-02
341	Sr	Measured	µg	BDL	1.16E-02	ADL	3.50E-03			DLL	7.55E-03
342	Ta	Measured	µg	BDL	1.67E-01	BDL	1.67E-01			DLL	1.67E-01
343	Tb	Measured	µg	ADL	1.27E-01	BDL	4.82E-01			DLL	3.04E-01
344	Ti	Measured	µg	ADL	2.19E-02	BDL	8.30E-03			DLL	1.51E-02
345	Tl	Measured	µg	BDL	1.33E-02	BDL	1.33E-02			DLL	1.33E-02
346	U	Measured	µg	BDL	3.49E-02	BDL	3.49E-02			DLL	3.49E-02
347	V	Measured	µg	ADL	9.40E-03	ADL	4.70E-03			DLL	7.05E-03
348	W	Measured	µg	ADL	2.36E-02	BDL	1.67E-01			DLL	9.51E-02
349	Y	Measured	µg	ADL	7.10E-03	ADL	1.19E-02			DLL	9.50E-03
350	Zn	Measured	µg	ADL	8.20E-03	ADL	1.88E-02			DLL	1.35E-02
351	Zr	Measured	µg	BDL	1.50E-02	ADL	5.40E-03			DLL	1.02E-02

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Alfa**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
353	Ions																		
354	NH4+	Measured	μg																
355	Cl-	Measured	μg																
356	NO3-	Measured	μg																
357	K+	Measured	μg																
358	Na+	Measured	μg																
359	SO42-	Measured	μg																
361																			

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Alfa**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
362	**Species Concentrations (with dilution air blank subtraction)**																		
365	Carbon																		
366	OC	Calculated	mg/dscm			ADL	1.14E+00			ADL	1.36E+00			ADL	1.23E+00		#	ADL	1.24E+00
367	EC	Calculated	mg/dscm			ADL	1.19E-02			ADL	2.82E-02			ADL	2.11E-02		#	ADL	2.04E-02
368	Total C	Calculated	mg/dscm			ADL	1.15E+00			ADL	1.39E+00			ADL	1.26E+00		#	ADL	1.26E+00
369	OC Backup	Calculated	mg/dscm			ADL	1.77E-01			ADL	2.29E-01			ADL	1.76E-01			ADL	1.94E-01
370	EC Backup	Calculated	mg/dscm		B	ADL	4.13E-04			BDL	1.01E-04	FB	B	ADL	1.87E-04	FB	B	DLL	2.34E-04
371	Total C Backup	Calculated	mg/dscm		B	ADL	1.61E-02		B	ADL	1.64E-02		B	ADL	1.49E-02		B	ADL	1.58E-02
373	Elements																		
374	Ag	Calculated	mg/dscm			BBL	5.54E-05			BDL	5.12E-06			BDL	4.34E-06			DLL	2.16E-05
375	Al	Calculated	mg/dscm			BDL	3.59E-04	FB		BBL	9.38E-04			BDL	5.73E-05	FB	B	DLL	4.52E-04
376	As	Calculated	mg/dscm			BDL	1.76E-06			BDL	2.04E-06			BDL	1.73E-06			BDL	1.84E-06
377	Au	Calculated	mg/dscm			BDL	4.85E-06	FB		BBL	7.44E-05	FB	B	ADL	2.96E-05	FB	B	DLL	3.63E-05
378	Ba	Calculated	mg/dscm			BDL	2.03E-05			ADL	9.00E-04			BDL	2.00E-05	FB		DLL	3.14E-04
379	Br	Calculated	mg/dscm	FB		ADL	5.51E-05	FB		ADL	1.91E-05	FB	B	BBL	3.52E-05	FB	B	DLL	3.64E-05
380	Ca	Calculated	mg/dscm			ADL	7.97E-03			ADL	8.94E-03			ADL	5.98E-03			ADL	7.63E-03
381	Cd	Calculated	mg/dscm			BDL	8.83E-06	FB		BBL	1.35E-04			BDL	8.65E-06	FB		DLL	5.10E-05
382	Ce	Calculated	mg/dscm	FB	B	BBL	3.49E-04			BDL	5.10E-04			BDL	6.48E-05	FB	B	DLL	3.08E-04
383	Cl	Calculated	mg/dscm			ADL	5.37E-04			ADL	1.40E-03	FB	B	ADL	4.70E-05			ADL	6.61E-04
384	Co	Calculated	mg/dscm			BDL	4.51E-07			BDL	5.22E-07			BDL	4.42E-07			BDL	4.71E-07
385	Cr	Calculated	mg/dscm	FB		ADL	7.29E-05			BDL	9.77E-06	FB	B	BBL	3.44E-05	FB	B	DLL	3.90E-05
386	Cs	Calculated	mg/dscm	FB		BBL	2.79E-04	FB	B	ADL	2.67E-04			BDL	1.22E-04	FB	B	DLL	2.23E-04
387	Cu	Calculated	mg/dscm		B	BBL	2.56E-05			BDL	1.78E-06			BDL	1.51E-06		B	DLL	9.61E-06
388	Eu	Calculated	mg/dscm			BDL	9.45E-04		B	ADL	1.45E-03			BDL	1.43E-04		B	DLL	8.47E-04
389	Fe	Calculated	mg/dscm			ADL	4.58E-04	FB	B	BBL	1.58E-04			ADL	9.22E-05		B	DLL	2.36E-04
390	Ga	Calculated	mg/dscm			BDL	1.54E-06			BDL	1.78E-06			BDL	1.51E-06			BDL	1.61E-06
391	Hf	Calculated	mg/dscm			BDL	2.21E-05			BDL	2.56E-05			BDL	2.17E-05			BDL	2.31E-05
392	Hg	Calculated	mg/dscm			BDL	4.46E-05			BDL	5.25E-05			BDL	3.25E-06			BDL	3.34E-05
393	In	Calculated	mg/dscm			BDL	4.20E-06			BDL	6.08E-05			BDL	4.12E-06			BDL	2.30E-05
394	Ir	Calculated	mg/dscm			BDL	4.85E-06			BDL	5.62E-06			BDL	4.76E-06			BDL	5.08E-06
395	K	Calculated	mg/dscm			ADL	2.40E-04			ADL	1.34E-04		B	ADL	4.61E-05		B	ADL	1.40E-04
396	La	Calculated	mg/dscm	FB	B	BBL	6.07E-05	FB		ADL	3.10E-04			BDL	2.86E-05	FB	B	DLL	1.33E-04
397	Mg	Calculated	mg/dscm			BDL	3.05E-03			BDL	2.50E-04			BDL	2.36E-04			BDL	1.18E-03
398	Mn	Calculated	mg/dscm			BDL	4.43E-06			BDL	5.12E-06	FB		BBL	5.40E-05	FB		DLL	2.12E-05
399	Mo	Calculated	mg/dscm			BDL	2.44E-06			BDL	2.82E-06			BDL	2.39E-06			BDL	2.55E-06
400	Na	Calculated	mg/dscm			BDL	1.55E-03			BDL	1.17E-03			BDL	1.64E-03			BDL	1.45E-03
401	Nb	Calculated	mg/dscm			BDL	9.95E-06			BDL	1.53E-06			BDL	1.36E-05			BDL	8.36E-06
402	Ni	Calculated	mg/dscm	FB		ADL	1.45E-05			BDL	1.01E-06			BDL	8.58E-07	FB		DLL	5.45E-06
403	Pb	Calculated	mg/dscm	FB	B	ADL	6.33E-06	FB		ADL	4.98E-05	FB	B	BBL	7.61E-05	FB	B	DLL	4.41E-05
404	Pd	Calculated	mg/dscm			BDL	7.96E-06			BDL	9.21E-06			BDL	7.80E-06			BDL	8.32E-06
405	P	Calculated	mg/dscm			ADL	4.38E-04			ADL	6.13E-04			ADL	8.22E-04			ADL	6.24E-04
406	Rb	Calculated	mg/dscm			BDL	5.97E-06	FB	B	BBL	1.93E-05	FB	B	BBL	1.34E-05	FB	B	DLL	1.29E-05
407	S	Calculated	mg/dscm			ADL	1.09E-02			ADL	6.36E-03			ADL	4.79E-03			ADL	7.34E-03
408	Sb	Calculated	mg/dscm			BDL	1.31E-04	FB	B	ADL	4.88E-05	FB	B	ADL	1.36E-05	FB	B	DLL	6.44E-05
409	Sc	Calculated	mg/dscm			BDL	6.24E-04			BDL	5.67E-05			BDL	5.01E-04			BDL	3.94E-04
410	Se	Calculated	mg/dscm			BDL	1.99E-06			BDL	1.96E-05			BDL	1.95E-06			BDL	7.84E-06
411	Si	Calculated	mg/dscm	FB	B	ADL	4.13E-04	FB		ADL	3.63E-04			ADL	1.40E-03	FB	B	ADL	7.26E-04
412	Sm	Calculated	mg/dscm	FB	B	ADL	1.65E-04			BDL	1.05E-04			BDL	8.70E-05	FB	B	DLL	1.19E-04
413	Sn	Calculated	mg/dscm	FB		BBL	9.95E-05	FB		BBL	1.22E-04			BDL	1.70E-05	FB	B	DLL	7.95E-05
414	Sr	Calculated	mg/dscm			ADL	1.66E-05			ADL	1.75E-05			ADL	2.93E-05		B	ADL	2.11E-05
415	Ta	Calculated	mg/dscm			BDL	2.21E-05			BDL	2.56E-05			BDL	2.17E-05			BDL	2.31E-05
416	Tb	Calculated	mg/dscm			BDL	6.44E-05			BDL	4.06E-04			BDL	6.08E-05			BDL	1.77E-04
417	Ti	Calculated	mg/dscm			ADL	2.05E-04			ADL	2.47E-04	FB		ADL	6.58E-05			ADL	1.73E-04
418	Tl	Calculated	mg/dscm	FB		BBL	2.21E-05	FB		BBL	2.70E-05	FB	B	BBL	1.24E-05	FB	B	BBL	2.05E-05
419	U	Calculated	mg/dscm			BDL	4.63E-06			BBL	7.10E-05			BBL	5.64E-05			DLL	4.40E-05
420	V	Calculated	mg/dscm			BDL	2.11E-06			BDL	5.22E-07			BDL	4.42E-07			BDL	1.02E-06
421	W	Calculated	mg/dscm	FB		ADL	1.90E-04	FB		BBL	3.39E-04	FB	B	BBL	8.76E-05	FB	B	DLL	2.05E-04
422	Y	Calculated	mg/dscm			ADL	1.89E-05	FB	B	BBL	9.76E-06			BDL	3.81E-05	FB	B	DLL	2.23E-05
423	Zn	Calculated	mg/dscm			ADL	1.30E-03			ADL	1.46E-03			ADL	8.81E-04			ADL	1.21E-03
424	Zr	Calculated	mg/dscm			BDL	4.60E-05			BDL	2.30E-06			BDL	1.57E-05			BDL	2.13E-05

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Alfa**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
426	Ions																		
427	NH4+	Calculated	mg/dscm			BDL	2.98591E-05			BDL	3.61656E-05			BDL	2.91603E-05			BDL	3.17283E-05
428	Cl-	Calculated	mg/dscm			BDL	2.98591E-05			BDL	3.61656E-05			BDL	2.91603E-05			BDL	3.17283E-05
429	NO3-	Calculated	mg/dscm		#	ADL	0.003673327		#	ADL	0.006015448		#	ADL	0.002193416		#	ADL	0.00396073
430	K+	Calculated	mg/dscm			BDL	0.000896067			BDL	0.001085306			BDL	0.000875082			BDL	0.000952152
431	Na+	Calculated	mg/dscm		#	ADL	0.000611143		#	ADL	0.000134053			BDL	2.91603E-05		#	DLL	0.000258119
432	SO42-	Calculated	mg/dscm		#	ADL	0.007132594		#	ADL	0.008502171		#	ADL	0.006211186		#	ADL	0.007281984

	A	B	C	D E F	G	H I J	K	L M N	O	P Q R	S
1	**Modified CTM 39, Site Alfa**				Run 1		Run 2		Run 3		Average
2	Parameter	Type	Units		Value		Value		Value		Value
435	**Reconstructed Mass (applying oxide factors for elements and 1/2 RL for BDL, subtract OC Backup and dilution air blank)**										
436	OC	Calculated	mg/dscm	ADL	1.04E+00	ADL	1.22E+00	ADL	1.14E+00	ADL	1.13E+00
437	EC	Calculated	mg/dscm	ADL	1.19E-02	ADL	2.82E-02	ADL	2.11E-02	ADL	2.04E-02
438	Total C	Calculated	mg/dscm								
439	OC Backup	Calculated	mg/dscm								
440	EC Backup	Calculated	mg/dscm								
441	Total C Backup	Calculated	mg/dscm								
443	Elements										
444	Ag	Calculated	mg/dscm	BBL	7.18E-05	BDL	3.32E-06	BDL	2.81E-06	DLL	2.60E-05
445	Al	Calculated	mg/dscm	BDL	3.39E-04	BBL	1.77E-03	BDL	5.41E-05	DLL	7.22E-04
446	As	Calculated	mg/dscm	BDL	1.35E-06	BDL	1.57E-06	BDL	1.33E-06	BDL	1.41E-06
447	Au	Calculated	mg/dscm	BDL	2.72E-06	BBL	8.35E-05	ADL	3.32E-05	DLL	3.98E-05
448	Ba	Calculated	mg/dscm	BDL	1.25E-05	ADL	1.11E-03	BDL	1.23E-05	DLL	3.78E-04
449	Br	Calculated	mg/dscm	ADL	7.71E-05	ADL	2.67E-05	BBL	4.93E-05	DLL	5.10E-05
450	Ca	Calculated	mg/dscm	ADL	1.43E-02	ADL	1.61E-02	ADL	1.08E-02	ADL	1.37E-02
451	Cd	Calculated	mg/dscm	BDL	5.04E-06	BBL	1.55E-04	BDL	4.94E-06	DLL	5.49E-05
452	Ce	Calculated	mg/dscm	BBL	4.29E-04	BDL	3.13E-04	BDL	3.98E-05	DLL	2.61E-04
453	Cl	Calculated	mg/dscm	ADL	1.39E-03	ADL	3.61E-03	ADL	1.21E-04	ADL	1.70E-03
454	Co	Calculated	mg/dscm	BDL	3.07E-07	BDL	3.55E-07	BDL	3.01E-07	BDL	3.21E-07
455	Cr	Calculated	mg/dscm	ADL	1.40E-04	BDL	9.39E-06	BBL	6.62E-05	DLL	7.20E-05
456	Cs	Calculated	mg/dscm	BBL	2.96E-04	ADL	2.83E-04	BDL	6.47E-05	DLL	2.15E-04
457	Cu	Calculated	mg/dscm	BBL	3.20E-05	BDL	1.11E-06	BDL	9.44E-07	DLL	1.13E-05
458	Eu	Calculated	mg/dscm	BDL	5.47E-04	ADL	1.68E-03	BDL	8.29E-05	DLL	7.71E-04
459	Fe	Calculated	mg/dscm	ADL	6.55E-04	BBL	2.26E-04	ADL	1.32E-04	DLL	3.38E-04
460	Ga	Calculated	mg/dscm	BDL	1.03E-06	BDL	1.20E-06	BDL	1.01E-06	BDL	1.08E-06
461	Hf	Calculated	mg/dscm	BDL	1.30E-05	BDL	1.51E-05	BDL	1.28E-05	BDL	1.36E-05
462	Hg	Calculated	mg/dscm	BDL	2.41E-05	BDL	2.83E-05	BDL	1.75E-06	BDL	1.81E-05
463	In	Calculated	mg/dscm	BDL	2.54E-06	BDL	3.67E-05	BDL	2.49E-06	BDL	1.39E-05
464	Ir	Calculated	mg/dscm	BDL	2.83E-06	BDL	3.28E-06	BDL	2.77E-06	BDL	2.96E-06
465	K	Calculated	mg/dscm	ADL	4.36E-04	ADL	2.43E-04	ADL	8.39E-05	ADL	2.55E-04
466	La	Calculated	mg/dscm	BBL	7.12E-05	ADL	3.63E-04	BDL	1.68E-05	DLL	1.50E-04
467	Mg	Calculated	mg/dscm	BDL	3.53E-03	BDL	2.89E-04	BDL	2.73E-04	BDL	1.36E-03
468	Mn	Calculated	mg/dscm	BDL	4.47E-06	BDL	5.17E-06	BBL	1.09E-04	DLL	3.95E-05
469	Mo	Calculated	mg/dscm	BDL	1.83E-06	BDL	2.12E-06	BDL	1.79E-06	BDL	1.91E-06
470	Na	Calculated	mg/dscm	BDL	1.86E-03	BDL	1.40E-03	BDL	1.96E-03	BDL	1.74E-03
471	Nb	Calculated	mg/dscm	BDL	7.12E-06	BDL	1.10E-06	BDL	9.71E-06	BDL	5.98E-06
472	Ni	Calculated	mg/dscm	ADL	2.04E-05	BDL	7.13E-07	BDL	6.04E-07	DLL	7.25E-06
473	Pb	Calculated	mg/dscm	ADL	7.31E-06	ADL	5.75E-05	BBL	8.78E-05	DLL	5.09E-05
474	Pd	Calculated	mg/dscm	BDL	5.18E-06	BDL	5.99E-06	BDL	5.07E-06	BDL	5.41E-06
475	P	Calculated	mg/dscm	ADL	1.00E-03	ADL	1.40E-03	ADL	1.88E-03	ADL	1.43E-03
476	Rb	Calculated	mg/dscm	BDL	4.10E-06	BBL	2.65E-05	BBL	1.84E-05	DLL	1.64E-05
477	S	Calculated	mg/dscm	ADL	3.26E-02	ADL	1.91E-02	ADL	1.43E-02	ADL	2.20E-02
478	Sb	Calculated	mg/dscm	BDL	8.68E-05	ADL	6.48E-05	ADL	1.81E-05	DLL	5.66E-05
479	Sc	Calculated	mg/dscm	BDL	4.78E-04	BDL	4.35E-05	BDL	3.84E-04	BDL	3.02E-04
480	Se	Calculated	mg/dscm	BDL	1.60E-06	BDL	1.57E-05	BDL	1.57E-06	BDL	6.30E-06
481	Si	Calculated	mg/dscm	ADL	8.83E-04	ADL	7.77E-04	ADL	3.00E-03	ADL	1.55E-03
482	Sm	Calculated	mg/dscm	ADL	1.92E-04	BDL	6.08E-05	BDL	5.05E-05	DLL	1.01E-04
483	Sn	Calculated	mg/dscm	BBL	1.26E-04	BBL	1.55E-04	BDL	1.08E-05	DLL	9.74E-05
484	Sr	Calculated	mg/dscm	ADL	2.26E-05	ADL	2.39E-05	ADL	3.99E-05	ADL	2.88E-05
485	Ta	Calculated	mg/dscm	BDL	1.35E-05	BDL	1.56E-05	BDL	1.32E-05	BDL	1.41E-05
486	Tb	Calculated	mg/dscm	BDL	3.79E-05	BDL	2.39E-04	BDL	3.57E-05	BDL	1.04E-04
487	Ti	Calculated	mg/dscm	ADL	3.42E-04	ADL	4.12E-04	ADL	1.10E-04	ADL	2.88E-04
488	Tl	Calculated	mg/dscm	BBL	2.47E-05	BBL	3.02E-05	BBL	1.39E-05	BBL	2.29E-05
489	U	Calculated	mg/dscm	BDL	2.78E-06	BBL	8.53E-05	BBL	6.78E-05	DLL	5.19E-05
490	V	Calculated	mg/dscm	BDL	1.88E-06	BDL	4.66E-07	BDL	3.94E-07	BDL	9.15E-07
491	W	Calculated	mg/dscm	ADL	2.40E-04	BBL	4.27E-04	BBL	1.10E-04	DLL	2.59E-04
492	Y	Calculated	mg/dscm	ADL	2.40E-05	BBL	1.24E-05	BDL	2.42E-05	DLL	2.02E-05
493	Zn	Calculated	mg/dscm	ADL	1.93E-03	ADL	2.17E-03	ADL	1.31E-03	ADL	1.81E-03
494	Zr	Calculated	mg/dscm	BDL	3.10E-05	BDL	1.55E-06	BDL	1.06E-05	BDL	1.44E-05

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Alfa**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
496	Ions																		
497	NH4+	Calculated	mg/dscm			BDL	1.49E-05			BDL	1.81E-05			BDL	1.46E-05			BDL	1.59E-05
498	Cl-	Calculated	mg/dscm			BDL	3.85E-05			BDL	4.66E-05			BDL	3.76E-05			BDL	4.09E-05
499	NO3-	Calculated	mg/dscm			ADL	3.67E-03			ADL	6.02E-03			ADL	2.19E-03			ADL	3.96E-03
500	K+	Calculated	mg/dscm			BDL	8.15E-04			BDL	9.87E-04			BDL	7.96E-04			BDL	8.66E-04
501	Na+	Calculated	mg/dscm			ADL	1.46E-03			ADL	3.21E-04			BDL	3.49E-05			DLL	6.06E-04
502	SO42-	Calculated	mg/dscm			ADL	1.19E-02			ADL	1.42E-02			ADL	1.03E-02			ADL	1.21E-02
503																			
504	Reconstructed mas	Calculated	mg/dscm			DLL	1.12E+00			DLL	1.31E+00			DLL	1.20E+00			DLL	1.21E+00
505	Species mass closure		%				90%				101%				94%				95%
509																			

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Alfa**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
658	**Species Profile (fraction of sum of species, with dilution air blank)**																		
659	OC	Calculated	mg/mg		0	ADL	0.92983		0	ADL	0.93290		0	ADL	0.95052		#	ADL	0.93779
660	EC	Calculated	mg/mg		0	ADL	0.01066		0	ADL	0.02154		0	ADL	0.01756		#	ADL	0.01687
661	Total C	Calculated	mg/mg		0	ADL	0.00000		0	ADL	0.00000		0	ADL	0.00000		#	ADL	0.00000
662	OC Backup	Calculated	mg/mg																
663	EC Backup	Calculated	mg/mg																
664	Total C Backup	Calculated	mg/mg																
665																			
666	Elements (as oxides)																		
667	Ag	Calculated	mg/mg			BBL	0.00006			BDL	0.00000			BDL	0.00000			DLL	0.00002
668	Al	Calculated	mg/mg			BDL	0.00030	FB		BBL	0.00135			BDL	0.00005	FB	B	DLL	0.00060
669	As	Calculated	mg/mg			BDL	0.00000			BDL	0.00000			BDL	0.00000			BDL	0.00000
670	Au	Calculated	mg/mg			BDL	0.00000	FB		BBL	0.00006	FB	B	ADL	0.00003	FB	B	DLL	0.00003
671	Ba	Calculated	mg/mg			BDL	0.00001			ADL	0.00085			BDL	0.00001	FB		DLL	0.00031
672	Br	Calculated	mg/mg	FB		ADL	0.00007	FB		ADL	0.00002	FB	B	BBL	0.00004	FB	B	DLL	0.00004
673	Ca	Calculated	mg/mg			ADL	0.01285			ADL	0.01229			ADL	0.00895			ADL	0.01136
674	Cd	Calculated	mg/mg			BDL	0.00000	FB		BBL	0.00012			BDL	0.00000	FB		DLL	0.00005
675	Ce	Calculated	mg/mg	FB	B	BBL	0.00038			BDL	0.00024			BDL	0.00003	FB	B	DLL	0.00022
676	Cl	Calculated	mg/mg			ADL	0.00124			ADL	0.00276	FB	B	ADL	0.00010			ADL	0.00141
677	Co	Calculated	mg/mg			BDL	0.00000			BDL	0.00000			BDL	0.00000			BDL	0.00000
678	Cr	Calculated	mg/mg	FB		ADL	0.00013			BDL	0.00001	FB	B	BBL	0.00006	FB	B	DLL	0.00006
679	Cs	Calculated	mg/mg	FB		BBL	0.00027	FB	B	ADL	0.00022			BDL	0.00005	FB	B	DLL	0.00018
680	Cu	Calculated	mg/mg		B	BBL	0.00003			BDL	0.00000			BDL	0.00000		B	DLL	0.00001
681	Eu	Calculated	mg/mg			BDL	0.00049		B	ADL	0.00129			BDL	0.00007		B	DLL	0.00064
682	Fe	Calculated	mg/mg			ADL	0.00059	FB	B	BBL	0.00017			ADL	0.00011		B	DLL	0.00028
683	Ga	Calculated	mg/mg			BDL	0.00000			BDL	0.00000			BDL	0.00000			BDL	0.00000
684	Hf	Calculated	mg/mg			BDL	0.00001			BDL	0.00001			BDL	0.00001			BDL	0.00001
685	Hg	Calculated	mg/mg			BDL	0.00002			BDL	0.00002			BDL	0.00000			BDL	0.00001
686	In	Calculated	mg/mg			BDL	0.00000			BDL	0.00003			BDL	0.00000			BDL	0.00001
687	Ir	Calculated	mg/mg			BDL	0.00000			BDL	0.00000			BDL	0.00000			BDL	0.00000
688	K	Calculated	mg/mg			ADL	0.00039			ADL	0.00019		B	ADL	0.00007		B	ADL	0.00021
689	La	Calculated	mg/mg	FB	B	BBL	0.00006	FB		ADL	0.00028			BDL	0.00001	FB	B	DLL	0.00012
690	Mg	Calculated	mg/mg			BDL	0.00317			BDL	0.00022			BDL	0.00023			BDL	0.00113
691	Mn	Calculated	mg/mg			BDL	0.00000			BDL	0.00000	FB		BBL	0.00009	FB		DLL	0.00003
692	Mo	Calculated	mg/mg			BDL	0.00000			BDL	0.00000			BDL	0.00000			BDL	0.00000
693	Na	Calculated	mg/mg			BDL	0.00166			BDL	0.00107			BDL	0.00163			BDL	0.00144
694	Nb	Calculated	mg/mg			BDL	0.00001			BDL	0.00000			BDL	0.00001			BDL	0.00000
695	Ni	Calculated	mg/mg	FB		ADL	0.00002			BDL	0.00000			BDL	0.00000	FB		DLL	0.00001
696	Pb	Calculated	mg/mg	FB	B	ADL	0.00001	FB		ADL	0.00004	FB	B	BBL	0.00007	FB	B	DLL	0.00004
697	Pd	Calculated	mg/mg			BDL	0.00000			BDL	0.00000			BDL	0.00000			BDL	0.00000
698	P	Calculated	mg/mg			ADL	0.00090			ADL	0.00107			ADL	0.00157			ADL	0.00118
699	Rb	Calculated	mg/mg			BDL	0.00000	FB	B	BBL	0.00002	FB	B	BBL	0.00002	FB	B	DLL	0.00001
700	S	Calculated	mg/mg			ADL	0.02919			ADL	0.01456			ADL	0.01194			ADL	0.01819
701	Sb	Calculated	mg/mg			BDL	0.00008	FB	B	ADL	0.00005	FB	B	ADL	0.00002	FB	B	DLL	0.00005
702	Sc	Calculated	mg/mg			BDL	0.00043			BDL	0.00003			BDL	0.00032			BDL	0.00025
703	Se	Calculated	mg/mg			BDL	0.00000			BDL	0.00001			BDL	0.00000			BDL	0.00001
704	Si	Calculated	mg/mg	FB	B	ADL	0.00079	FB		ADL	0.00059			ADL	0.00250	FB	B	ADL	0.00129
705	Sm	Calculated	mg/mg	FB	B	ADL	0.00017			BDL	0.00005			BDL	0.00004	FB	B	DLL	0.00008
706	Sn	Calculated	mg/mg	FB		BBL	0.00011	FB		BBL	0.00012			BDL	0.00001	FB	B	DLL	0.00008
707	Sr	Calculated	mg/mg			ADL	0.00002			ADL	0.00002			ADL	0.00003		B	ADL	0.00002
708	Ta	Calculated	mg/mg			BDL	0.00001			BDL	0.00001			BDL	0.00001			BDL	0.00001
709	Tb	Calculated	mg/mg			BDL	0.00003			BDL	0.00018			BDL	0.00003			BDL	0.00009
710	Ti	Calculated	mg/mg			ADL	0.00031			ADL	0.00032	FB		ADL	0.00009			ADL	0.00024
711	Tl	Calculated	mg/mg	FB		BBL	0.00002	FB		BBL	0.00002	FB	B	BBL	0.00001	FB	B	BBL	0.00002
712	U	Calculated	mg/mg			BDL	0.00000			BBL	0.00007			BBL	0.00006			DLL	0.00004
713	V	Calculated	mg/mg			BDL	0.00000			BDL	0.00000			BDL	0.00000			BDL	0.00000
714	W	Calculated	mg/mg	FB		ADL	0.00021	FB		BBL	0.00033	FB	B	BBL	0.00009	FB	B	DLL	0.00021
715	Y	Calculated	mg/mg			ADL	0.00002	FB	B	BBL	0.00001			BDL	0.00002	FB	B	DLL	0.00002
716	Zn	Calculated	mg/mg			ADL	0.00173			ADL	0.00166			ADL	0.00109			ADL	0.00149
717	Zr	Calculated	mg/mg			BDL	0.00003			BDL	0.00000			BDL	0.00001			BDL	0.00001
718																			

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Alfa**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
719	Ions (Cl-, K+,Na+ as oxides)																		
720	NH4+	Calculated	mg/mg			BDL	0.00001			BDL	0.00001			BDL	0.00001			BDL	0.00001
721	Cl-	Calculated	mg/mg			BDL	0.00003			BDL	0.00004			BDL	0.00003			BDL	0.00003
722	NO3-	Calculated	mg/mg	#		ADL	0.00329	#		ADL	0.00460	#		ADL	0.00183	#		ADL	0.00328
723	K+	Calculated	mg/mg			BDL	0.00073			BDL	0.00075			BDL	0.00066			BDL	0.00072
724	Na+	Calculated	mg/mg	#		ADL	0.00131	#		ADL	0.00025			BDL	0.00003	#		DLL	0.00050
725	SO42-	Calculated	mg/mg	#		ADL	0.01065	#		ADL	0.01083	#		ADL	0.00861	#		ADL	0.01004
726																			
727																			

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Alfa**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
797	**Results for 142-mm filter and recovery rinses (with dilution air blank correction)**																		
798	Vds(std)'	Calculated	dscm				21.867				30.218				20.090				
799	mar,probe	Calculated	mg	FB		BDL	1.740	FB		BDL	1.880	FB		BDL	1.040	FB		BDL	1.553
800	mar,venturi-chamb	Calculated	mg	FB		BDL	2.170	FB		BDL	3.050	FB		BDL	2.790	FB		BDL	2.670
801	mwr,chamber	Calculated	mg	FB		BDL	0.430	FB		BDL	0.970	FB		BDL	0.070	FB		BDL	0.490
802	mf142mm	Calculated	mg			ADL	6.670			ADL	4.130			ADL	8.600			ADL	6.467
803	Cpm,probe	Calculated	mg/dscm	FB		BDL	0.694	FB		BDL	0.750	FB		BDL	0.424	FB		BDL	0.623
804	Cpm,venturi-chaml	Calculated	mg/dscm	FB		BDL	0.866	FB		BDL	1.218	FB		BDL	1.137	FB		BDL	1.073
805	Cpm,chamber	Calculated	mg/dscm	FB		BDL	0.172	FB		BDL	0.387	FB		BDL	0.029	FB		BDL	0.196
806	Cpm,142mmf	Calculated	mg/dscm			ADL	4.789			ADL	2.582			ADL	6.553			ADL	4.641
807																			
808	**Results for 142mm and 47mm filters with recovery rinses (with dilution air blank correction)**																		
809	mf47q,est	Calculated	mg	estimated			0.701	estimated			0.610	estimated			0.746	estimated			0.686
810	Cs,f+r,total	Calculated	mg/dscm	FB		DLL	4.939	FB		DLL	4.466	FB		DLL	5.681	FB		DLL	5.029
811	Es,f+r,total	Calculated	lb/MMBtu	FB		DLL	5.79E-03	FB		DLL	5.19E-03	FB		DLL	6.51E-03	FB		DLL	5.83E-03
812	Es,f+r,total	Calculated	kg/GJ	FB		DLL	2.49E-03	FB		DLL	2.23E-03	FB		DLL	2.80E-03	FB		DLL	2.51E-03
816																			
817	**Results for 142mm and 47mm filters without recovery rinses (with dilution air blank correction)**																		
818	**Cs,f,total**	Calculated	**mg/dscm**			**ADL**	**3.21**			**ADL**	**2.11**			**ADL**	**4.09**			**ADL**	**3.14**
819	**Es,f,total**	Calculated	**lb/MMBtu**			**ADL**	**3.76E-03**			**ADL**	**2.45E-03**			**ADL**	**4.69E-03**			**ADL**	**3.63E-03**
820	**Es,f,total**	Calculated	**kg/GJ**			**ADL**	**1.62E-03**			**ADL**	**1.05E-03**			**ADL**	**2.02E-03**			**ADL**	**1.56E-03**

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Buick**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
3	k1	Calibration					0.8517				0.8517				0.8517				0.8517
4	n1	Calibration					0.5				0.5				0.5				0.5
5	k2	Calibration					10.545				10.545				10.545				10.545
6	n2	Calibration					0.5				0.5				0.5				0.5
7	Cdmfm1	Calibration					1.018				1.018				1.018				1.018
8	Csmfm1	Calibration					1.01				1.01				1.01				1.01
9	Csmfm2	Calibration					1.012				1.012				1.012				1.012
10	T1m	Measured	F				503.0072937				340.128112				326.7581944				389.9645334
11	T1	Calculated	R				963.0072937				800.128112				786.7581944				849.9645334
12	T2m	Measured	F				99.15396429				76.68254427				92.64943452				89.49531436
13	T2	Calculated	R				559.1539643				536.6825443				552.6494345				549.4953144
14	Stack T	Measured	F				884.0136091				928.1606406				942.4025357				918.1922618
15	Filter T	Measured	F				93.32527976				91.596				103.12				96.01375992
16	T3m	Measured	F				88.02492063				87.66473698			estir	99.12				91.6032192
17	T3	Calculated	R				548.0249206				547.664737				559.12				551.6032192
18	Pbar	Measured	in. Hg				26.5649127				26.3136875				26.07756746				26.31872255
19	Ps	Measured	iwc				-0.911251984				-0.957630208				-0.848501984				-0.905794726
20	Pst	Calculated	in. Hg				26.49790888				26.24327351				26.01517761				26.25212
21	Cyclone dP	Measured	iwc				-2.400680556				-2.470742188				-2.209071429				-2.360164724
22	P1	Calculated	in. Hg				26.32138825				26.06160129				25.85274589				26.07857848
23	Sample venturi dP	Measured	iwc				0.767597222				0.574338542				0.53828373				0.626739831
24	Dil venturi dP	Measured	iwc				0.405111111				1.469791667				1.229202381				1.03470172
25	P2	Calculated	in. Hg				26.3474916				26.12470286				25.90983173				26.12734206
26	Exhaust Vac	Measured	iwc				5.544498016				9.158914062				7.954144841				7.552518973
27	P3	Calculated	in. Hg				26.15722902				25.64023794				25.49270387				25.76339028
28	%O2	Measured	%vd				15.34				15.15				15.24				15.24333333
29	%CO2	Measured	%vd				3.94				3.94				3.98				3.953333333
30	Ms	Calculated	lb/lb-mole				29.244				29.2364				29.2464				29.24226667
31	Mws	Calculated	lb/lb-mole				28.31875712				27.92525726				28.54640638				28.26347358
32	Mwdil	Calculated	lb/lb-mole				28.9544123				28.9181686				28.89105169				28.92121087
33	Q1	Calculated	wacf/min				0.848157766				0.676785823				0.645184389				0.723375993
34	Q2	Calculated	wacf/min				5.746089036				10.77512053				10.04544485				8.855551472
35	RHdil	Measured	%				1.987734127				13.33089844				12.07700397				9.131878844
36	RH mix	Measured	%				16.36461508				18.21423698				12.96345437				15.84743547
37	**Bwdil**	**Calculated**	**v/v**				0.001420939				0.004724832				0.007196746				0.004447505
38	**Bwds**	**Calculated**	**v/v**				0.008359156				0.009384166				0.009567895				0.009103739
39	Qmix,std	Calculated	wacf/min				5.187169258				9.64512079				8.685188261				7.839159436
40	**Bws**	**Calculated**	**v/v**				0.082287698				0.116687083				0.062241573				0.087072118
41																			
42	**PM2.5 Concentration**																		
43	Run duration	Measured	minutes				237.9				178.4				238.4166667				218.2388889
44	mf47ds	Measured	mg			ADL	0.758			ADL	0.01			ADL	0.009			ADL	0.259
45	mf47dab	Measured	mg			ADL	0.011			ADL	0.008			ADL	0.007			ADL	0.008666667
46	mf47ds-stfb1	Measured	mg			ADL	0.008			ADL	0.008			ADL	0.008			ADL	0.008
47	mf47dab-stfb1	Measured	mg			ADL	0.004			ADL	0.004			ADL	0.004			ADL	0.004
48	mf47ds-stfb2	Measured	mg			ADL	0.008			ADL	0.008			ADL	0.008			ADL	0.008
49	mf47dab-stfb2	Measured	mg			ADL	0.006			ADL	0.006			ADL	0.006			ADL	0.006
50	qf47ds,tq	Calculated	wacm/min				0.036299911				0.036968315				0.03683153				0.036699918
51	Vf47ds,tq(std)	Calculated	dscm				8.563561256				6.533257365				8.69723246				7.93135036
52	qf47ds,q	Calculated	wacm/min				0.03641229				0.03712152				0.036965077				0.036832962
53	Vf47ds,q(std)	Calculated	dscm				8.590072758				6.560332703				8.728767721				7.959724394
54	qf47dab	Calculated	wacm/min				0.036975853				0.037224005				0.037200505				0.037133454
55	Vf47dab(std)	Calculated	dscm				8.784055957				6.609386022				8.805390958				8.066277646
57	Vdv(std)	Calculated	dscm				29.53558339				46.17583764				55.41314592				
58	Vd(std)	Calculated	dscm				20.75152743				39.56645162				46.60775496				37.64882117
59	Vs(std)	Calculated	dscm				2.479305741				1.747712896				2.100455274				2.10915797
60	Vds(std)	Calculated	dscm				23.23083317				41.31416452				48.70821024				37.75106931
61	DR	Calculated	v/v				9.369894479				23.63898819				23.18935844				18.73274704
62	**Cpm2.5**	**Calculated**	**mg/dscm**			ADL	0.818890885	FB	B	ADL	0.008780317	FB	B	ADL	0.006356805			ADL	0.278009336
64																			

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Buick**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
65	**PM2.5 Emission Factor**																		
66	Fd	Input	dscf/MMBtu				8615				8615				8615				8615
67	**Epm2.5**	**Calculated**	**lb/MMBtu**			ADL	0.00165551	FB	B	ADL	1.71642E-05	FB	B	ADL	1.26242E-05				0.000561766
68	**Epm2.5**	**Calculated**	**kg/GJ**			ADL	0.000711712	FB	B	ADL	7.37896E-06	FB	B	ADL	5.42719E-06				0.000241506
69																			
70	**Stack gas flow rate**																		
71	Qfuel(15C)	Input	lb/hr			estir	10045.61898			estir	10850.44241				10799				10565.02046
72	HHV(15C)	Input	Btu/lb				21901				21687				21702				21763.33333
73	Qstk,dry(25C)	Calculated	dscf/hr				7246295.944				7494269.258				7582581.392				7441048.865
74							1263.346596				1364.561956				1358.09251				
75	**PM2.5 Mass Flow Rate**						75.94360703				82.02797022				81.63907213				
76	Mpm2.5	Calculated	lb/hr			ADL	370.4428329	FB	B	ADL	4.10788791	FB	B	ADL	3.009089341			ADL	125.85327
77																			
78																			

	A	B	C	D E F	G	H I J	K	L M N	O	P Q R	S
1	**Modified CTM 39, Site Buick**				Run 1		Run 2		Run 3		Average
2	Parameter	Type	Units		Value		Value		Value		Value
79	**Species Lab Results - Samples**										
80	Carbon										
81	OC	Measured	µg	ADL	387.11548	ADL	49.20986	ADL	57.29804	ADL	164.5411267
82	EC	Measured	µg	ADL	24.90398	ADL	1.7841	BDL	0.763166667	DLL	9.150415556
83	Total C	Measured	µg	ADL	412.01945	ADL	50.99396	ADL	57.29804	ADL	173.43715
84	OC Backup	Measured	µg	ADL	81.57181	ADL	37.95779	ADL	47.93059	ADL	55.82006333
85	EC Backup	Measured	µg	ADL	12.75143	ADL	0.28678	ADL	0.21856	ADL	4.418923333
86	Total C Backup	Measured	µg	ADL	94.32324	ADL	38.24458	ADL	48.14915	ADL	60.23899
88	Elements										
89	Ag	Measured	µg	BDL	0.0334	BDL	0.0334	BDL	0.0334	BDL	0.0334
90	Al	Measured	µg	BDL	0.4573	BDL	0.4623	BDL	0.4615	BDL	0.460366667
91	As	Measured	µg	BDL	0.0133	BDL	0.0133	BDL	0.0133	BDL	0.0133
92	Au	Measured	µg	BDL	0.0366	BDL	0.0366	BDL	0.0366	BDL	0.0366
93	Ba	Measured	µg	ADL	0.0419	BDL	0.1182	BDL	0.1175	DLL	0.092533333
94	Br	Measured	µg	ADL	0.6851	ADL	0.0301	ADL	0.0018	ADL	0.239
95	Ca	Measured	µg	ADL	0.0801	ADL	0.0083	BDL	0.0125	DLL	0.033633333
96	Cd	Measured	µg	ADL	0.0436	BDL	0.0666	ADL	0.0507	DLL	0.053633333
97	Ce	Measured	µg	BDL	0.4685	BDL	0.4668	ADL	0.1974	DLL	0.377566667
98	Cl	Measured	µg	ADL	0.2433	ADL	0.0171	ADL	0.0277	ADL	0.096033333
99	Co	Measured	µg	BDL	0.0034	BDL	0.0034	BDL	0.0034	BDL	0.0034
100	Cr	Measured	µg	ADL	0.0013	BDL	0.0133	ADL	0.0236	DLL	0.012733333
101	Cs	Measured	µg	BDL	0.1683	BDL	0.1691	ADL	0.1343	DLL	0.157233333
102	Cu	Measured	µg	ADL	0.0012	BDL	0.0116	BDL	0.0116	DLL	0.008133333
103	Eu	Measured	µg	BDL	0.9813	ADL	0.0707	BDL	0.982	DLL	0.678
104	Fe	Measured	µg	ADL	0.0825	ADL	0.0035	ADL	0.0848	ADL	0.056933333
105	Ga	Measured	µg	BDL	0.0116	BDL	0.0116	BDL	0.0116	BDL	0.0116
106	Hf	Measured	µg	BDL	0.1666	BDL	0.1666	BDL	0.1666	BDL	0.1666
107	Hg	Measured	µg	ADL	0.0012	BDL	0.025	ADL	0.0024	DLL	0.009533333
108	In	Measured	µg	ADL	0.0172	BDL	0.0317	BDL	0.0317	DLL	0.026866667
109	Ir	Measured	µg	BDL	0.0366	BDL	0.0366	BDL	0.0366	BDL	0.0366
110	K	Measured	µg	ADL	0.1614	ADL	0.0236	BDL	0.0216	DLL	0.068866667
111	La	Measured	µg	BDL	0.1974	BDL	0.1974	BDL	0.1974	BDL	0.1974
112	Mg	Measured	µg	BDL	1.8308	ADL	0.2009	BDL	1.8563	DLL	1.296
113	Mn	Measured	µg	ADL	0.0048	ADL	0.0001	ADL	0.0201	ADL	0.008333333
114	Mo	Measured	µg	BDL	0.0184	BDL	0.0184	BDL	0.0184	BDL	0.0184
115	Na	Measured	µg	BDL	7.1858	ADL	3.8757	BDL	7.6982	DLL	6.253233333
116	Nb	Measured	µg	BDL	0.01	BDL	0.01	BDL	0.01	BDL	0.01
117	Ni	Measured	µg	BDL	0.0066	ADL	0.0012	BDL	0.0066	DLL	0.0048
118	Pb	Measured	µg	ADL	0.0236	BDL	0.0199	ADL	0.0165	DLL	0.02
119	Pd	Measured	µg	BDL	0.06	BDL	0.06	BDL	0.06	BDL	0.06
120	Ph	Measured	µg	ADL	2.4308	ADL	0.0383	ADL	0.0124	ADL	0.827166667
121	Rb	Measured	µg	BDL	0.0034	BDL	0.0034	ADL	0.0024	DLL	0.003066667
122	S	Measured	µg	BDL	0.0167	BDL	0.0167	BDL	0.0167	BDL	0.0167
123	Sb	Measured	µg	BDL	0.0833	BDL	0.0833	ADL	0.0536	DLL	0.0734
124	Sc	Measured	µg	BDL	0.3569	BDL	0.3578	BDL	0.3569	BDL	0.3572
125	Se	Measured	µg	BDL	0.015	ADL	0.0089	BDL	0.015	DLL	0.012966667
126	Si	Measured	µg	ADL	124.123	ADL	0.2928	ADL	0.0478	ADL	41.48786667
127	Sm	Measured	µg	ADL	0.4477	ADL	0.0236	BDL	0.6648	DLL	0.3787
128	Sn	Measured	µg	ADL	0.0578	BDL	0.06	BDL	0.06	DLL	0.059266667
129	Sr	Measured	µg	ADL	0.0023	BDL	0.0116	BDL	0.0116	DLL	0.0085
130	Ta	Measured	µg	BDL	0.1666	BDL	0.1666	BDL	0.1666	BDL	0.1666
131	Tb	Measured	µg	BDL	0.4857	ADL	0.1738	BDL	0.4748	DLL	0.3781
132	Ti	Measured	µg	ADL	0.0054	ADL	0.0301	BDL	0.0083	DLL	0.0146
133	Tl	Measured	µg	ADL	0.0054	ADL	0.0124	BDL	0.0133	DLL	0.010366667
134	U	Measured	µg	BDL	0.0349	ADL	0.0095	ADL	0.0224	DLL	0.022266667
135	V	Measured	µg	BDL	0.0034	ADL	0.0059	BDL	0.0034	DLL	0.004233333
136	W	Measured	µg	BDL	0.1666	ADL	0.0071	ADL	0.0248	DLL	0.066166667
137	Yt	Measured	µg	ADL	0.0272	BDL	0.0116	ADL	0.0083	DLL	0.0157
138	Zn	Measured	µg	ADL	0.0035	BDL	0.0199	ADL	0.0023	DLL	0.008566667
139	Zr	Measured	µg	BDL	0.015	ADL	0.0077	ADL	0.0112	DLL	0.0113

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Buick**					Run 1				Run 2				Run 3				Average	
2	Parameter	Type	Units			Value				Value				Value				Value	
141	Ions																		
142	NH4+	Measured	µg			BDL	0.0167			BDL	0.0167			BDL	0.0167			BDL	0.0167
143	Cl-	Measured	µg			BDL	0.0167			BDL	0.0167			BDL	0.0167			BDL	0.0167
144	NO3-	Measured	µg			ADL	0.419238725			ADL	0.100402133			ADL	0.250457916			ADL	0.256699591
145	K+	Measured	µg			BDL	0.502022499			BDL	0.501172873			BDL	0.50115676			BDL	0.50145071
146	Na+	Measured	µg			ADL	0.159182184			BDL	0.569839361			BDL	0.574558161			DLL	0.434526569
147	SO42-	Measured	µg			BDL	0.0167			BDL	0.0167			BDL	0.0167			BDL	0.0167
148																			

	A	B	C	F	G	J	K	N	O	R	S
1	**Modified CTM 39, Site Buick**				Run 1		Run 2		Run 3		Average
2	Parameter	Type	Units		Value		Value		Value		Value
149	**Species Lab Results - Run Dilution Air**										
150	Carbon										
151	OC	Measured	μg								
152	EC	Measured	μg								
153	Total C	Measured	μg								
154	OC Backup	Measured	μg	ADL	32.05789	ADL	32.67148	ADL	29.43353	ADL	31.38763333
155	EC Backup	Measured	μg	ADL	12.75143	ADL	0.28678	ADL	0.21856	ADL	4.418923333
156	Total C Backup	Measured	μg	ADL	94.32324	ADL	38.24458	ADL	48.14915	ADL	60.23899
158	Elements										
159	Ag	Measured	μg	BDL	0.0334	BDL	0.0334	BDL	0.0334	BDL	0.0334
160	Al	Measured	μg	BDL	0.4623	ADL	0.202	BDL	0.4607	DLL	0.375
161	As	Measured	μg	BDL	0.0133	BDL	0.0133	BDL	0.0133	BDL	0.0133
162	Au	Measured	μg	ADL	0.0259	BDL	0.0366	ADL	0.0153	DLL	0.025933333
163	Ba	Measured	μg	ADL	0.0666	BDL	0.1199	BDL	0.1175	DLL	0.101333333
164	Br	Measured	μg	ADL	0.0124	ADL	0.0006	BDL	0.0116	DLL	0.0082
165	Ca	Measured	μg	ADL	0.0165	BDL	0.0133	BDL	0.0133	DLL	0.014366667
166	Cd	Measured	μg	BDL	0.0666	ADL	0.0153	BDL	0.0666	DLL	0.0495
167	Ce	Measured	μg	ADL	0.4059	ADL	0.2916	BDL	0.4668	DLL	0.3881
168	Cl	Measured	μg	ADL	0.228	ADL	0.0089	ADL	0.0324	ADL	0.089766667
169	Co	Measured	μg	BDL	0.0034	BDL	0.0034	BDL	0.0034	BDL	0.0034
170	Cr	Measured	μg	BDL	0.0133	ADL	0.0166	BDL	0.0133	DLL	0.0144
171	Cs	Measured	μg	BDL	0.1699	BDL	0.1683	ADL	0.0023	DLL	0.1135
172	Cu	Measured	μg	ADL	0.0024	ADL	0.0849	BDL	0.0116	DLL	0.032966667
173	Eu	Measured	μg	ADL	0.0094	ADL	0.781	BDL	0.9804	DLL	0.590266667
174	Fe	Measured	μg	ADL	0.0141	ADL	0.0024	ADL	0.0683	ADL	0.028266667
175	Ga	Measured	μg	BDL	0.0116	BDL	0.0116	BDL	0.0116	BDL	0.0116
176	Hf	Measured	μg	BDL	0.1666	BDL	0.1666	BDL	0.1666	BDL	0.1666
177	Hg	Measured	μg	BDL	0.025	ADL	0.0059	BDL	0.025	DLL	0.018633333
178	In	Measured	μg	BDL	0.0317	BDL	0.0317	BDL	0.0317	BDL	0.0317
179	Ir	Measured	μg	BDL	0.0366	BDL	0.0366	BDL	0.0366	BDL	0.0366
180	K	Measured	μg	ADL	0.0024	ADL	0.0118	ADL	0.0024	ADL	0.005533333
181	La	Measured	μg	ADL	0.0613	ADL	0.1143	BDL	0.1991	DLL	0.1249
182	Mg	Measured	μg	BDL	1.8612	ADL	1.7865	ADL	0.5083	DLL	1.385333333
183	Mn	Measured	μg	BDL	0.0334	BDL	0.0334	BDL	0.0334	BDL	0.0334
184	Mo	Measured	μg	BDL	0.0184	ADL	0.0041	BDL	0.0184	DLL	0.013633333
185	Na	Measured	μg	BDL	7.4912	BDL	7.7062	BDL	7.4184	BDL	7.5386
186	Nb	Measured	μg	ADL	0.0036	BDL	0.01	BDL	0.01	DLL	0.007866667
187	Ni	Measured	μg	BDL	0.0066	BDL	0.0066	BDL	0.0066	BDL	0.0066
188	Pb	Measured	μg	ADL	0.0377	ADL	0.0401	ADL	0.0094	ADL	0.029066667
189	Pd	Measured	μg	BDL	0.06	ADL	0.0001	BDL	0.06	DLL	0.040033333
190	Ph	Measured	μg	ADL	0.0135	BDL	0.0266	ADL	0.0218	DLL	0.020633333
191	Rb	Measured	μg	ADL	0.0012	BDL	0.0034	ADL	0.0001	DLL	0.001566667
192	S	Measured	μg	BDL	0.0167	BDL	0.0167	BDL	0.0167	BDL	0.0167
193	Sb	Measured	μg	BDL	0.0833	ADL	0.0631	ADL	0.0631	DLL	0.069833333
194	Sc	Measured	μg	BDL	0.3578	ADL	0.1391	BDL	0.3569	DLL	0.2846
195	Se	Measured	μg	BDL	0.015	BDL	0.015	BDL	0.015	BDL	0.015
196	Si	Measured	μg	ADL	0.4447	ADL	0.096	ADL	0.129	ADL	0.223233333
197	Sm	Measured	μg	BDL	0.6597	BDL	0.6648	ADL	0.0083	DLL	0.444266667
198	Sn	Measured	μg	BDL	0.06	ADL	0.0236	ADL	0.0201	DLL	0.034566667
199	Sr	Measured	μg	ADL	0.0059	BDL	0.0116	ADL	0.0118	DLL	0.009766667
200	Ta	Measured	μg	BDL	0.1666	BDL	0.1666	BDL	0.1666	BDL	0.1666
201	Tb	Measured	μg	BDL	0.4731	BDL	0.4806	ADL	0.0183	DLL	0.324
202	Ti	Measured	μg	ADL	0.0089	ADL	0.003	BDL	0.0083	DLL	0.006733333
203	Tl	Measured	μg	BDL	0.0133	BDL	0.0133	BDL	0.0133	BDL	0.0133
204	U	Measured	μg	BDL	0.0349	ADL	0.0071	BDL	0.0349	DLL	0.025633333
205	V	Measured	μg	ADL	0.0094	ADL	0.0094	ADL	0.0024	ADL	0.007066667
206	W	Measured	μg	ADL	0.0177	ADL	0.079	BDL	0.1666	DLL	0.087766667
207	Yt	Measured	μg	ADL	0.0095	BDL	0.0116	ADL	0.0095	DLL	0.0102
208	Zn	Measured	μg	ADL	0.0177	ADL	0.0235	BDL	0.0199	DLL	0.020366667
209	Zr	Measured	μg	ADL	0.0042	BDL	0.015	ADL	0.0112	DLL	0.010133333

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Buick**					Run 1				Run 2				Run 3				Average	
2	Parameter	Type	Units			Value				Value				Value				Value	
211	Ions																		
212	NH4+	Measured	μg																
213	Cl-	Measured	μg																
214	NO3-	Measured	μg																
215	K+	Measured	μg																
216	Na+	Measured	μg																
217	SO42-	Measured	μg																
218																			
219																			

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Buick**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
220	**Species Lab Results - STFB Samples**																		
221	Carbon																		
222	OC	Measured	µg			ADL	8.04047			ADL	3.90335							DLL	5.97191
223	EC	Measured	µg			ADL	0.09622			BDL	0.763166667							DLL	0.429693333
224	Total C	Measured	µg			ADL	8.13669			ADL	3.90335							DLL	6.02002
225	OC Backup	Measured	µg			ADL	7.23388			ADL	6.96475							DLL	7.099315
226	EC Backup	Measured	µg			BDL	0.763166667			BDL	0.763166667							DLL	0.763166667
227	Total C Backup	Measured	µg			ADL	7.23388			ADL	6.96475							DLL	7.099315
229	Elements																		
230	Ag	Measured	µg			BDL	0.0334			BDL	0.0334							DLL	0.0334
231	Al	Measured	µg			BDL	0.4615			BDL	0.4615							DLL	0.4615
232	As	Measured	µg			BDL	0.0133			BDL	0.0133							DLL	0.0133
233	Au	Measured	µg			ADL	0.0177			ADL	0.0036							DLL	0.01065
234	Ba	Measured	µg			ADL	0.089			BDL	0.1175							DLL	0.10325
235	Br	Measured	µg			ADL	0.0207			ADL	0.0089							DLL	0.0148
236	Ca	Measured	µg			BDL	0.0133			BDL	0.0125							DLL	0.0129
237	Cd	Measured	µg			BDL	0.0666			ADL	0.0436							DLL	0.0551
238	Ce	Measured	µg			ADL	0.1432			BDL	0.4668							DLL	0.305
239	Cl	Measured	µg			ADL	0.0065			BDL	0.0116							DLL	0.00905
240	Co	Measured	µg			BDL	0.0034			BDL	0.0034							DLL	0.0034
241	Cr	Measured	µg			ADL	0.0048			ADL	0.0013							DLL	0.00305
242	Cs	Measured	µg			BDL	0.1674			ADL	0.033							DLL	0.1002
243	Cu	Measured	µg			BDL	0.0116			BDL	0.0116							DLL	0.0116
244	Eu	Measured	µg			BDL	0.9779			ADL	0.3416							DLL	0.65975
245	Fe	Measured	µg			ADL	0.0047			ADL	0.0212							DLL	0.01295
246	Ga	Measured	µg			BDL	0.0116			BDL	0.0116							DLL	0.0116
247	Hf	Measured	µg			BDL	0.1666			BDL	0.1666							DLL	0.1666
248	Hg	Measured	µg			BDL	0.025			BDL	0.025							DLL	0.025
249	In	Measured	µg			ADL	0.0289			ADL	0.0183							DLL	0.0236
250	Ir	Measured	µg			BDL	0.0366			BDL	0.0366							DLL	0.0366
251	K	Measured	µg			ADL	0.0012			BDL	0.0216							DLL	0.0114
252	La	Measured	µg			BDL	0.1966			ADL	0.132							DLL	0.1643
253	Mg	Measured	µg			BDL	1.8612			BDL	1.8605							DLL	1.86085
254	Mn	Measured	µg			BDL	0.0334			BDL	0.0334							DLL	0.0334
255	Mo	Measured	µg			ADL	0.0053			BDL	0.0184							DLL	0.01185
256	Na	Measured	µg			ADL	0.5408			BDL	7.5397							DLL	4.04025
257	Nb	Measured	µg			BDL	0.01			BDL	0.01							DLL	0.01
258	Ni	Measured	µg			BDL	0.0066			BDL	0.0066							DLL	0.0066
259	Pb	Measured	µg			ADL	0.0106			ADL	0.0224							DLL	0.0165
260	Pd	Measured	µg			BDL	0.06			BDL	0.06							DLL	0.06
261	Ph	Measured	µg			ADL	0.0265			ADL	0.0029							DLL	0.0147
262	Rb	Measured	µg			BDL	0.0034			ADL	0.0048							DLL	0.0041
263	S	Measured	µg			BDL	0.0167			BDL	0.0167							DLL	0.0167
264	Sb	Measured	µg			ADL	0.0548			BDL	0.0833							DLL	0.06905
265	Sc	Measured	µg			BDL	0.3569			BDL	0.3569							DLL	0.3569
266	Se	Measured	µg			BDL	0.015			BDL	0.015							DLL	0.015
267	Si	Measured	µg			ADL	0.1773			BDL	0.0512							DLL	0.11425
268	Sm	Measured	µg			BDL	0.6606			BDL	0.6597							DLL	0.66015
269	Sn	Measured	µg			ADL	0.059			ADL	0.0295							DLL	0.04425
270	Sr	Measured	µg			BDL	0.0116			BDL	0.0116							DLL	0.0116
271	Ta	Measured	µg			BDL	0.1666			BDL	0.1666							DLL	0.1666
272	Tb	Measured	µg			BDL	0.4764			BDL	0.4723							DLL	0.47435
273	Ti	Measured	µg			ADL	0.0325			ADL	0.0042							DLL	0.01835
274	Tl	Measured	µg			ADL	0.0113			BDL	0.0133							DLL	0.0123
275	U	Measured	µg			BDL	0.0349			BDL	0.0349							DLL	0.0349
276	V	Measured	µg			ADL	0.0012			BDL	0.0034							DLL	0.0023
277	W	Measured	µg			BDL	0.1666			BDL	0.1666							DLL	0.1666
278	Yt	Measured	µg			ADL	0.013			ADL	0.0012							DLL	0.0071
279	Zn	Measured	µg			ADL	0.0129			BDL	0.0199							DLL	0.0164
280	Zr	Measured	µg			ADL	0.0018			ADL	0.016							DLL	0.0089

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Buick**					Run 1				Run 2				Run 3				Average	
2	Parameter	Type	Units			Value				Value				Value				Value	
282	Ions																		
283	NH4+	Measured	µg			BDL	0.0167			BDL	0.0167							DLL	0.0167
284	Cl-	Measured	µg			BDL	0.0167			BDL	0.0167							DLL	0.0167
285	NO3-	Measured	µg			ADL	0.088581817			ADL	0.159572873							DLL	0.124077345
286	K+	Measured	µg			BDL	0.501154035			BDL	0.501166498							DLL	0.501160267
287	Na+	Measured	µg			BDL	0.580636343			ADL	0.035211205							DLL	0.307923774
288	SO42-	Measured	µg			BDL	0.0167			BDL	0.0167							DLL	0.0167
289																			
290																			

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Buick**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
291	**Species Lab Results - STFB Dilution Air**																		
292	Carbon																		
293	OC	Measured	µg																
294	EC	Measured	µg																
295	Total C	Measured	µg																
296	OC Backup	Measured	µg			ADL	8.16895			ADL	7.27283							DLL	7.72089
297	EC Backup	Measured	µg			BDL	0.763166667			ADL	0.05896							DLL	0.411063333
298	Total C Backup	Measured	µg			ADL	8.16895			ADL	7.3318							DLL	7.750375
300	Elements																		
301	Ag	Measured	µg			BDL	0.0334			BDL	0.0334							DLL	0.0334
302	Al	Measured	µg			BDL	0.4615			BDL	0.4623							DLL	0.4619
303	As	Measured	µg			BDL	0.0133			BDL	0.0133							DLL	0.0133
304	Au	Measured	µg			BDL	0.0366			BDL	0.0366							DLL	0.0366
305	Ba	Measured	µg			BDL	0.1191			BDL	0.1182							DLL	0.11865
306	Br	Measured	µg			ADL	0.0053			ADL	0.003							DLL	0.00415
307	Ca	Measured	µg			BDL	0.0133			BDL	0.0125							DLL	0.0129
308	Cd	Measured	µg			BDL	0.0666			BDL	0.0666							DLL	0.0666
309	Ce	Measured	µg			ADL	0.2398			BDL	0.4668							DLL	0.3533
310	Cl	Measured	µg			ADL	0.195			ADL	0.0195							DLL	0.10725
311	Co	Measured	µg			BDL	0.0034			BDL	0.0034							DLL	0.0034
312	Cr	Measured	µg			BDL	0.0133			BDL	0.0133							DLL	0.0133
313	Cs	Measured	µg			ADL	0.0389			BDL	0.1683							DLL	0.1036
314	Cu	Measured	µg			BDL	0.0116			ADL	0.0118							DLL	0.0117
315	Eu	Measured	µg			BDL	0.9804			BDL	0.9796							DLL	0.98
316	Fe	Measured	µg			ADL	0.0177			ADL	0.0766							DLL	0.04715
317	Ga	Measured	µg			BDL	0.0116			BDL	0.0116							DLL	0.0116
318	Hf	Measured	µg			BDL	0.1666			BDL	0.1666							DLL	0.1666
319	Hg	Measured	µg			BDL	0.025			BDL	0.025							DLL	0.025
320	In	Measured	µg			ADL	0.0042			ADL	0.0183							DLL	0.01125
321	Ir	Measured	µg			BDL	0.0366			BDL	0.0366							DLL	0.0366
322	K	Measured	µg			BDL	0.0216			BDL	0.0216							DLL	0.0216
323	La	Measured	µg			BDL	0.1983			BDL	0.1974							DLL	0.19785
324	Mg	Measured	µg			BDL	1.8513			BDL	1.8588							DLL	1.85505
325	Mn	Measured	µg			ADL	0.0177			ADL	0.0071							DLL	0.0124
326	Mo	Measured	µg			BDL	0.0184			BDL	0.0184							DLL	0.0184
327	Na	Measured	µg			BDL	7.7524			BDL	7.8645							DLL	7.80845
328	Nb	Measured	µg			BDL	0.01			BDL	0.01							DLL	0.01
329	Ni	Measured	µg			BDL	0.0066			BDL	0.0066							DLL	0.0066
330	Pb	Measured	µg			ADL	0.0212			ADL	0.0248							DLL	0.023
331	Pd	Measured	µg			BDL	0.06			BDL	0.06							DLL	0.06
332	Ph	Measured	µg			BDL	0.0266			BDL	0.0266							DLL	0.0266
333	Rb	Measured	µg			ADL	0.0036			ADL	0.0024							DLL	0.003
334	S	Measured	µg			BDL	0.0167			BDL	0.0167							DLL	0.0167
335	Sb	Measured	µg			ADL	0.0466			ADL	0.0678							DLL	0.0572
336	Sc	Measured	µg			BDL	0.3569			BDL	0.3569							DLL	0.3569
337	Se	Measured	µg			BDL	0.015			ADL	0.0112							DLL	0.0131
338	Si	Measured	µg			ADL	0.3046			ADL	0.0866							DLL	0.1956
339	Sm	Measured	µg			BDL	0.6597			BDL	0.6581							DLL	0.6589
340	Sn	Measured	µg			ADL	0.0425			ADL	0.0236							DLL	0.03305
341	Sr	Measured	µg			BDL	0.0116			ADL	0.0035							DLL	0.00755
342	Ta	Measured	µg			BDL	0.1666			BDL	0.1666							DLL	0.1666
343	Tb	Measured	µg			BDL	0.4756			ADL	0.0784							DLL	0.277
344	Ti	Measured	µg			ADL	0.0348			ADL	0.0018							DLL	0.0183
345	Tl	Measured	µg			BDL	0.0133			ADL	0.0042							DLL	0.00875
346	U	Measured	µg			BDL	0.0349			BDL	0.0349							DLL	0.0349
347	V	Measured	µg			BDL	0.0034			BDL	0.0034							DLL	0.0034
348	W	Measured	µg			ADL	0.0743			ADL	0.0189							DLL	0.0466
349	Yt	Measured	µg			ADL	0.0001			ADL	0.0095							DLL	0.0048
350	Zn	Measured	µg			ADL	0.0012			ADL	0.0071							DLL	0.00415
351	Zr	Measured	µg			BDL	0.015			ADL	0.0148							DLL	0.0149

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Buick**					Run 1				Run 2				Run 3				Average	
2	Parameter	Type	Units			Value				Value				Value				Value	
353	Ions																		
354	NH4+	Measured	μg																
355	Cl-	Measured	μg																
356	NO3-	Measured	μg																
357	K+	Measured	μg																
358	Na+	Measured	μg																
359	SO42-	Measured	μg																
360																			
361																			

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Buick**					Run 1				Run 2				Run 3				Average	
2	Parameter	Type	Units			Value				Value				Value				Value	
362	**Species Concentrations (with dilution air blank subtraction)**																		
365	Carbon																		
366	OC	Calculated	mg/dscm			ADL	0.422258495			ADL	0.177318949			ADL	0.152221348			ADL	0.250599597
367	EC	Calculated	mg/dscm			ADL	0.027164807	FB		ADL	0.006428686			BDL	0.002027474			DLL	0.011873655
368	Total C	Calculated	mg/dscm			ADL	0.449423291			ADL	0.183747635			ADL	0.152221348			ADL	0.261797425
369	OC Backup	Calculated	mg/dscm		B	ADL	0.058430655		B	ADL	0.024865203		B	ADL	0.053163491		B	ADL	0.04548645
370	EC Backup	Calculated	mg/dscm		B	ADL	0.001758817		B	ADL	5.10592E-05		B	ADL	2.98738E-05		B	ADL	0.00061325
371	Total C Backup	Calculated	mg/dscm		B	ADL	0.013010096		B	ADL	0.00680918		B	ADL	0.00658125		B	ADL	0.008800175
373	Elements																		
374	Ag	Calculated	mg/dscm			BDL	4.71968E-06			BDL	6.4454E-06			BDL	4.887E-06			BDL	5.35069E-06
375	Al	Calculated	mg/dscm			BDL	5.98558E-05			BDL	0.000980813			BDL	6.95415E-05			BDL	0.00037007
376	As	Calculated	mg/dscm			BDL	1.87939E-06			BDL	2.56658E-06			BDL	1.94602E-06			BDL	2.13067E-06
377	Au	Calculated	mg/dscm			BDL	1.53674E-05			BDL	7.06292E-06			BDL	5.90307E-05			BDL	2.71537E-05
378	Ba	Calculated	mg/dscm	FB	B	BBL	6.34599E-05			BDL	0.000410691			BDL	1.71923E-05	FB	B	DLL	0.000163781
379	Br	Calculated	mg/dscm			ADL	0.000737793	FB		ADL	0.000106854	FB		BBL	2.92317E-05			DLL	0.000291293
380	Ca	Calculated	mg/dscm		B	ADL	7.19201E-05			BBL	4.55562E-05			BDL	3.35157E-05		B	DLL	5.03306E-05
381	Cd	Calculated	mg/dscm	FB		BBL	6.34599E-05			BDL	0.000188569	FB		BBL	0.00016783	FB	B	DLL	0.000139953
382	Ce	Calculated	mg/dscm			BDL	0.000125851			BDL	0.00069019	FB		BBL	0.001176324	FB	B	DLL	0.000664122
383	Cl	Calculated	mg/dscm		B	ADL	4.89588E-05	FB	B	ADL	3.13872E-05	FB	B	BBL	8.16472E-05		B	DLL	5.39977E-05
384	Co	Calculated	mg/dscm			BDL	4.80447E-07			BDL	6.56118E-07			BDL	4.97479E-07			BDL	5.44681E-07
385	Cr	Calculated	mg/dscm	FB		BBL	1.26729E-05			BDL	5.68596E-05			ADL	2.94088E-05	FB	B	DLL	3.29805E-05
386	Cs	Calculated	mg/dscm			BDL	2.22576E-05			BDL	3.53725E-05	FB		ADL	0.000352287	FB	B	DLL	0.000136639
387	Cu	Calculated	mg/dscm		B	BBL	2.28684E-06			BDL	0.000290806			BDL	1.69728E-06		B	DLL	9.82634E-05
388	Eu	Calculated	mg/dscm			BDL	0.001064741	FB	B	BBL	0.002675143			BDL	0.000147716	FB	B	DLL	0.001295866
389	Fe	Calculated	mg/dscm			ADL	7.68329E-05	FB	B	ADL	4.44322E-06		B	ADL	5.39873E-05	FB	B	ADL	4.50878E-05
390	Ga	Calculated	mg/dscm			BDL	1.63917E-06			BDL	2.23852E-06			BDL	1.69728E-06			BDL	1.85832E-06
391	Hf	Calculated	mg/dscm			BDL	2.35419E-05			BDL	3.21498E-05			BDL	2.43765E-05			BDL	2.66894E-05
392	Hg	Calculated	mg/dscm			BBL	2.38213E-05			BDL	7.02472E-05			BBL	6.29994E-05		B	DLL	5.23559E-05
393	In	Calculated	mg/dscm	FB		BBL	3.02054E-05			BDL	6.11734E-06			BDL	4.63826E-06	FB		DLL	1.36537E-05
394	Ir	Calculated	mg/dscm			BDL	5.17187E-06			BDL	7.06292E-06			BDL	5.35522E-06			BDL	5.86334E-06
395	K	Calculated	mg/dscm			ADL	0.00017431	FB	B	ADL	4.49725E-05			BDL	5.1544E-05			DLL	9.02756E-05
396	La	Calculated	mg/dscm			BDL	0.000157577			BDL	0.000322734			BDL	2.45991E-05			BDL	0.000168303
397	Mg	Calculated	mg/dscm			BDL	0.00022974		B	BBL	0.00611926			BDL	0.003668534		B	DLL	0.003339178
398	Mn	Calculated	mg/dscm			BBL	3.18252E-05			BBL	0.000114404			BBL	8.41671E-05			BBL	7.67989E-05
399	Mo	Calculated	mg/dscm			BDL	2.60006E-06			BDL	5.25322E-05			BDL	2.69224E-06			BDL	1.92748E-05
400	Na	Calculated	mg/dscm			BDL	0.007137996	FB		BBL	0.026395882			BDL	0.00183147	FB		DLL	0.011788449
401	Nb	Calculated	mg/dscm			BDL	7.51132E-06			BDL	1.92976E-06			BDL	1.46317E-06			BDL	3.63475E-06
402	Ni	Calculated	mg/dscm			BDL	9.32632E-07			BBL	2.26068E-05			BDL	9.65695E-07			DLL	8.16839E-06
403	Pb	Calculated	mg/dscm	FB	B	BBL	3.59225E-05			BDL	0.000137354	FB	B	ADL	2.03061E-05	FB	B	DLL	6.45274E-05
404	Pd	Calculated	mg/dscm			BDL	8.47847E-06			BDL	0.000216753			BDL	8.77905E-06			BDL	7.80034E-05
405	P	Calculated	mg/dscm			ADL	0.002646817	FB		ADL	4.74667E-05	FB	B	BBL	5.49354E-05			DLL	0.000916406
406	Rb	Calculated	mg/dscm			BDL	2.57672E-06			BDL	6.56118E-07	FB		ADL	6.1471E-06	FB	B	DLL	3.12665E-06
407	S	Calculated	mg/dscm			BDL	2.35984E-06			BDL	3.2227E-06			BDL	2.4435E-06			BDL	2.67535E-06
408	Sb	Calculated	mg/dscm			BDL	1.17709E-05			BDL	8.52655E-05	FB	B	BBL	0.00015901	FB	B	DLL	8.53489E-05
409	Sc	Calculated	mg/dscm			BDL	4.95752E-05			BDL	0.000818155			BDL	5.22207E-05			BDL	0.00030665
410	Se	Calculated	mg/dscm			BDL	2.11962E-06			BBL	5.13792E-05			BDL	2.19476E-06			DLL	1.85645E-05
411	Si	Calculated	mg/dscm			ADL	0.135386519	FB	B	ADL	0.000730598	FB	B	BBL	0.000325077			DLL	0.045480731
412	Sm	Calculated	mg/dscm			BBL	0.000628596			BBL	0.002277125			BDL	0.001751635		B	DLL	0.001552452
413	Sn	Calculated	mg/dscm	FB		BBL	5.7171E-05			BDL	0.000136259			BDL	0.000109326	FB	B	DLL	0.000100919
414	Sr	Calculated	mg/dscm		B	BBL	5.62182E-06			BDL	2.23852E-06			BDL	2.97357E-05		B	DLL	1.2532E-05
415	Ta	Calculated	mg/dscm			BDL	2.35419E-05			BDL	3.21498E-05			BDL	2.43765E-05			BDL	2.66894E-05
416	Tb	Calculated	mg/dscm			BDL	8.06391E-05			BBL	0.001646189			BDL	0.00121984		B	DLL	0.000982223
417	Ti	Calculated	mg/dscm	FB	B	BBL	8.48037E-06	FB		ADL	9.86336E-05			BDL	1.21443E-06	FB	B	DLL	3.61095E-05
418	Tl	Calculated	mg/dscm	FB		BBL	1.26729E-05	FB		BBL	4.55562E-05			BDL	1.94602E-06	FB		DLL	2.00584E-05
419	U	Calculated	mg/dscm			BDL	4.93164E-06		B	ADL	1.00539E-05			BBL	8.79471E-05		B	DLL	3.43109E-05
420	V	Calculated	mg/dscm			BDL	8.9568E-06	FB	B	BBL	3.21976E-05			BDL	3.01745E-06	FB	B	DLL	1.4724E-05
421	W	Calculated	mg/dscm			BDL	0.000165421		B	BBL	0.000270597			BBL	0.000419828		B	DLL	0.000285282
422	Y	Calculated	mg/dscm	FB	B	ADL	2.0709E-05			BDL	2.23852E-06	FB	B	BBL	2.39398E-05	FB	B	DLL	1.56291E-05
423	Zn	Calculated	mg/dscm	FB	B	BBL	1.68655E-05			BDL	8.0494E-05	FB		BBL	5.01475E-05	FB	B	DLL	4.9169E-05
424	Zr	Calculated	mg/dscm			BDL	1.24104E-05	FB		BBL	5.13792E-05	FB	B	ADL	1.63876E-06	FB	B	DLL	2.18094E-05

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Buick**					Run 1				Run 2				Run 3				Average	
2	Parameter	Type	Units			Value				Value				Value				Value	
426	Ions																		
427	NH4+	Calculated	mg/dscm			BDL	1.82161E-05			BDL	6.01755E-05			BDL	4.43662E-05			BDL	4.09192E-05
428	Cl-	Calculated	mg/dscm			BDL	1.82161E-05			BDL	6.01755E-05			BDL	4.43662E-05			BDL	4.09192E-05
429	NO3-	Calculated	mg/dscm	FB	#	ADL	0.000457298	FB	#	ADL	0.000361781	FB	#	ADL	0.000665381	FB	#	ADL	0.00049482
430	K+	Calculated	mg/dscm			BDL	0.000547597			BDL	0.001805887			BDL	0.001331403			BDL	0.001228296
431	Na+	Calculated	mg/dscm	FB	#	ADL	0.000173633			BDL	0.002053314			BDL	0.001526405	FB	#	DLL	0.001251118
432	SO42-	Calculated	mg/dscm			BDL	1.82161E-05			BDL	6.01755E-05			BDL	4.43662E-05			BDL	4.09192E-05
433																			
434																			

	A	B	C	D E F	G	H I J	K	L M N	O	P Q R	S
1	**Modified CTM 39, Site Buick**			Run 1		Run 2		Run 3		Average	
2	Parameter	Type	Units	Value		Value		Value		Value	
435	**Reconstructed Mass (applying oxide factors for elements and 1/2 RL for BDL, subtract OC Backup and dilution air blank)**										
436	OC	Calculated	mg/dscm	ADL	0.392934067	ADL	0.164650046	ADL	0.106982486	ADL	0.2215222
437	EC	Calculated	mg/dscm	ADL	0.027164807	ADL	0.006428686	BDL	0.001013737	DLL	0.011535743
438	Total C	Calculated	mg/dscm								
439	OC Backup	Calculated	mg/dscm								
440	EC Backup	Calculated	mg/dscm								
441	Total C Backup	Calculated	mg/dscm								
443	Elements										
444	Ag	Calculated	mg/dscm	BDL	3.0597E-06	BDL	4.17846E-06	BDL	3.16817E-06	BDL	3.46878E-06
445	Al	Calculated	mg/dscm	BDL	5.65305E-05	BDL	0.000926323	BDL	6.56781E-05	BDL	0.000349511
446	As	Calculated	mg/dscm	BDL	1.4414E-06	BDL	1.96844E-06	BDL	1.4925E-06	BDL	1.63412E-06
447	Au	Calculated	mg/dscm	BDL	8.61991E-06	BDL	3.96175E-06	BDL	3.31117E-05	BDL	1.52311E-05
448	Ba	Calculated	mg/dscm	BBL	7.82459E-05	BDL	0.000253191	BDL	1.0599E-05	DLL	0.000114012
449	Br	Calculated	mg/dscm	ADL	0.001033279	ADL	0.00014965	BBL	4.0939E-05	DLL	0.000407956
450	Ca	Calculated	mg/dscm	ADL	0.000129341	BBL	8.19284E-05	BDL	3.01373E-05	DLL	8.0469E-05
451	Cd	Calculated	mg/dscm	BBL	7.24933E-05	BDL	0.000107706	BBL	0.000191721	DLL	0.000123973
452	Ce	Calculated	mg/dscm	BDL	7.72967E-05	BDL	0.000423909	BBL	0.001444975	DLL	0.000648727
453	Cl	Calculated	mg/dscm	ADL	0.000126299	ADL	8.09692E-05	BBL	0.000210624	DLL	0.000139297
454	Co	Calculated	mg/dscm	BDL	3.27187E-07	BDL	4.4682E-07	BDL	3.38786E-07	BDL	3.70931E-07
455	Cr	Calculated	mg/dscm	BBL	2.43719E-05	BDL	5.46747E-05	ADL	5.65575E-05	DLL	4.52014E-05
456	Cs	Calculated	mg/dscm	BDL	1.17986E-05	BDL	1.87508E-05	ADL	0.000373492	DLL	0.00013468
457	Cu	Calculated	mg/dscm	BBL	2.86264E-06	BDL	0.000182014	BDL	1.06232E-06	DLL	6.19795E-05
458	Eu	Calculated	mg/dscm	BDL	0.000616449	BBL	0.003097634	BDL	8.55224E-05	DLL	0.001266535
459	Fe	Calculated	mg/dscm	ADL	0.000109851	ADL	6.35268E-06	ADL	7.71881E-05	ADL	6.44641E-05
460	Ga	Calculated	mg/dscm	BDL	1.10171E-06	BDL	1.50455E-06	BDL	1.14077E-06	BDL	1.24901E-06
461	Hf	Calculated	mg/dscm	BDL	1.38813E-05	BDL	1.89568E-05	BDL	1.43734E-05	BDL	1.57372E-05
462	Hg	Calculated	mg/dscm	BBL	2.57214E-05	BDL	3.79252E-05	BBL	6.80245E-05	DLL	4.38904E-05
463	In	Calculated	mg/dscm	BBL	3.6519E-05	BDL	3.698E-06	BDL	2.80388E-06	DLL	1.43403E-05
464	Ir	Calculated	mg/dscm	BDL	3.01644E-06	BDL	4.11937E-06	BDL	3.12337E-06	BDL	3.41973E-06
465	K	Calculated	mg/dscm	ADL	0.000316976	ADL	8.17806E-05	BDL	4.68652E-05	DLL	0.000148541
466	La	Calculated	mg/dscm	BDL	9.24022E-05	BDL	0.000189249	BDL	1.44247E-05	BDL	9.8692E-05
467	Mg	Calculated	mg/dscm	BDL	0.000266108	BBL	0.014175887	BDL	0.004249266	DLL	0.00623042
468	Mn	Calculated	mg/dscm	BBL	6.42656E-05	BBL	0.00023102	BBL	0.000169961	BBL	0.000155082
469	Mo	Calculated	mg/dscm	BDL	1.95046E-06	BDL	3.94074E-05	BDL	2.0196E-06	BDL	1.44592E-05
470	Na	Calculated	mg/dscm	BDL	0.008536936	BBL	0.063138159	BDL	0.00219041	DLL	0.024621835
471	Nb	Calculated	mg/dscm	BDL	5.37256E-06	BDL	1.38028E-06	BDL	1.04655E-06	BDL	2.5998E-06
472	Ni	Calculated	mg/dscm	BDL	6.56973E-07	BBL	3.18498E-05	BDL	6.80264E-07	DLL	1.10624E-05
473	Pb	Calculated	mg/dscm	BBL	4.14703E-05	BDL	7.92833E-05	ADL	2.34421E-05	DLL	4.80653E-05
474	Pd	Calculated	mg/dscm	BDL	5.51419E-06	BDL	0.000140971	BDL	5.70968E-06	BDL	5.07315E-05
475	P	Calculated	mg/dscm	ADL	0.006065043	ADL	0.000108768	BBL	0.000125882	DLL	0.002099897
476	Rb	Calculated	mg/dscm	BDL	1.77073E-06	BDL	4.50888E-07	ADL	8.44864E-06	DLL	3.55675E-06
477	S	Calculated	mg/dscm	BDL	3.53535E-06	BDL	4.82802E-06	BDL	3.66068E-06	BDL	4.00801E-06
478	Sb	Calculated	mg/dscm	BDL	7.8191E-06	BDL	5.66394E-05	BBL	0.000211252	DLL	9.19035E-05
479	Sc	Calculated	mg/dscm	BDL	3.80194E-05	BDL	0.000627446	BDL	4.00482E-05	BDL	0.000235171
480	Se	Calculated	mg/dscm	BDL	1.70407E-06	BBL	8.26127E-05	BDL	1.76448E-06	DLL	2.86938E-05
481	Si	Calculated	mg/dscm	Run 1 silicon excluded - probable contamination			0.001563011		0.000695455		0.001129233
482	Sm	Calculated	mg/dscm	BBL	0.00072893	BBL	0.002640593	BDL	0.001015613	DLL	0.001461712
483	Sn	Calculated	mg/dscm	BBL	7.25849E-05	BDL	8.64977E-05	BDL	6.94007E-05	DLL	7.61611E-05
484	Sr	Calculated	mg/dscm	BBL	7.67498E-06	BDL	1.52803E-06	BDL	2.02978E-05	DLL	9.8336E-06
485	Ta	Calculated	mg/dscm	BDL	1.4373E-05	BDL	1.96283E-05	BDL	1.48825E-05	BDL	1.62946E-05
486	Tb	Calculated	mg/dscm	BDL	4.74232E-05	BBL	0.001936221	BDL	0.000717378	DLL	0.000900341
487	Ti	Calculated	mg/dscm	BBL	1.41458E-05	ADL	0.000164527	BDL	1.01287E-06	DLL	5.98951E-05
488	Tl	Calculated	mg/dscm	BBL	1.41611E-05	BBL	5.09061E-05	BDL	1.08728E-06	DLL	2.20515E-05
489	U	Calculated	mg/dscm	BDL	2.96307E-06	ADL	1.20814E-05	BBL	0.000105682	DLL	4.02422E-05
490	V	Calculated	mg/dscm	BDL	7.99501E-06	BBL	5.74804E-05	BDL	2.69344E-06	DLL	2.27229E-05
491	W	Calculated	mg/dscm	BDL	0.000104306	BBL	0.000341249	BBL	0.000529443	DLL	0.000324999
492	Y	Calculated	mg/dscm	ADL	2.62994E-05	BDL	1.4214E-06	BBL	3.04022E-05	DLL	1.93743E-05
493	Zn	Calculated	mg/dscm	BBL	2.51202E-05	BDL	5.99458E-05	BBL	7.4692E-05	DLL	5.32527E-05
494	Zr	Calculated	mg/dscm	BDL	8.38199E-06	BBL	6.9403E-05	ADL	2.21363E-06	DLL	2.66662E-05

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Buick**					Run 1				Run 2				Run 3				Average	
2	Parameter	Type	Units			Value				Value				Value				Value	
496	Ions																		
497	NH4+	Calculated	mg/dscm			BDL	9.10803E-06			BDL	3.00877E-05			BDL	2.21831E-05			BDL	2.04596E-05
498	Cl-	Calculated	mg/dscm			BDL	2.34959E-05			BDL	7.7617E-05			BDL	5.72255E-05			BDL	5.27795E-05
499	NO3-	Calculated	mg/dscm			ADL	0.000457298			ADL	0.000361781			ADL	0.000665381			ADL	0.00049482
500	K+	Calculated	mg/dscm			BDL	0.000497891			BDL	0.001641963			BDL	0.001210549			BDL	0.001116801
501	Na+	Calculated	mg/dscm			ADL	0.000415325			BDL	0.002455733			BDL	0.001825558			DLL	0.001565539
502	SO42-	Calculated	mg/dscm			BDL	1.51763E-05			BDL	5.01337E-05			BDL	3.69626E-05			BDL	3.40908E-05
503																			
504	Reconstructed mas	Calculated	mg/dscm			DLL	0.439714245			DLL	0.264530174			DLL	0.12297198			DLL	0.27611521
505	Species mass closure		%				0.536963169				30.12763333				19.34493419				0.993186828
506																			
507	**Reconstructed mass (w/o Run 1 Si)**	**Calculated**	**mg/dscm**			DLL	0.439714245	FB		DLL	0.264530174	FB		DLL	0.12297198	FB		DLL	0.275738799
508	**Reconstructed mass (w/o Run 1 Si)**	**Calculated**	lb/MMBtu			DLL	0.000888948	FB		DLL	0.000517116	FB		DLL	0.000244214	FB		DLL	0.000550093
509	**Reconstructed mass (w/o Run 1 Si)**	**Calculated**	kg/GJ			DLL	0.000382163	FB		DLL	0.000222311	FB		DLL	0.000104989	FB		DLL	2.36E-04

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Buick**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
658	**Species Profile (fraction of sum of species, with dilution air blank)**																		
659	OC	Calculated	mg/mg		0	ADL	0.893612322		0	ADL	0.622424442		0	ADL	0.86997449		0	ADL	0.802281769
660	EC	Calculated	mg/mg		0	ADL	0.061778318	FB	0	ADL	0.024302279		0	BDL	0.00824364		0	DLL	0.041778731
661	Total C	Calculated	mg/mg																
662	OC Backup	Calculated	mg/mg																
663	EC Backup	Calculated	mg/mg																
664	Total C Backup	Calculated	mg/mg																
665																			
666	Elements (as oxides)																		
667	Ag	Calculated	mg/mg			BDL	6.95839E-06			BDL	1.57958E-05			BDL	2.57634E-05			BDL	1.25628E-05
668	Al	Calculated	mg/mg			BDL	0.000128562			BDL	0.003501768			BDL	0.00053409			BDL	0.001265814
669	As	Calculated	mg/mg			BDL	3.27805E-06			BDL	7.44128E-06			BDL	1.21369E-05			BDL	5.91824E-06
670	Au	Calculated	mg/mg			BDL	1.96034E-05			BDL	1.49766E-05			BDL	0.000269262			BDL	5.51621E-05
671	Ba	Calculated	mg/mg	FB	B	BBL	0.000177947			BDL	0.000957133			BDL	8.61907E-05	FB	B	DLL	0.000412914
672	Br	Calculated	mg/mg			ADL	0.002349888	FB		ADL	0.000565718	FB		BBL	0.000332913			DLL	0.001477484
673	Ca	Calculated	mg/mg		B	ADL	0.000294148			BBL	0.000309713			BDL	0.000245075		B	DLL	0.000291433
674	Cd	Calculated	mg/mg	FB		BBL	0.000164865			BDL	0.000407159	FB		BBL	0.00155906	FB	B	DLL	0.000448991
675	Ce	Calculated	mg/mg			BDL	0.000175788			BDL	0.001602496	FB		BBL	0.011750445	FB	B	DLL	0.002349479
676	Cl	Calculated	mg/mg		B	ADL	0.000287229	FB	B	ADL	0.000306087	FB	B	BBL	0.001712783		B	DLL	0.00050449
677	Co	Calculated	mg/mg			BDL	7.4409E-07			BDL	1.68911E-06			BDL	2.75499E-06			BDL	1.34339E-06
678	Cr	Calculated	mg/mg	FB		BBL	5.54267E-05			BDL	0.000206686			ADL	0.000459922	FB	B	DLL	0.000163705
679	Cs	Calculated	mg/mg			BDL	2.68325E-05			BDL	7.08834E-05	FB		ADL	0.003037209	FB	B	DLL	0.000487769
680	Cu	Calculated	mg/mg		B	BBL	6.51022E-06			BDL	0.000688063			BDL	8.63869E-06		B	DLL	0.00022447
681	Eu	Calculated	mg/mg			BDL	0.001401931	FB	B	BBL	0.011709944			BDL	0.000695462	FB	B	DLL	0.00458698
682	Fe	Calculated	mg/mg			ADL	0.000249825	FB	B	ADL	2.40149E-05		B	ADL	0.000627688	FB	B	ADL	0.000233468
683	Ga	Calculated	mg/mg			BDL	2.50552E-06			BDL	5.68763E-06			BDL	9.27668E-06			BDL	4.52352E-06
684	Hf	Calculated	mg/mg			BDL	3.15688E-05			BDL	7.16623E-05			BDL	0.000116883			BDL	5.69949E-05
685	Hg	Calculated	mg/mg			BBL	5.84956E-05			BDL	0.000143368			BBL	0.000553171		B	DLL	0.000158957
686	In	Calculated	mg/mg	FB		BBL	8.30516E-05			BDL	1.39795E-05			BDL	2.2801E-05	FB		DLL	5.19359E-05
687	Ir	Calculated	mg/mg			BDL	6.85999E-06			BDL	1.55724E-05			BDL	2.53991E-05			BDL	1.23851E-05
688	K	Calculated	mg/mg			ADL	0.000720868	FB	B	ADL	0.000309154			BDL	0.000381105			DLL	0.000537966
689	La	Calculated	mg/mg			BDL	0.000210141			BDL	0.000715416			BDL	0.000117301			BDL	0.00035743
690	Mg	Calculated	mg/mg			BDL	0.000605183		B	BBL	0.053588924			BDL	0.034554751		B	DLL	0.022564568
691	Mn	Calculated	mg/mg			BBL	0.000146153			BBL	0.000873322			BBL	0.001382114			BBL	0.000561658
692	Mo	Calculated	mg/mg			BDL	4.43573E-06			BDL	0.000148971			BDL	1.64233E-05			BDL	5.23664E-05
693	Na	Calculated	mg/mg			BDL	0.019414736	FB		BBL	0.238680367			BDL	0.017812271	FB		DLL	0.089172324
694	Nb	Calculated	mg/mg			BDL	1.22183E-05			BDL	5.21787E-06			BDL	8.5105E-06			BDL	9.41564E-06
695	Ni	Calculated	mg/mg			BDL	1.49409E-06			BBL	0.000120402			BDL	5.53186E-06			DLL	4.00643E-05
696	Pb	Calculated	mg/mg	FB	B	BBL	9.4312E-05			BDL	0.000299714	FB	B	ADL	0.00019063	FB	B	DLL	0.000174077
697	Pd	Calculated	mg/mg			BDL	1.25404E-05			BDL	0.00053291			BDL	4.64307E-05			BDL	0.000183733
698	P	Calculated	mg/mg			ADL	0.013793146	FB		ADL	0.000411173	FB	B	BBL	0.001023661			DLL	0.007605149
699	Rb	Calculated	mg/mg			BDL	4.02701E-06			BDL	1.70449E-06	FB		ADL	6.87038E-05	FB	B	DLL	1.28814E-05
700	S	Calculated	mg/mg			BDL	8.0401E-06			BDL	1.82513E-05			BDL	2.97684E-05			BDL	1.45157E-05
701	Sb	Calculated	mg/mg			BDL	1.77822E-05			BDL	0.000214113	FB	B	BBL	0.001717887	FB	B	DLL	0.000332845
702	Sc	Calculated	mg/mg			BDL	8.64639E-05			BDL	0.002371928			BDL	0.00032567			BDL	0.000851715
703	Se	Calculated	mg/mg			BDL	3.8754E-06			BBL	0.0003123			BDL	1.43486E-05			DLL	0.00010392
704	Si	Calculated	mg/mg			ADL	0	FB	B	ADL	0.00590863	FB	B	BBL	0.005655396			DLL	0.004089717
705	Sm	Calculated	mg/mg			BBL	0.001657736			BBL	0.009982199			BDL	0.008258896		B	DLL	0.005293848
706	Sn	Calculated	mg/mg	FB		BBL	0.000165073			BDL	0.000326986			BDL	0.000564362	FB	B	DLL	0.000275831
707	Sr	Calculated	mg/mg		B	BBL	1.74545E-05			BDL	5.77639E-06			BDL	0.00016506		B	DLL	3.56141E-05
708	Ta	Calculated	mg/mg			BDL	3.26871E-05			BDL	7.42008E-05			BDL	0.000121024			BDL	5.90138E-05
709	Tb	Calculated	mg/mg			BDL	0.00010785			BBL	0.00731947			BDL	0.005833669		B	DLL	0.003260742
710	Ti	Calculated	mg/mg	FB	B	BBL	3.21703E-05	FB		ADL	0.000621958			BDL	8.23662E-06	FB	B	DLL	0.000216921
711	Tl	Calculated	mg/mg	FB		BBL	3.22053E-05	FB		BBL	0.00019244			BDL	8.84165E-06	FB		DLL	7.98634E-05
712	U	Calculated	mg/mg			BDL	6.73862E-06		B	ADL	4.5671E-05			BBL	0.0008594		B	DLL	0.000145744
713	V	Calculated	mg/mg			BDL	1.81823E-05	FB	B	BBL	0.000217292			BDL	2.19028E-05	FB	B	DLL	8.22952E-05
714	W	Calculated	mg/mg			BDL	0.000237214		B	BBL	0.001290019			BBL	0.004305398		B	DLL	0.001177043
715	Y	Calculated	mg/mg	FB	B	ADL	5.98102E-05			BDL	5.37331E-06	FB	B	BBL	0.000247229	FB	B	DLL	7.01676E-05
716	Zn	Calculated	mg/mg	FB	B	BBL	5.71285E-05			BDL	0.000226612	FB		BBL	0.00060739	FB	B	DLL	0.000192864
717	Zr	Calculated	mg/mg			BDL	1.90624E-05	FB		BBL	0.000262363	FB	B	ADL	1.80011E-05	FB	B	DLL	9.65764E-05
718																			

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Buick**					Run 1				Run 2				Run 3				Average	
2	Parameter	Type	Units			Value				Value				Value				Value	
719	Ions (Cl-, K+,Na+ as oxides)																		
720	NH4+	Calculated	mg/mg			BDL	2.07135E-05			BDL	0.00011374			BDL	0.000180392			BDL	7.40981E-05
721	Cl-	Calculated	mg/mg			BDL	5.34344E-05			BDL	0.000293415			BDL	0.000465354			BDL	0.00019115
722	NO3-	Calculated	mg/mg	FB	#	ADL	0.001039989	FB	#	ADL	0.001367637	FB	#	ADL	0.005410836	FB	#	ADL	0.001792078
723	K+	Calculated	mg/mg			BDL	0.001132305			BDL	0.006207092			BDL	0.009844101			BDL	0.004044691
724	Na+	Calculated	mg/mg	FB	#	ADL	0.000944534			BDL	0.009283377			BDL	0.014845314	FB	#	DLL	0.005669875
725	SO42-	Calculated	mg/mg			BDL	3.45139E-05			BDL	0.00018952			BDL	0.000300577			BDL	0.000123466
726																			
727																			

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Modified CTM 39, Site Buick**						Run 1				Run 2				Run 3				Average
2	Parameter	Type	Units				Value				Value				Value				Value
797	**Results for 142-mm filter and recovery rinses (with dilution air blank correction)**																		
798	Vds(std)'	Calculated	dscm				6.077199158				28.22057445				31.28221005				21.85999455
799	mar,probe	Calculated	mg	FB		BDL	0.31	FB		BDL	0.56	FB		BDL	0.55				0.473333333
800	mar,venturi	Calculated	mg	FB		BDL	1.07	FB		BDL	2.55	FB		BDL	1.6				1.74
801	mwr,chamber	Calculated	mg	FB		BDL	1.77	FB		BDL	1.53	FB		BDL	0.7				1.333333333
802	mf142mm	Calculated	mg			no fi	0			no fi	0			no fi	0			no fi	0
803	Cs,probe	Calculated	mg/dscm	FB		BDL	0.125035003	FB		BDL	0.320418761	FB		BDL	0.261847994				0.235767252
804	Cs,venturi	Calculated	mg/dscm	FB		BDL	0.431572429	FB		BDL	1.459049713	FB		BDL	0.761739619				0.884120587
805	Cs,chamber	Calculated	mg/dscm	FB		BDL	0.713909532	FB		BDL	0.875429828	FB		BDL	0.333261083				0.640866814
806	Cs,142mmf	Calculated	mg/dscm			no fi	-0.010481358			no fi	-0.027402228			no fi	-0.01763982			no fi	-0.018507802
807																			
808	**Results for 142mm and 47mm filters with recovery rinses (with dilution air blank correction)**																		
809	mf47q,est	Calculated	mg				0.760346654				0.010041442				0.009032633				0.25980691
810	Cs,f+r,total	Calculated	mg/dscm	FB		DLL	1.872443598	FB		DLL	2.638963313	FB		DLL	1.347793984	FB		DLL	1.953066965
811	Es,f+r,total	Calculated	lb/MMBtu	FB		DLL	0.003785425	FB		DLL	0.00515877	FB		DLL	0.002676626	FB		DLL	0.003873607
812	Es,f+r,total	Calculated	kg/GJ	FB		DLL	0.001627372	FB		DLL	0.002217779	FB		DLL	0.001150694	FB		DLL	0.001665282
816																			
817	**Results for 142mm and 47mm filters without recovery rinses (with dilution air blank correction)**																		
818	Cs,f,total	Calculated	mg/dscm				0.601926635				-0.015934989				-0.009054713				0.192312311
819	Es,f,total	Calculated	lb/MMBtu				0.001216885				-3.11505E-05				-1.7982E-05				0.000389251
820	Es,f,total	Calculated	kg/GJ				0.000523144				-1.33917E-05				-7.73056E-06				0.000167341

APPENDIX B
U.S. EPA AP-42 EMISSION FACTOR DATA SUMMARIES

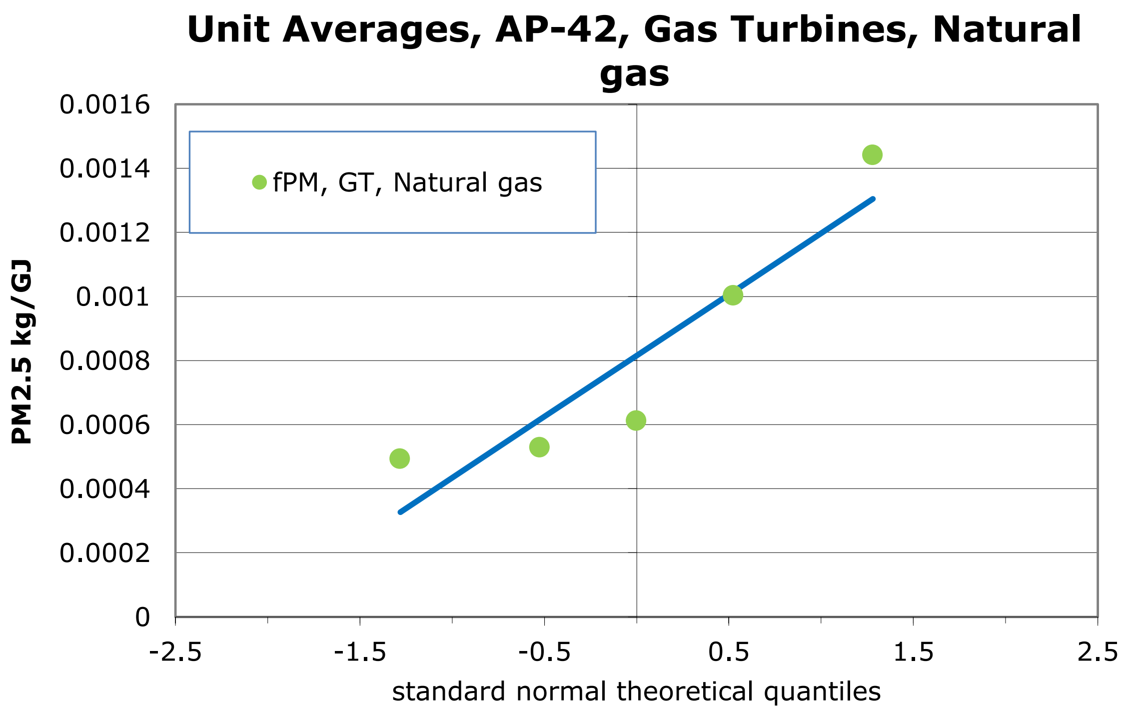
Parameter	Units	Value	Value	Value (1)	Value (2)
Data set		fPM	cPM	f+cPM	f+cPM
Number of units tested		5	5	5	5
Mean	kg/GJ	8.16E-04	2.03E-03	2.84E-03	2.84E-03
Median	kg/GJ	6.12E-04	2.22E-03		3.61E-03
Geometric mean	kg/GJ	7.46E-04	1.19E-03		2.18E-03
Minimum	kg/GJ	4.93E-04	2.54E-04	7.47E-04	7.47E-04
Maximum	kg/GJ	1.44E-03	4.70E-03	6.14E-03	5.23E-03
Standard deviation	kg/GJ	4.04E-04	1.84E-03	1.88E-03	1.93E-03
COV	%	50	91	91	68
Confidence level	%	95%	95%		95%
Measurement bias	%	6.5	6.5		6.5
t factor (2 tail)		2.78	2.78		2.78
t factor (1 tail)		1.53	1.53		1.53
Total uncertainty	%	62	113	129	85
Total uncertainty	kg/GJ	5.05E-04	2.28E-03	2.34E-03	2.40E-03
95% confidence upper bound	kg/GJ	1.10E-03	3.29E-03		4.18E-03
Data distribution		normal	normal		normal
99% confidence upper prediction limit	kg/GJ	2.48E-03	9.56E-03		1.08E-02

(1) by combining fPM + cPM factors
(2) by combining fPM+cPM unit average results

AP-42 Data Gas Turbines
Unit averages

FacilityID	UnitID	Make	Model	Rating (MW)	Fuel	Controls	Pollutant	Run ID	Test Date	Test Method	Test Run Emission Value lb/MMBtu	Test Run Emission Value kg/GJ	ln (Run Value)
WDNR Fon du Lac	WDNR0098-1	ABB	GT11N1	86	natural gas	Water injection	fPM	Average	4/18/1994	EPA 5	0.001423911	0.0006121461573	-7.398539485
WDNR Fon du Lac	WDNR0098-2	ABB	GT11N1	86	natural gas	Water injection	fPM	Average	4/18/1994	EPA 5	0.001146864	0.0004930419774	-7.614916241
WDNR Fon du Lac	WDNR0099-1	ABB	GT11N1	86	natural gas	Water injection	fPM	Average	6/12/1994	EPA 5	0.002332621	0.0010028046025	-6.904954602
WDNR Fon du Lac	WDNR0099-2	ABB	GT11N1	86	natural gas	Water injection	fPM	Average	6/12/1994	EPA 5	0.003352109	0.0014410874203	-6.542357297
WDNR Fon du Lac	WDNR0102-1	ABB	GT11N1	86	natural gas	Water injection	fPM	Average	4/16/1996	EPA 5	0.001230803	0.0005291278058	-7.544280556

x

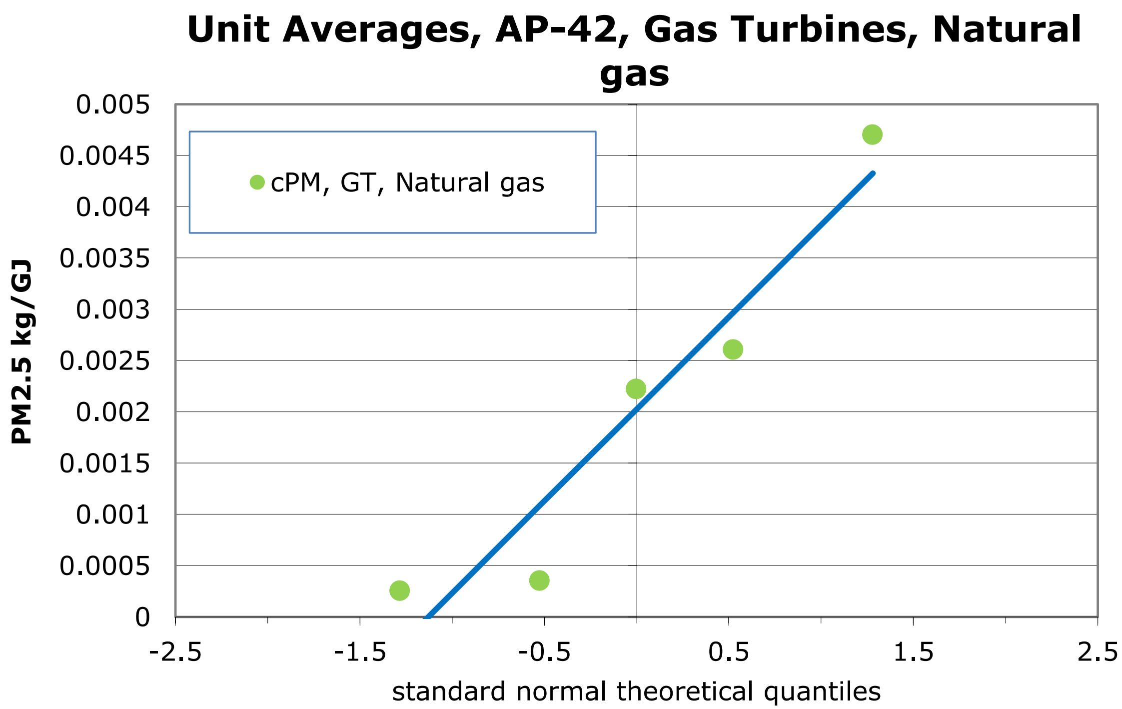


Raw Statistics	
Number of Valid Observations	5
Number of Distinct Observations	5
Minimum	4.93E-04
Maximum	1.44E-03
Mean of Raw Data	8.16E-04
Standard Deviation of Raw Data	4.04E-04
Khat	5.75
Theta hat	1.42E-04
Kstar	2.433
Theta star	3.35E-04
Mean of Log Transformed Data	-7.201
Standard Deviation of Log Transformed Data	0.461
Normal GOF Test Results	
Correlation Coefficient R	0.925
Shapiro Wilk Test Statistic	0.848
Shapiro Wilk Critical (0.05) Value	0.762
Approximate Shapiro Wilk P Value	N/A
Lilliefors Test Statistic	0.293
Lilliefors Critical (0.05) Value	0.396
Data appear Normal at (0.05) Significance Level	

AP-42 Data Gas Turbines
Unit averages

FacilityID	UnitID	Make	Model	Rating (MW)	Fuel	Controls	Pollutant	Run ID	Test Date	Test Method	Test Run Emission Value lb/MMBtu	Test Run Emission Value kg/GJ	ln (Run Value)
WDNR Fon du Lac	WDNR0098-1	ABB	GT11N1	86	natural gas	Water injection	cPM	Average	4/18/1994	EPA 5 back half	0.000814236	0.0003500436672	-7.957452648
WDNR Fon du Lac	WDNR0098-2	ABB	GT11N1	86	natural gas	Water injection	cPM	Average	4/18/1994	EPA 5 back half	0.000591123	0.0002541266799	-8.277677676
WDNR Fon du Lac	WDNR0099-1	ABB	GT11N1	86	natural gas	Water injection	cPM	Average	6/12/1994	EPA 5 back half	0.006061204	0.0026057396217	-5.95003872
WDNR Fon du Lac	WDNR0099-2	ABB	GT11N1	86	natural gas	Water injection	cPM	Average	6/12/1994	EPA 5 back half	0.005162558	0.0022194077444	-6.110514901
WDNR Fon du Lac	WDNR0102-1	ABB	GT11N1	86	natural gas	Water injection	cPM	Average	4/16/1996	EPA 5 back half	0.01093901	0.0047027314937	-5.35961177

x

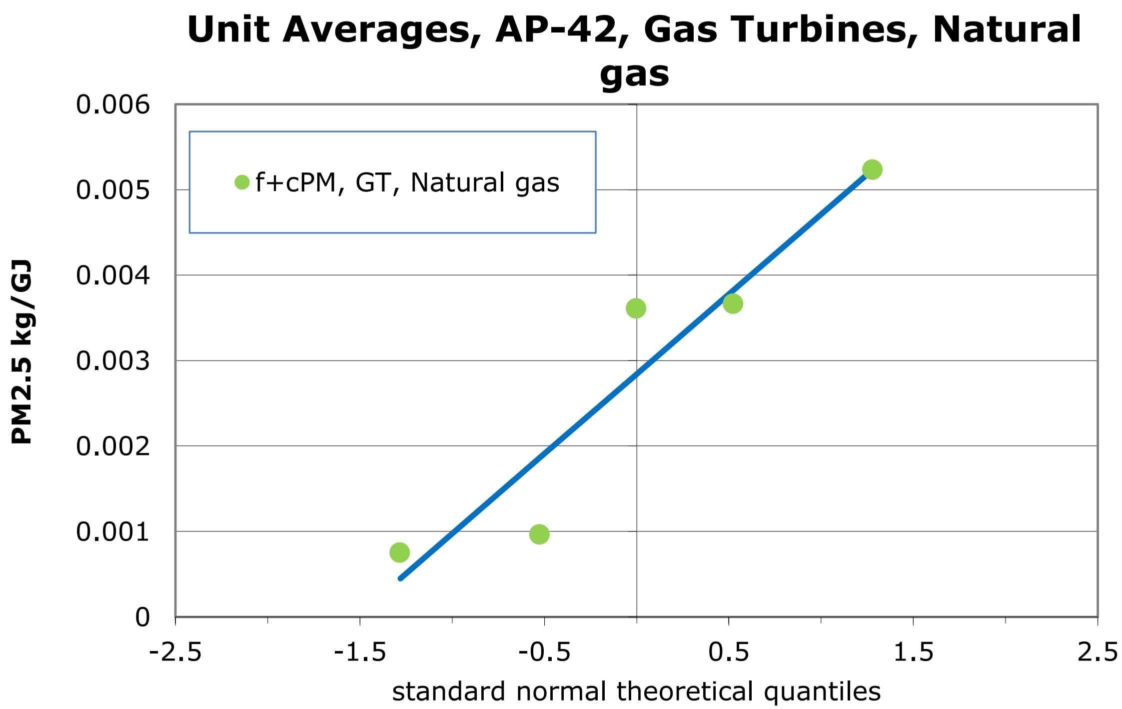


Raw Statistics	
Number of Valid Observations	5
Number of Distinct Observations	5
Minimum	2.54E-04
Maximum	4.70E-03
Mean of Raw Data	2.03E-03
Standard Deviation of Raw Data	1.84E-03
Khat	1.08
Theta hat	1.88E-03
Kstar	0.565
Theta star	3.58E-03
Mean of Log Transformed Data	-6.731
Standard Deviation of Log Transformed Data	1.301
Normal GOF Test Results	
Correlation Coefficient R	0.958
Shapiro Wilk Test Statistic	0.909
Shapiro Wilk Critical (0.05) Value	0.762
Approximate Shapiro Wilk P Value	N/A
Lilliefors Test Statistic	0.219
Lilliefors Critical (0.05) Value	0.396
Data appear Normal at (0.05) Significance Level	

AP-42 Data Gas Turbines
Unit averages

FacilityID	UnitID	Make	Model	Rating (MW)	Fuel	Controls	Pollutant	Run ID	Test Date	Test Method	Test Run Emission Value lb/MMBtu	Test Run Emission Value kg/GJ	ln (Run Value)
WDNR Fon du Lac	WDNR0098-1	ABB	GT11N1	86	natural gas	Water injection	f+cPM	Average	4/18/1994	EPA5 + back half	0.002238147	0.0009621898245	-6.946298804
WDNR Fon du Lac	WDNR0098-2	ABB	GT11N1	86	natural gas	Water injection	f+cPM	Average	4/18/1994	EPA5 + back half	0.001737987	0.0007471686572	-7.199219619
WDNR Fon du Lac	WDNR0099-1	ABB	GT11N1	86	natural gas	Water injection	f+cPM	Average	6/12/1994	EPA5 + back half	0.008393825	0.0036085442242	-5.62445085
WDNR Fon du Lac	WDNR0099-2	ABB	GT11N1	86	natural gas	Water injection	f+cPM	Average	6/12/1994	EPA5 + back half	0.008514667	0.0036604951646	-5.61015685
WDNR Fon du Lac	WDNR0102-1	ABB	GT11N1	86	natural gas	Water injection	f+cPM	Average	4/16/1996	EPA5 + back half	0.012169813	0.0052318592995	-5.252988557

x



Raw Statistics	
Number of Valid Observations	5
Number of Distinct Observations	5
Minimum	7.47E-04
Maximum	5.23E-03
Mean of Raw Data	2.84E-03
Standard Deviation of Raw Data	1.93E-03
Khat	2.049
Theta hat	1.39E-03
Kstar	0.953
Theta star	2.98E-03
Mean of Log Transformed Data	-6.127
Standard Deviation of Log Transformed Data	0.881
Normal GOF Test Results	
Correlation Coefficient R	0.949
Shapiro Wilk Test Statistic	0.886
Shapiro Wilk Critical (0.05) Value	0.762
Approximate Shapiro Wilk P Value	N/A
Lilliefors Test Statistic	0.254
Lilliefors Critical (0.05) Value	0.396
Data appear Normal at (0.05) Significance Level	

Natural Gas

Emission Factor Report for PM-filterable with Steam/Water Injection

21-Jun-16

ID	Manufacturer	Model	Rating (MW)	Load (%)	EF (lb/MMBtu)	Count of Runs	ND Count	Control Device
WDNR0102-1	ABB	GT11N1	86	100	1.23E-03	3	0	Water Injection for NOx control.
WDNR0099-2	ABB	GT11N1	86	100	3.35E-03	3	0	Water Injection for NOx control.
WDNR0099-1	ABB	GT11N1	86	100	2.33E-03	2	0	Water Injection for NOx control.
WDNR0098-2	ABB	GT11N1	86	100	1.15E-03	3	0	Water Injection for NOx control.
WDNR0098-1	ABB	GT11N1	86	100	1.42E-03	3	0	Water Injection for NOx control.

Avg EF =	**1.90E-03**
Count =	**5**
Std Dev =	**9.39E-04**
RSD(%) =	**49.5%**

Natural Gas

Emission Factor Report for PM-condensibles with Steam/Water Injection

21-Jun-16

ID	Manufacturer	Model	Rating (MW)	Load (%)	EF (lb/MMBtu)	Count of Runs	ND Count	Control Device
WDNR0102-1	ABB	GT11N1	86	100	1.10E-02	3	0	Water Injection for NOx control.
WDNR0099-2	ABB	GT11N1	86	100	5.16E-03	3	0	Water Injection for NOx control.
WDNR0099-1	ABB	GT11N1	86	100	6.06E-03	2	0	Water Injection for NOx control.
WDNR0098-2	ABB	GT11N1	86	100	5.91E-04	3	0	Water Injection for NOx control.
WDNR0098-1	ABB	GT11N1	86	100	8.15E-04	3	0	Water Injection for NOx control.

Avg EF =	**4.73E-03**
Count =	**5**
Std Dev =	**4.29E-03**
RSD(%) =	**90.9%**

AP-42 Data - 4-stroke RICE

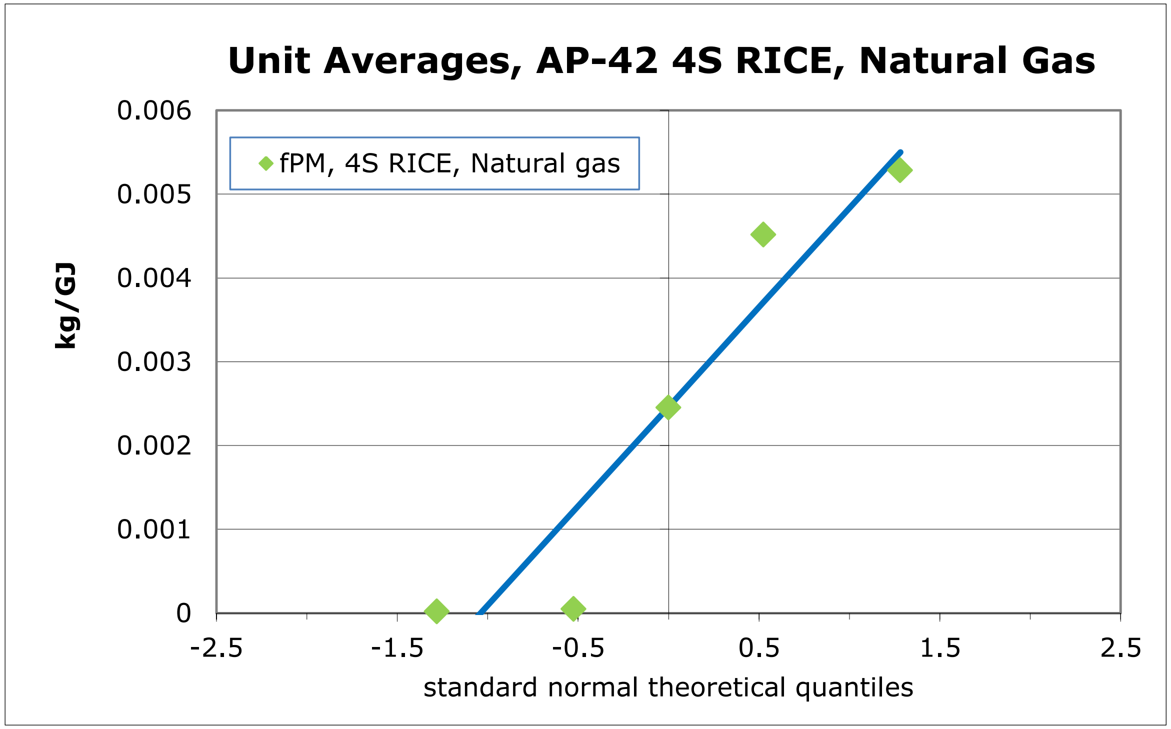
Parameter	Units	Value	Value	Value (1)
Pollutant		fPM	cPM	fPM+cPM
Number of units tested		5	2	
Mean	kg/GJ	2.46E-03	4.26E-03	6.73E-03
Median	kg/GJ	2.45E-03	4.26E-03	
Geometric mean	kg/GJ	5.54E-04	4.01E-03	
Minimum	kg/GJ	1.90E-05	2.82E-03	2.84E-03
Maximum	kg/GJ	5.28E-03	5.70E-03	1.10E-02
Standard deviation	kg/GJ	2.45E-03	2.03E-03	3.18E-03
COV	%	99	48	47
Confidence level	%	95%	95%	
Measurement bias	%	6.5	6.5	
t factor (2 tail)		2.78	12.71	
t factor (1 tail)		1.53	3.08	
Total uncertainty	%	124	428	446
Total uncertainty	kg/GJ	3.04E-03	1.83E-02	1.85E-02
95% confidence upper bound	kg/GJ	4.15E-03	8.69E-03	
Data distribution		normal	normal	
99% confidence upper prediction limit	kg/GJ	1.25E-02	8.35E-02	

(1) By combining fPM + cPM factors

AP-42 Data 4-stroke RICE

Unit averages

FacilityID	UnitID	Category	Make	Model	Rating	Fuel	Controls	Pollutant	Run ID	Test Date	Test Method	Test Run Emission Value lb/MMBtu
GRI Site 3A	29.38x	4SLB	Cooper Bessemer	LSV-16 turbo	4200	natural gas	None	fPM		6/16/1994	201	0.000044183379
GRI Site 3A	29.34x	4SLB	Cooper Bessemer	LSV-16 turbo	4200	natural gas	None	fPM		6/15/1994	201	0.000109506219
Elk Hills Naval Petroleum Reserve No. 1	102.1	4SRB	Waukesha	L7042 GSIU	1500	natural gas	PCC	fPM		5/25/1993	5	0.012288658317
Elk Hills Naval Petroleum Reserve No. 1	102.2	4SRB	Waukesha	L7042 GSIU	1500	natural gas	PCC	fPM		7/22/1993	5	0.005706347534
Elk Hills Naval Petroleum Reserve No. 1	133	4SRB	Waukesha	L7042 GSIU	1500	natural gas	PCC	fPM		5/26/1993	5	0.010508330643



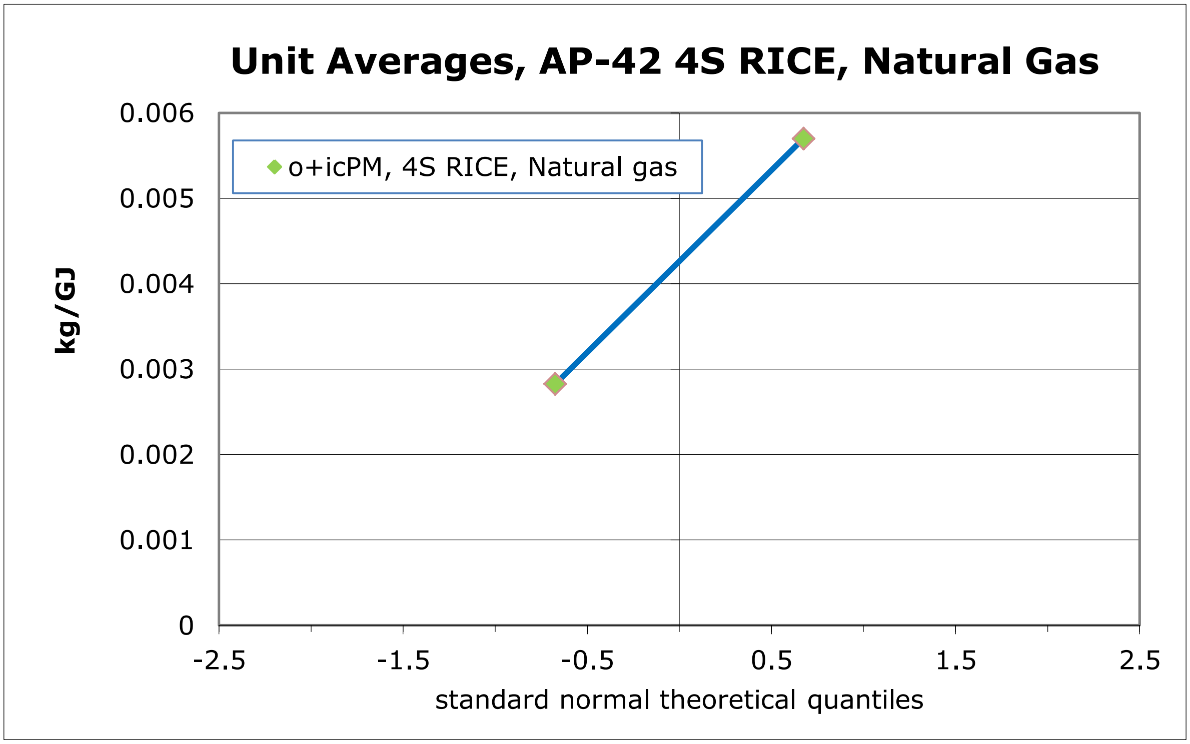
Raw Statistics	
Number of Valid Observations	5
Number of Distinct Observations	5
Minimum	1.90E-05
Maximum	0.00528
Mean of Raw Data	0.00246
Standard Deviation of Raw Data	2.45E-03
Khat	0.435
Theta hat	5.66E-03
Kstar	0.307
Theta star	0.00802
Mean of Log Transformed Data	-7.498
Standard Deviation of Log Transformed Data	2.7
Normal GOF Test Results	
Correlation Coefficient R	0.951
Shapiro Wilk Test Statistic	0.874
Shapiro Wilk Critical (0.05) Value	0.762
Approximate Shapiro Wilk P Value	N/A
Lilliefors Test Statistic	0.238
Lilliefors Critical (0.05) Value	0.396
Data appear Normal at (0.05) Significance Level	

AP-42 Data 4-stroke RICE
Unit averages

FacilityID	UnitID	Category	Make	Model	Rating	Fuel	Controls	Pollutant	Run ID	Test Date	Test Method	Test Run Emission Value lb/MMBtu	Test Run Emission Value kg/GJ
GRI Site 3A	29.38x	4SLB	Cooper Bessemer	LSV-16 turbo	4200	natural gas	None	o+icPM		6/16/1994	202	0.006570373153	0.002824633994
GRI Site 3A	29.34x	4SLB	Cooper Bessemer	LSV-16 turbo	4200	natural gas	None	o+icPM		6/15/1994	202	0.013255013665	0.005698392058

AP-42 Data - 4-stroke RICE

Parameter	Units	Value
Pollutant		cPM
Number of units tested		2
Mean	kg/GJ	4.26E-03
Median	kg/GJ	4.26E-03
Geometric mean	kg/GJ	4.01E-03
Minimum	kg/GJ	2.82E-03
Maximum	kg/GJ	5.70E-03
Standard deviation	kg/GJ	2.03E-03
COV	%	48
Confidence level	%	95%
Measurement bias	%	6.5
t factor (2 tail)		12.71
t factor (1 tail)		3.08
Total uncertainty	%	428
Total uncertainty	kg/GJ	1.83E-02
95% confidence upper bound	kg/GJ	8.69E-03
Data distribution		normal
99% confidence upper prediction limit	kg/GJ	8.35E-02



Unit Averages, AP-42 4S RICE, Natural Gas
o+icPM, 4S RICE, Natural gas
kg/GJ
0.006
0.005
0.004
0.003
0.002
0.001
0
-2.5
-1.5
-0.5
0.5
1.5
2.5
standard normal theoretical quantiles

Engine Family: 4SRB

Emission Factor Report for PM-10 with PCC

30-Jun-16

ID	Manufacturer	Model	Rating (HP)	Load (%)	EF (lb/MMBtu)	Count of Runs	ND Count
133	Waukesha	L7042 GSIU	1500	67	1.05E-02	3	0
102.2	Waukesha	L7042 GSIU	1500	63	5.70E-03	2	0
102.1	Waukesha	L7042 GSIU	1500	66	1.23E-02	3	0

Avg EF =	**9.50E-03**
Std Dev =	**3.41E-03**
Count =	**3**
RSD(%) =	**35.9%**

Engine Family: 4SLB

Emission Factor Report for PM-10 with No Control

03-Mar-16

ID	Manufacturer	Model	Rating (HP)	Load (%)	EF (lb/MMBtu)	Count of Runs	ND Count
29.38x	Cooper Bessemer	LSV-16	4200	99	1.10E-04	1	0
29.34x	Cooper Bessemer	LSV-16	4200	101	4.42E-05	1	0

Avg EF =	**7.71E-05**
Std Dev =	**4.65E-05**
Count =	**2**
RSD(%) =	**60.3%**

Engine Family: 4SLB

Emission Factor Report for PM-Organic Condensible with No Control

30-Jun-16

ID	Manufacturer	Model	Rating (HP)	Load (%)	EF (lb/MMBtu)	Count of Runs	ND Count
29.38x	Cooper Bessemer	LSV-16	4200	99	2.19E-03	1	0
29.34x	Cooper Bessemer	LSV-16	4200	101	6.63E-03	1	0

Avg EF =	**4.41E-03**
Std Dev =	**3.14E-03**
Count =	**2**
RSD(%) =	**71.2%**

Engine Family: 4SLB

Emission Factor Report for PM-Inorganic Condensible with No Control

30-Jun-16

ID	Manufacturer	Model	Rating (HP)	Load (%)	EF (lb/MMBtu)	Count of Runs	ND Count
29.38x	Cooper Bessemer	LSV-16	4200	99	4.38E-03	1	0
29.34x	Cooper Bessemer	LSV-16	4200	101	6.63E-03	1	0

Avg EF =	**5.50E-03**
Std Dev =	**1.59E-03**
Count =	**2**
RSD(%) =	**28.9%**

APPENDIX C
GE ENERGY GAS TURBINE TEST DATA SUMMARY

Table C-1: Paired CTM 39 PM2.5 result for a gas turbine combined cycle unit– 47-mm filter only (2008).

	Fuel Heat Input MMBtu/hr	O2 %vol, dry	Exhaust Gas Temper-ature °F	PM2.5 mass (A-TMF)* µg/dscm	PM2.5 mass (A-TMF)* lb/MMBtu	PM2.5 mass (B-TMF)* µg/dscm	PM2.5 mass (B-TMF)* lb/MMBtu
Run 1	1561	13.81	228	62.69	9.92E-05	33.79	5.35E-05
Run 2	1577	13.87	215	13.78	2.20E-05	-10.38	-1.66E-05
Run 3	1560	13.85	213	13.44	2.14E-05	-26.76	-4.26E-05
Run 4	1560	13.84	215	6.76	1.08E-05	6.81	1.08E-05
Run 5	1567	13.84	216	6.92	1.10E-05	-23.19	-3.68E-05
Run 6	1560	13.87	214	65.36	1.04E-04	259.36	4.14E-04
Run 7	1536	13.51	215	-16.47	-2.50E-05	-23.6	-3.58E-05
Run 8	1513	13.86	219	-14.99	-2.39E-05	43.55	6.94E-05
Run 9	1545	13.77	215	199.1	3.13E-04	-30.4	-4.78E-05
Average	1553.2	13.80	216.7	37.40	5.92E-05	25.46	4.09E-05
Average-A & B						31.43	5.00E-05

*A and B represent results for each in a pair of modified CTM 39 sampling trains that collected samples simultaneously.

Table C-2: PM2.5 species results for modified CTM 39 Train A – GE Energy test program (2008).

Parameter	Units	A Run 1	A Run 2	A Run 3	A Run 4	A Run 5	A Run 6	A Run 7	A Run 8	A Run 9	A Average
Organic carbon	µg/dscm	196.53	212.66	166.42	142.13	220.31	212.23	128.8	220.91	235.28	192.81
Elemental carbon	µg/dscm	9.46	15.57	8.44	5.16	28.34	10.47	15.79	19.9	31.61	16.08
Ammonium	µg/dscm	2.34	1.95	3.2	3.19	4.26	1.86	1.8	2.03	2.45	2.56
Chloride	µg/dscm	1.3	2.19	2.23	2.92	3.2	1.47	0.5	4.09	2.7	2.29
Nitrate	µg/dscm	1.7	0.45	1.76	0.69	1.49	1.94	1.61	1.38	1.36	1.38
Sulfate	µg/dscm	2.64	1.84	2.07	1.99	3.81	2.23	1.92	1.66	2.36	2.28
Al	µg/dscm	1.27	0.46	ND	0.47	ND	ND	0.49	ND	0.59	0.66
Br	µg/dscm	ND	0.11	ND	ND	ND	ND	ND	ND	ND	0.11
Ca	µg/dscm	ND	0.17	ND	2.18	ND	0.28	0.68	ND	1.38	0.94
Cl	µg/dscm	ND	ND	ND	0.52	0.37	0.15	0.27	ND	0.79	0.42
Cr	µg/dscm	ND	ND	ND	ND	ND	0.08	ND	ND	0.06	0.07
Cu	µg/dscm	ND	ND	ND	ND	0.17	ND	ND	ND	ND	0.17
Fe	µg/dscm	0.18	0.34	ND	0.37	0.2	0.29	0.28	ND	1.48	0.45
K	µg/dscm	ND	ND	ND	0.21	ND	ND	ND	ND	0.22	0.22
Mo	µg/dscm	ND	ND	ND	0.19	ND	ND	ND	ND	ND	0.19
Ni	µg/dscm	ND	ND	ND	ND	0.06	ND	ND	ND	0.04	0.05
Pb	µg/dscm	ND	ND	ND	0.22	ND	ND	ND	ND	ND	0.22
Rb	µg/dscm	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
S	µg/dscm	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Se	µg/dscm	0.15	ND	ND	ND	ND	ND	ND	ND	ND	0.15
Si	µg/dscm	5.35	1.21	ND	1.62	ND	1.84	1.07	ND	1.01	2.02
Sm	µg/dscm	ND	0.1	ND	ND	ND	ND	ND	ND	ND	0.10
Sr	µg/dscm	0.15	0.14	ND	0.11	ND	ND	ND	0.15	ND	0.14
Ti	µg/dscm	ND	0.07	ND	ND	ND	ND	ND	0.08	0.08	0.08
V	µg/dscm	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Y	µg/dscm	0.1	ND	ND	ND	ND	ND	ND	0.12	ND	0.11
Zn	µg/dscm	ND	ND	ND	0.25	0.69	ND	0.14	ND	0.1	0.30

Table C-3: PM2.5 species results for modified CTM 39Train B – GE Energy test program (2008).

		B Run 1	B Run 2	B Run 3	B Run 4	B Run 5	B Run 6	B Run 7	B Run 8	B Run 9	B Average
Organic carbon	µg/dscm	217.11	247	193.39	399.9	186.02	493.09	154.15	233.8	181.77	256.25
Elemental carbon	µg/dscm	3.15	16.68	32.25	10.03	6.67	58.4	30.61	45.3	28.76	25.76
Ammonium	µg/dscm	2.37	2.1	3.23	6.12	2.85	2.23	1.93	2.02	2.37	2.80
Chloride	µg/dscm	2.41	0.28	1.86	1.35	1.31	1.01	1.96	1.98	0.48	1.40
Nitrate	µg/dscm	2.56	1.85	5.77	1.24	1.59	2.88	0.91	1.3	2.38	2.28
Sulfate	µg/dscm	3.15	3.65	2.48	15.98	3.07	2.8	2.45	2.68	1.44	4.19
Al	µg/dscm	ND	ND	ND	ND	ND	1.78	0.45	0.73	ND	0.99
Ca	µg/dscm	ND	ND	ND	ND	ND	0.21	0.15	0.22	ND	0.19
Cl	µg/dscm	ND	ND	ND	ND	ND	0.14	0.29	ND	ND	0.22
Fe	µg/dscm	0.17	0.29	ND	0.67	ND	0.6	1.22	1.4	ND	0.73
K	µg/dscm	ND	ND	ND	ND	ND	0.16	0.12	ND	ND	0.14
Ni	µg/dscm	0.04	0.05	ND	ND	0.05	ND	ND	ND	ND	0.05
Rb	µg/dscm	ND	ND	ND	ND	ND	ND	ND	ND	0.06	0.06
S	µg/dscm	ND	ND	ND	ND	ND	0.52	ND	ND	ND	0.52
Si	µg/dscm	ND	ND	0.57	2.3	ND	17.22	0.81	3.36	1.17	4.24
Sr	µg/dscm	0.13	ND	ND	ND	ND	ND	ND	ND	ND	0.13
Ti	µg/dscm	ND	ND	0.06	ND	ND	ND	0.06	0.07	0.07	0.07
V	µg/dscm	0.01	ND	ND	0.01	ND	ND	ND	ND	0.01	0.01
Y	µg/dscm	0.11	ND	ND	ND	ND	ND	0.09	ND	ND	0.10
Zn	µg/dscm	ND	ND	ND	ND	ND	0.07	0.08	0.09	ND	0.08

APPENDIX D
API RICE TEST DATA SUMMARY

Table D-1: API reciprocating engine test results – two-stroke lean burn engine (2003).

Parameter	Units	Run 1	Run 2	Run 3	Average
Fuel Flow Rate (60 °F, 14.5 psia)	1000 scfd	400.1	399.0	402.4	400.5
Fuel heat input	MMBtu/hr	17.76	17.78	17.80	17.78
Engine speed	RPM	322	--	--	322
Engine load	hp	2261	2264	2267	2264
Fuel HHV (Dry, 14.696 psia, 60 °F)	Btu/scf	1068.7	1072.7	1065.1	1068.8
Total fuel sulfur (STP)	gr/100 scf	0.006	0.004	0.009	0.0063
O_2	%vol	14.4	14.3	14.6	14.5
Exhaust temperature	°F	589	589	589	589
Stack gas flow rate	dscfm	8400	8220	8700	8440
PM2.5 (TMF)	mg/dscm	9.92E+00	1.08E+01	1.07E+01	1.05E+01
PM2.5 (TMF)	lb/hr	3.10E-01	3.33E-01	3.46E-01	3.30E-01
PM2.5 (TMF)	lb/MMBtu	1.75E-02	1.87E-02	1.94E-02	1.85E-02
PM2.5 (TMF)	kg/GJ	7.51E-03	8.05E-03	8.35E-03	7.97E-03
PM2.5 (probe/venturi)	mg/dscm	4.34E-01	1.22E+00	7.96E-01	8.17E-01
PM2.5 (probe/venturi)	lb/hr	1.36E-02	3.75E-02	2.57E-02	2.56E-02
PM2.5 (TMF/probe/venturi)	mg/dscm	1.04E+01	1.20E+01	1.15E+01	1.13E+01
PM2.5 (TMF/probe/venturi)	lb/hr	3.24E-01	3.70E-01	3.71E-01	3.55E-01
PM2.5 (TMF/probe/venturi)	lb/MMBtu	1.82E-02	2.08E-02	2.09E-02	2.00E-02
PM2.5 (TMF/probe/venturi)	kg/GJ	7.84E-03	8.96E-03	8.97E-03	8.59E-03
Organic Carbon	mg/dscm	8.22E+00	7.95E+00	8.37E+00	8.18E+00
Elemental Carbon	mg/dscm	6.32E-02	9.36E-02	4.65E-02	6.78E-02
Backup OC	mg/dscm	4.27E-01	4.74E-01	6.17E-01	5.06E-01
Acenaphthene	mg/dscm	9.65E-05	1.37E-04	1.02E-04	1.12E-04
Acenaphthylene	mg/dscm	5.28E-04	6.12E-04	5.44E-04	5.61E-04
Anthracene	mg/dscm	4.52E-05	6.05E-05	6.02E-05	5.53E-05
Anthraquinone	mg/dscm	3.63E-04	3.97E-04	3.86E-04	3.82E-04
Anthrone	mg/dscm	ND	ND	ND	ND e
Benz(a)anthracene-7,12-dionene	mg/dscm	ND	7.54E-05	4.63E-05	6.09E-05

Table D-1: API reciprocating engine test results – two-stroke lean burn engine (2003).

Parameter	Units	Run 1	Run 2	Run 3	Average	
Benzanthrone	mg/dscm	1.97E-04	ND	2.34E-04	2.15E-04	
Biphenyl	mg/dscm	2.11E-04	2.67E-04	1.93E-04	2.24E-04	
Dibenzofuran	mg/dscm	2.96E-04	3.02E-04	2.50E-04	2.83E-04	
1,3+1,6+1,7-dimethylnaphthalene	mg/dscm	1.47E-03	1.63E-03	1.29E-03	1.46E-03	
2,6+2,7-dimethylnaphthalene	mg/dscm	6.05E-04	6.55E-04	5.23E-04	5.95E-04	
1,4+1,5+2,3-dimethylnaphthalene	mg/dscm	5.61E-04	6.36E-04	4.92E-04	5.63E-04	
1,2-dimethylnaphthalene	mg/dscm	2.13E-04	2.90E-04	2.21E-04	2.41E-04	
C-dimethylphenanthrene	mg/dscm	2.16E-04	2.27E-04	1.33E-04	1.92E-04	
D-dimethylphenanthrene	mg/dscm	8.70E-05	1.15E-04	9.03E-05	9.75E-05	
1,7-dimethylphenanthrene	mg/dscm	3.91E-05	5.70E-05	4.29E-05	4.63E-05	
E-dimethylphenanthrene	mg/dscm	3.01E-05	2.07E-05	ND	2.54E-05	
1+2-ethylnaphthalene	mg/dscm	8.18E-04	8.49E-04	7.10E-04	7.92E-04	
Fluoranthene	mg/dscm	4.41E-05	7.95E-05	7.70E-05	6.69E-05	
Fluorene	mg/dscm	2.53E-04	2.24E-04	2.44E-04	2.40E-04	
9-fluorenone	mg/dscm	8.19E-04	8.25E-04	9.29E-04	8.58E-04	
D-MePy/MeFl	mg/dscm	ND	5.75E-06	ND	5.75E-06	e
2-Methylbiphenyl	mg/dscm	6.11E-04	7.13E-04	6.75E-04	6.66E-04	
4-Methylbiphenyl	mg/dscm	1.31E-04	1.17E-04	1.14E-04	1.21E-04	
3-Methylbiphenyl	mg/dscm	3.16E-04	3.54E-04	ND	3.35E-04	
A-methylfluorene	mg/dscm	2.49E-04	2.11E-04	2.93E-04	2.51E-04	
B-methylfluorene	mg/dscm	1.24E-04	1.38E-04	1.58E-04	1.40E-04	
2-methylnaphthalene	mg/dscm	2.71E-03	2.88E-03	2.50E-03	2.70E-03	
1-methylnaphthalene	mg/dscm	2.13E-03	2.26E-03	1.95E-03	2.11E-03	
C-methylphenanthrene	mg/dscm	2.20E-04	2.44E-04	1.67E-04	2.11E-04	
2-methylphenanthrene	mg/dscm	2.06E-04	2.04E-04	1.59E-04	1.90E-04	
1-methylphenanthrene	mg/dscm	1.83E-04	1.13E-04	1.38E-04	1.45E-04	a
A-methylphenanthrene	mg/dscm	1.22E-04	1.27E-04	1.09E-04	1.19E-04	
4-methylpyrene	mg/dscm	5.91E-05	6.16E-05	2.84E-05	4.97E-05	a
Naphthalene	mg/dscm	6.03E-03	6.06E-03	5.38E-03	5.82E-03	
Phenanthrene	mg/dscm	5.17E-04	5.51E-04	4.66E-04	5.11E-04	

Table D-1: API reciprocating engine test results – two-stroke lean burn engine (2003).

Parameter	Units	Run 1	Run 2	Run 3	Average			
Pyrene	mg/dscm	4.07E-05	1.12E-04	6.78E-05	7.34E-05			
B-trimethylnaphthalene	mg/dscm	2.71E-04	3.21E-04	2.43E-04	2.79E-04			
C-trimethylnaphthalene	mg/dscm	2.60E-04	2.79E-04	2.42E-04	2.60E-04	a		
E-trimethylnaphthalene	mg/dscm	2.35E-04	2.22E-04	1.89E-04	2.15E-04			
J-trimethylnaphthalene	mg/dscm	1.44E-04	1.66E-04	1.52E-04	1.54E-04			
F-trimethylnaphthalene	mg/dscm	1.55E-04	1.36E-04	1.23E-04	1.38E-04			
A-trimethylnaphthalene	mg/dscm	1.11E-04	1.34E-04	1.12E-04	1.19E-04			
2,3,5+I-trimethylnaphthalene	mg/dscm	1.16E-04	5.82E-05	1.80E-05	6.40E-05	a		
2,4,5-trimethylnaphthalene	mg/dscm	ND	2.01E-05	ND	2.01E-05	e		
Xanthone	mg/dscm	2.77E-04	3.30E-04	2.96E-04	3.01E-04			
Al	mg/dscm	1.96E-04	ND	ND	1.96E-04	e		
Ba	mg/dscm	6.74E-04	ND	5.96E-04	6.35E-04		b	
Br	mg/dscm	7.19E-05	5.34E-05	6.85E-05	6.46E-05			
Ca	mg/dscm	1.27E-02	1.38E-02	1.55E-02	1.40E-02			
Cl	mg/dscm	4.11E-04	4.66E-04	3.69E-04	4.15E-04		b	d
Cr	mg/dscm	9.03E-05	2.22E-05	ND	5.62E-05			
Cu	mg/dscm	1.93E-03	2.35E-05	2.26E-04	7.26E-04	a		d
Fe	mg/dscm	7.78E-04	ND	ND	7.78E-04	e		
K	mg/dscm	5.96E-04	3.38E-04	2.21E-04	3.85E-04	a		
Mg	mg/dscm	2.34E-04	6.68E-04	8.86E-05	3.30E-04	a	b	d
Mo	mg/dscm	1.51E-03	1.69E-03	1.92E-03	1.71E-03			
Na	mg/dscm	3.42E-04	3.25E-04	ND	3.33E-04	a	b	d
P	mg/dscm	1.38E-03	8.52E-04	1.30E-03	1.18E-03			
Rb	mg/dscm	9.51E-06	8.90E-06	1.35E-05	1.06E-05			
S	mg/dscm	2.15E-02	2.21E-02	2.27E-02	2.21E-02			
Si	mg/dscm	2.69E-03	8.44E-03	1.16E-02	7.57E-03	a		d
Sr	mg/dscm	ND	7.28E-06	2.88E-05	1.80E-05			
U	mg/dscm	ND	ND	3.02E-05	3.02E-05	e		
Y	mg/dscm	ND	ND	4.15E-05	4.15E-05	e		
Zn	mg/dscm	4.24E-03	4.53E-03	5.07E-03	4.61E-03			
Zr	mg/dscm	ND	ND	5.45E-05	5.45E-05	e		

Table D-1: API reciprocating engine test results – two-stroke lean burn engine (2003).

Parameter	Units	Run 1	Run 2	Run 3	Average
Sulfate	mg/dscm	2.07E-02	2.29E-02	2.15E-02	2.17E-02
Nitrate	mg/dscm	8.81E-03	1.60E-02	2.62E-02	1.70E-02
Chloride	mg/dscm	4.24E-03	3.44E-03	5.59E-03	4.42E-03 a b
Ammonium	mg/dscm	5.64E-03	7.10E-03	5.63E-03	6.12E-03
Soluble Na	mg/dscm	6.06E-04	1.55E-03	5.04E-03	2.40E-03 a b d

a - 95% confidence lower bound of the average concentration is less than the dilution sampler blank concentration.

b - 95% confidence lower bound of the average concentration is less than the field blank concentration.

d - 95% confidence lower bound of the average concentration is less than the ambient concentration.

e - Insufficient data to calculate 95% confidence lower bound of the average concentration (i.e. zero or one valid run).

Table D-2: API reciprocating engine test results – four-stroke rich burn engine (2003).

Run	Units	Run 1	Run 2	Run 3	Average	
Fuel Flow Rate (60 °F, 14.5 psia)	1000 scfd	279.4	284.6	281.8	281.9	
Fuel heat input	MMBtu/hr	12.36	12.60	12.48	12.48	
Engine speed	RPM	313	320	320	318	
Engine load	hp	1220	1244	1232	1232	
Fuel HHV (Dry, 14.696 psia, 60 °F)	Btu/scf	1062.8	1061.6	1066.1	1063.5	
Total fuel sulfur (STP)	gr/100 scf	0.01	0.011	0.011	0.0107	
O_2	%vol	11.0	11.4	11.2	11.2	
Exhaust temperature	°F	652	657	667	659	
Stack gas flow rate	dscfm	4040	4330	4210	4190	
PM2.5 (TMF)	mg/dscm	1.44E+00	1.26E+00	9.02E-01	1.20E+00	
PM2.5 (TMF)	lb/hr	2.04E-02	1.89E-02	1.31E-02	1.75E-02	
PM2.5 (TMF)	lb/MMBtu	1.65E-03	1.50E-03	1.05E-03	1.40E-03	
PM2.5 (TMF)	kg/GJ	7.09E-04	6.45E-04	4.53E-04	6.02E-04	
PM2.5 (probe/venturi)	mg/dscm	2.80E-01	5.41E-01	2.00E-01	3.40E-01	
PM2.5 (probe/venturi)	lb/hr	3.96E-03	8.14E-03	2.91E-03	5.00E-03	
PM2.5 (TMF/probe/venturi)	mg/dscm	1.72E+00	1.80E+00	1.10E+00	1.54E+00	
PM2.5 (TMF/probe/venturi)	lb/hr	2.43E-02	2.70E-02	1.61E-02	2.25E-02	
PM2.5 (TMF/probe/venturi)	lb/MMBtu	1.97E-03	2.15E-03	1.29E-03	1.80E-03	
PM2.5 (TMF/probe/venturi)	kg/GJ	8.47E-04	9.22E-04	5.53E-04	7.74E-04	
Organic Carbon	mg/dscm	1.05E+00	9.19E-01	7.27E-01	8.99E-01	
Elemental Carbon	mg/dscm	1.35E-02	1.66E-02	4.99E-02	2.67E-02	d
Backup OC	mg/dscm	1.66E-01	1.71E-01	1.65E-01	1.68E-01	
Acenaphthene	mg/dscm	4.59E-05	ND	ND	4.59E-05	e
Acenaphthylene	mg/dscm	4.36E-04	6.74E-04	4.21E-04	5.10E-04	
Anthracene	mg/dscm	2.37E-05	3.88E-05	1.09E-05	2.45E-05	
Anthraquinone	mg/dscm	1.68E-04	1.62E-04	1.61E-04	1.64E-04	
Anthrone	mg/dscm	ND	ND	ND	ND	e
Benzanthrone	mg/dscm	ND	5.19E-05	ND	5.19E-05	e
Biphenyl	mg/dscm	1.37E-04	2.70E-04	1.81E-04	1.96E-04	
Dibenzofuran	mg/dscm	ND	9.47E-05	9.20E-05	9.34E-05	

Table D-2: API reciprocating engine test results – four-stroke rich burn engine (2003).

Run	Units	Run 1	Run 2	Run 3	Average	
C-dimethylphenanthrene	mg/dscm	4.54E-05	5.39E-05	7.12E-05	5.68E-05	a
D-dimethylphenanthrene	mg/dscm	ND	ND	4.94E-05	4.94E-05	e
1+2-ethylnaphthalene	mg/dscm	1.53E-04	2.16E-04	2.18E-04	1.95E-04	
Fluoranthene	mg/dscm	7.64E-05	9.37E-05	9.36E-05	8.79E-05	
Fluorene	mg/dscm	1.38E-04	1.70E-04	1.43E-04	1.50E-04	
9-fluorenone	mg/dscm	2.36E-04	2.81E-04	2.37E-04	2.51E-04	
C-MePy/MeFl	mg/dscm	2.06E-06	8.06E-06	9.35E-06	6.49E-06	
2-Methylbiphenyl	mg/dscm	7.94E-04	7.24E-04	5.48E-04	6.88E-04	
4-Methylbiphenyl	mg/dscm	5.11E-05	5.84E-05	5.93E-05	5.63E-05	
B-methylfluorene	mg/dscm	ND	8.06E-05	ND	8.06E-05	e
2-methylnaphthalene	mg/dscm	3.99E-04	6.30E-04	5.22E-04	5.17E-04	
1-methylnaphthalene	mg/dscm	2.78E-04	4.52E-04	3.51E-04	3.60E-04	
C-methylphenanthrene	mg/dscm	6.09E-05	6.80E-05	8.94E-05	7.28E-05	a
1-methylphenanthrene	mg/dscm	2.53E-05	3.02E-05	4.94E-05	3.50E-05	a
2-methylphenanthrene	mg/dscm	2.84E-05	4.53E-05	2.60E-05	3.32E-05	a
4-methylpyrene	mg/dscm	1.55E-05	1.56E-05	2.18E-05	1.76E-05	a
Naphthalene	mg/dscm	2.09E-03	4.18E-03	2.88E-03	3.05E-03	
Phenanthrene	mg/dscm	3.49E-04	4.08E-04	3.04E-04	3.53E-04	
Pyrene	mg/dscm	6.72E-06	1.56E-05	4.78E-05	2.34E-05	
B-trimethylnaphthalene	mg/dscm	3.25E-05	5.14E-05	5.10E-05	4.50E-05	a
C-trimethylnaphthalene	mg/dscm	2.48E-05	4.58E-05	5.72E-05	4.26E-05	
E-trimethylnaphthalene	mg/dscm	2.32E-05	3.63E-05	5.04E-05	3.66E-05	a
J-trimethylnaphthalene	mg/dscm	1.19E-05	2.37E-05	3.28E-05	2.28E-05	a
F-trimethylnaphthalene	mg/dscm	8.77E-06	2.07E-05	2.55E-05	1.83E-05	a
2,3,5+I-trimethylnaphthalene	mg/dscm	ND	ND	6.76E-06	6.76E-06	e
Xanthone	mg/dscm	4.75E-05	4.99E-05	ND	4.87E-05	
Al	mg/dscm	ND	6.08E-04	ND	6.08E-04	e
Ba	mg/dscm	ND	ND	5.10E-04	5.10E-04	e
Br	mg/dscm	7.12E-06	1.04E-05	6.25E-06	7.92E-06	
Ca	mg/dscm	1.02E-02	7.76E-03	6.25E-03	8.06E-03	
Cl	mg/dscm	ND	3.87E-04	ND	3.87E-04	e

Table D-2: API reciprocating engine test results – four-stroke rich burn engine (2003).

Run	Units	Run 1	Run 2	Run 3	Average			
Co	mg/dscm	1.25E-04	5.52E-04	1.11E-04	2.63E-04			
Cr	mg/dscm	1.47E-04	1.99E-04	7.29E-05	1.40E-04			
Cu	mg/dscm	9.57E-04	6.49E-04	2.40E-05	5.43E-04	a		d
Fe	mg/dscm	2.43E-03	1.02E-01	1.06E-03	3.51E-02	a		d
K	mg/dscm	1.40E-04	4.35E-04	4.23E-05	2.06E-04	a		d
La	mg/dscm	3.65E-04	ND	ND	3.65E-04	e		
Mg	mg/dscm	2.68E-04	ND	2.36E-04	2.52E-04		b	d
Mn	mg/dscm	3.07E-05	3.06E-04	ND	1.69E-04			
Mo	mg/dscm	1.25E-03	1.04E-03	9.86E-04	1.09E-03			
Na	mg/dscm	2.53E-03	ND	2.89E-04	1.41E-03	a	b	d
Ni	mg/dscm	5.46E-05	6.47E-05	ND	5.97E-05			
P	mg/dscm	1.04E-03	6.55E-04	5.06E-04	7.34E-04			
Rb	mg/dscm	ND	5.74E-06	ND	5.74E-06	e		
S	mg/dscm	1.45E-02	1.88E-02	1.29E-02	1.54E-02			
Se	mg/dscm	1.49E-05	1.30E-05	ND	1.40E-05			
Si	mg/dscm	5.48E-02	1.77E-02	2.88E-02	3.38E-02			
Sn	mg/dscm	1.16E-04	1.13E-04	1.75E-04	1.35E-04			
Sr	mg/dscm	ND	9.63E-06	ND	9.63E-06	e		
V	mg/dscm	ND	5.56E-05	ND	5.56E-05	e		
Zn	mg/dscm	3.07E-03	8.85E-03	2.25E-03	4.72E-03			d
Sulfate	mg/dscm	3.77E-02	4.14E-02	3.52E-02	3.81E-02			
Nitrate	mg/dscm	8.94E-03	5.64E-03	2.93E-03	5.83E-03	a		
Chloride	mg/dscm	5.89E-03	4.29E-03	3.69E-03	4.62E-03	a	b	
Ammonium	mg/dscm	1.09E-02	1.09E-02	9.97E-03	1.06E-02			
Soluble Na	mg/dscm	2.66E-04	2.56E-04	3.07E-04	2.76E-04	a	b	

a - 95% confidence lower bound of the average concentration is less than the dilution sampler blank concentration.

b - 95% confidence lower bound of the average concentration is less than the field blank concentration.

d - 95% confidence lower bound of the average concentration is less than the ambient concentration.

e - Insufficient data to calculate 95% confidence lower bound of the average concentration (i.e. zero or one valid run).

Table D-3: API reciprocating engine test results - 4SLB (2003).

Run	Units	Run 1	Run 2	Run 3	Average	
Fuel Flow Rate (60 °F, 14.5 psia)	1000 scfd	225.1	224.3	224.9	224.8	
Fuel heat input	MMBtu/hr	9.94	9.89	9.96	9.93	
Engine speed	RPM	924	933	934	930	
Engine load	hp	1553	1546	1557	1552	
Fuel HHV (Dry, 14.696 psia, 60 °F)	Btu/scf	1064.9	1066.2	1065.9	1065.7	
Total fuel sulfur (STP)	gr/100 scf	0.039	0.003	0.009	0.0170	
O_2	%vol	12.5	12.3	12.1	12.3	
Exhaust temperature	°F	703	721	718	714	
Stack gas flow rate	dscfm	3650	3580	3530	3587	
PM2.5 (TMF)	mg/dscm	5.47E+00	3.30E+00	2.25E+00	3.68E+00	
PM2.5 (TMF)	lb/hr	7.39E-02	4.24E-02	2.90E-02	4.84E-02	
PM2.5 (TMF)	lb/MMBtu	7.44E-03	4.29E-03	2.91E-03	4.88E-03	
PM2.5 (TMF)	kg/GJ	3.20E-03	1.84E-03	1.25E-03	2.10E-03	
PM2.5 (probe/venturi)	mg/dscm	ND	1.69E-01	1.85E-01	1.77E-01	
PM2.5 (probe/venturi)	lb/hr	ND	2.16E-03	2.38E-03	2.27E-03	
PM2.5 (TMF/probe/venturi)	mg/dscm	5.47E+00	3.47E+00	2.44E+00	3.79E+00	
PM2.5 (TMF/probe/venturi)	lb/hr	7.39E-02	4.46E-02	3.14E-02	5.00E-02	
PM2.5 (TMF/probe/venturi)	lb/MMBtu	7.44E-03	4.51E-03	3.15E-03	5.03E-03	
PM2.5 (TMF/probe/venturi)	kg/GJ	3.20E-03	1.94E-03	1.35E-03	2.16E-03	
Organic Carbon	mg/dscm	3.39E+00	2.98E+00	2.04E+00	2.80E+00	
Elemental Carbon	mg/dscm	ND	1.66E-02	ND	1.66E-02	e
Backup OC	mg/dscm	2.34E-01	2.90E-01	2.71E-01	2.65E-01	
Anthraquinone	mg/dscm	3.96E-04	7.45E-04	8.18E-04	6.53E-04	
Anthrone	mg/dscm	ND	ND	ND	ND	e
Benz(a)anthracene-7,12-dionene	mg/dscm	9.01E-05	ND	ND	9.01E-05	e
Benzanthrone	mg/dscm	1.17E-04	ND	ND	1.17E-04	e
Biphenyl	mg/dscm	1.34E-04	1.39E-04	ND	1.36E-04	
Dibenzofuran	mg/dscm	2.17E-04	2.50E-04	1.65E-04	2.11E-04	
C-dimethylphenanthrene	mg/dscm	5.75E-05	1.03E-04	7.52E-05	7.86E-05	a
D-dimethylphenanthrene	mg/dscm	ND	5.26E-05	4.75E-05	5.01E-05	a

Table D-3: API reciprocating engine test results - 4SLB (2003).

Run	Units	Run 1	Run 2	Run 3	Average			
1+2-ethylnaphthalene	mg/dscm	2.15E-04	2.01E-04	ND	2.08E-04			
Fluoranthene	mg/dscm	2.40E-05	3.65E-05	3.67E-05	3.24E-05			
9-fluorenone	mg/dscm	1.47E-03	1.88E-03	1.75E-03	1.70E-03			
D-MePy/MeFl	mg/dscm	ND	2.92E-06	3.60E-06	3.26E-06	a		
2-Methylbiphenyl	mg/dscm	4.70E-04	5.21E-04	5.19E-04	5.03E-04			
4-Methylbiphenyl	mg/dscm	2.65E-05	5.99E-05	ND	4.32E-05			
B-methylfluorene	mg/dscm	7.60E-05	7.89E-05	ND	7.75E-05	a		
2-methylnaphthalene	mg/dscm	6.84E-04	6.09E-04	3.57E-04	5.50E-04			
1-methylnaphthalene	mg/dscm	3.74E-04	3.16E-04	1.78E-04	2.90E-04			
C-methylphenanthrene	mg/dscm	7.66E-05	1.49E-04	1.43E-04	1.23E-04	a		
1-methylphenanthrene	mg/dscm	2.70E-05	3.51E-05	4.75E-05	3.65E-05	a		
2-methylphenanthrene	mg/dscm	3.90E-05	4.53E-05	1.08E-05	3.17E-05	a		
4-methylpyrene	mg/dscm	1.10E-05	2.87E-05	3.55E-05	2.51E-05	a		
Naphthalene	mg/dscm	3.37E-03	2.36E-03	2.39E-03	2.71E-03			
Phenanthrene	mg/dscm	1.56E-04	1.66E-04	9.44E-05	1.39E-04			
C-trimethylnaphthalene	mg/dscm	4.10E-05	4.72E-05	5.77E-05	4.87E-05			
B-trimethylnaphthalene	mg/dscm	4.55E-05	6.13E-05	3.85E-05	4.85E-05	a		
J-trimethylnaphthalene	mg/dscm	2.80E-05	3.80E-05	3.31E-05	3.30E-05	a		
E-trimethylnaphthalene	mg/dscm	3.05E-05	3.89E-05	2.29E-05	3.08E-05	a		
F-trimethylnaphthalene	mg/dscm	2.50E-05	3.07E-05	1.74E-05	2.44E-05	a		
2,4,5-trimethylnaphthalene	mg/dscm	2.25E-05	ND	1.62E-05	1.94E-05	a		
A-trimethylnaphthalene	mg/dscm	7.51E-06	1.56E-05	ND	1.16E-05			
2,3,5+I-trimethylnaphthalene	mg/dscm	4.00E-06	9.73E-06	ND	6.87E-06			
Xanthone	mg/dscm	3.04E-04	4.29E-04	4.42E-04	3.92E-04			
Ag	mg/dscm	6.96E-05	ND	ND	6.96E-05	e		
Al	mg/dscm	1.01E-02	ND	ND	1.01E-02	e		
Ba	mg/dscm	3.72E-04	3.41E-04	7.03E-04	4.72E-04		b	d
Br	mg/dscm	8.07E-05	2.35E-05	1.27E-05	3.90E-05			d
Ca	mg/dscm	1.45E-02	7.93E-03	8.38E-03	1.03E-02			
Cd	mg/dscm	1.12E-04	ND	ND	1.12E-04	e		
Cl	mg/dscm	3.29E-03	2.91E-04	6.32E-04	1.40E-03	a	b	d

Table D-3: API reciprocating engine test results - 4SLB (2003).

Run	Units	Run 1	Run 2	Run 3	Average			
Co	mg/dscm	2.14E-03	2.25E-05	4.60E-05	7.36E-04			
Cr	mg/dscm	6.31E-04	1.65E-05	5.44E-05	2.34E-04			
Cu	mg/dscm	2.82E-03	1.55E-03	7.92E-04	1.72E-03	a		d
Fe	mg/dscm	6.01E-01	1.62E-03	2.07E-04	2.01E-01	a		d
K	mg/dscm	2.68E-03	8.09E-05	6.94E-05	9.45E-04	a		d
La	mg/dscm	ND	3.91E-04	3.59E-04	3.75E-04			
Mg	mg/dscm	ND	2.44E-04	7.12E-04	4.78E-04		b	d
Mn	mg/dscm	1.65E-03	ND	ND	1.65E-03	e		
Mo	mg/dscm	1.77E-03	1.47E-03	1.57E-03	1.60E-03			
Na	mg/dscm	ND	ND	1.63E-03	1.63E-03	e		
Ni	mg/dscm	4.69E-04	3.13E-05	6.07E-05	1.87E-04			
P	mg/dscm	ND	3.74E-04	7.34E-04	5.54E-04		b	
Rb	mg/dscm	2.67E-05	1.72E-05	ND	2.19E-05			
S	mg/dscm	5.47E-02	2.72E-03	2.95E-03	2.01E-02	a		d
Se	mg/dscm	5.60E-05	ND	ND	5.60E-05	e		
Si	mg/dscm	4.53E-02	2.49E-02	7.25E-03	2.58E-02	a		d
Sn	mg/dscm	9.72E-05	8.41E-05	ND	9.07E-05			
Sr	mg/dscm	4.19E-05	1.95E-05	ND	3.07E-05			
V	mg/dscm	2.66E-04	ND	ND	2.66E-04	e		
Y	mg/dscm	1.09E-05	2.78E-05	ND	1.94E-05			
Zn	mg/dscm	4.96E-02	1.62E-03	1.58E-03	1.76E-02			d
Zr	mg/dscm	ND	1.81E-05	ND	1.81E-05	e		
Sulfate	mg/dscm	7.68E-02	5.57E-03	6.34E-03	2.96E-02	a		d
Nitrate	mg/dscm	1.29E-02	4.58E-03	8.50E-03	8.65E-03	a		
Chloride	mg/dscm	1.01E-02	2.61E-03	3.64E-03	5.47E-03	a	b	d
Ammonium	mg/dscm	1.34E-02	ND	ND	1.34E-02	e		
Soluble Na	mg/dscm	8.72E-04	3.23E-04	8.06E-04	6.67E-04	a	b	

a - 95% confidence lower bound of the average concentration is less than the dilution sampler blank concentration.

b - 95% confidence lower bound of the average concentration is less than the field blank concentration.

d - 95% confidence lower bound of the average concentration is less than the ambient concentration.

e - Insufficient data to calculate 95% confidence lower bound of the average concentration (i.e. zero or one valid run).

APPENDIX E
CEPEI 2012 TECHNICAL MEMORANDUM

Fine Particulate Emissions from Natural Gas-Fired Combustion Sources: Alternative $PM_{2.5}$ Emission Factors

Technical Memorandum

Prepared for:

Canadian Energy Partnership for Environmental Innovation (CEPEI)

Prepared by:

innovative environmental solutions, inc.

October 2012

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

There is very little data available on fine particulate ($PM_{2.5}$) emissions from natural gas-fired sources. Thus, emission factors from the U.S. EPA AP-42 document are the common reference when estimating $PM_{2.5}$ emissions from natural gas-fired sources. Since $PM_{2.5}$ emissions are low, there was little historical concern for these emissions and minimal effort expended to improve emission factors. However, as $PM_{2.5}$ emissions are more closely scrutinized the accuracy of AP-42 emission factors gains importance, especially since it has been shown that results from traditional $PM_{2.5}$ methods likely introduce significant positive bias when measuring the very low emissions from gas-fired sources. An assessment of these factors and review of alternative emission factors is warranted.

The only notable alternative data to that used for AP-42 emission factor development is from a U.S. collaborative project conducted from 2001 to 2005. The multi-party project included state and federal agencies and used advanced dilution tunnel methods to characterize $PM_{2.5}$ emissions from natural gas-fired equipment. The project concluded that dilution tunnel results are more appropriate than emission factors based on conventional methods, such as the AP-42 emission factors. Based on the conclusions from the U.S. collaborative project, it is apparent that dilution tunnel results are the preferred alternative to AP-42 emission factors.

The U.S. collaborative project dilution tunnel tests measured $PM_{2.5}$ emissions, and present $PM_{2.5}$ mass rates as well as speciated data that identify the chemical components that comprise $PM_{2.5}$ emissions. An understanding of combustion chemistry and the species measured indicates that particulate from gas-fired sources is fine particulate (<2.5 μm). Thus, coarser particulate was not measured in the collaborative project and results are not presented using protocol sometimes associated with conventional test methods (e.g., "filterable" or "condensable" emissions).

There are considerations that need to be addressed when defining the emission factor because the selection of the factor may have both policy and technical implications. In addition, the context for data use is important (e.g., source estimate, source emission limit, national inventory). AP-42 emission factors are typically the average of the emissions data used, and EPA cautions against using AP-42 factors for establishing permit limits. However, AP-42 factors are used for that purpose because alternatives are not available. This memorandum presents the 95% confidence limit upper bound or maximum value from dilution tunnel data as alternatives to AP-42 factors. Emission factors are presented for boilers, process heaters, and turbines, but there is little difference in the $PM_{2.5}$ emissions for these different source types based on the data from the U.S. collaborative project. The differences in source-specific emission factors likely include measurement uncertainty as a significant contributor. Natural gas-fired reciprocating engine emissions are a data gap. The AP-42 data for reciprocating engines is based on three or fewer tests from Gas Research Institute testing that was not focused on particulate measurement, and dilution tunnel results are not available.

The summary of dilution tunnel $PM_{2.5}$ emission factors for natural gas-fired sources includes:

- Boilers: 2.7×10^{-4} kg/GJ (0.27 g/GJ) based on the maximum (Note: kg/GJ units are used for other factors presented in this section);
  - The average emission factor is 1.4×10^{-4} kg/GJ and the value based on the 95% confidence upper bound is 2.3×10^{-4} kg/GJ;
- Process Heaters: 1.34×10^{-4} kg/GJ (based on the maximum);

  - The average emission factor is 6.9×10^{-5} kg/GJ and the 95% confidence upper bound value is 1.4×10^{-4} kg/GJ (note that the 95% confidence interval upper bound emission factor is larger than the maximum due to the small number of samples – i.e., three tests);
- Turbines: 2.3×10^{-4} kg/GJ (based on the maximum);
  - The average emission factor is 7.1×10^{-5} kg/GJ and the 95% confidence upper bound value is 1.1×10^{-4} kg/GJ;
- If all of the natural gas-fired data are considered as a single dataset, the maximum emission factor is 2.7×10^{-4} kg/GJ (0.27 g/GJ), and the average emission factor is 9.6×10^{-5} kg/GJ (0.096 g/GJ). The 95% confidence upper bound emission factor is 1.3×10^{-4} kg/GJ (0.13 g/GJ).

As shown in Table 1 of this memorandum, the range of the dilution tunnel test data is relatively narrow, especially when considering the very low level of mass emissions measured. To improve lower detection limits and improve performance when sampling streams with low mass emissions, dilution tunnel testing uses methods with detection limits commensurate with ambient test methods rather than stack test methods. For example, the mass measured with dilution tunnel tests would typically be below method detection limits for conventional exhaust stack reference methods.

Since the measurement results include uncertainty associated with the low levels measured and limited data is available (i.e., 32 tests), and the test results fall within a relatively narrow band without obvious outliers, the data imply similar emissions for gas-fired sources regardless of the source type. As noted in conclusions from the U.S. collaborative project reports:

- For gas-fired sources, dilution sampling indicates fine particulate mass emissions are extremely low and probably similar to ambient air $PM_{2.5}$ concentrations in many cases.
- The most important factor affecting $PM_{2.5}$ variability is *not* equipment type, operating condition, or emission controls, but rather due to test methods, with the method choice (i.e., traditional impinger methods versus dilution tunnel) and sampling artifacts related to sulfur species the most important factors affecting variability in $PM_{2.5}$ emission results.

Conclusions regarding test methods indicate that dilution tunnel results for gas-fired sources are more representative of actual emissions than conventional test methods that serve as the basis for AP-42 emission factors. These conclusions also indicate that the test method from which emission estimates are derived may be a primary basis for perceptions about the significance of $PM_{2.5}$ emissions from a source. If unit or facility emissions are assessed based on the lower emission factor from dilution tunnel tests, different conclusions may be reached regarding the significance of a source when compared to estimates based on AP-42 factors. Thus, care should be taken to ensure that test method flaws do not erroneously impact regulatory decisions.

Since the dilution tunnel results are significantly lower than AP-42 emission factors and uncertainty is inherent for such low measurements, conservatism may be desired for $PM_{2.5}$ emission estimates. Thus, the *maximum* emission factor from the data set or specific source type may be considered as a preferred alternative for emission estimates. The maximum emission factors for natural gas-fired sources include:

- Boilers: 2.7×10^{-4} kg/GJ (0.27 g/GJ);
- Process heaters: 1.3×10^{-4} kg/GJ (0.13 g/GJ); and
- Turbines: 2.3×10^{-4} kg/GJ (0.23 g/GJ).

1.0 Introduction

According to the U.S. EPA AP-42 document[1] (AP-42 document), an "emission factor is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. … Such factors facilitate estimation of emissions from various sources of air pollution." The AP-42 document is a primary reference used throughout the world for estimating emissions of common pollutants. In the AP-42 document, EPA cautions about the use of AP-42 emission factors, indicating:

> "Emission factors in AP-42 are neither EPA-recommended emission limits (e. g., best available control technology or BACT, or lowest achievable emission rate or LAER) nor standards (e. g., National Emission Standard for Hazardous Air Pollutants or NESHAP, or New Source Performance Standards or NSPS). Use of these factors as source-specific permit limits and/or as emission regulation compliance determinations is not recommended by EPA."

However, AP-42 emission factors are commonly used for exactly this purpose when other information is not available, and AP-42 emission factors serve as de facto standards in many cases. For fine particulate emissions from natural gas-fired combustion, very little data is available. Thus, AP-42 emission factors have been the common reference when estimating fine particulate emissions from natural gas-fired sources. Since emissions are low, there was little historical concern for these emissions and minimal effort has been expended to conduct tests. However, as fine particulate emissions face additional scrutiny, the veracity of the AP-42 fine particulate emission factors has become more important. An assessment of these factors and review of alternatives is warranted.

Fine particulate matter is defined as particulate with an aerodynamic mean diameter of 2.5 microns or less ($PM_{2.5}$). Understanding $PM_{2.5}$ emissions is more complex than other conventional pollutants, because $PM_{2.5}$ is comprised of a mixture of chemical species. In some cases, the species are directly emitted as particulate, and in other cases (e.g., aerosols) the pollutants condense in the atmosphere as the stack plume cools. In addition, secondary $PM_{2.5}$ can be formed from atmospheric reactions (i.e., "direct" emissions are a $PM_{2.5}$ precursor).

For combustion sources, the common constituents of $PM_{2.5}$ include sulfate, nitrate, ammonium, elemental carbon, organic compounds, and other inorganic materials. In addition, sulfate, nitrate, and ammonium are formed in the atmosphere from SO_2, NOx, and ammonia emissions. These emissions, which are considered $PM_{2.5}$ precursors, are not counted as "primary" emissions as represented in $PM_{2.5}$ emission factors. Elemental carbon, organic and inorganic compounds, and sulfate, nitrate and ammonium are the "direct" or primary emissions represented by emission factors, and this includes species that condense as the combustion exhaust plume cools to ambient temperature. Since it is a gaseous fuel, natural gas combustion has characteristically low particulate emissions with all of the particulate considered $PM_{2.5}$.

The Canadian Energy Partnership for Environmental Innovation (CEPEI) has recently investigated U.S. $PM_{2.5}$ regulatory criteria, the U.S. EPA AP-42 document $PM_{2.5}$ emission factors, challenges with measuring $PM_{2.5}$ from gas-fired sources, and data other than the AP-42 emission factors, including a U.S. collaborative project that measured $PM_{2.5}$ emissions using a

[1] AP-42, Compilation of Air Pollutant Emission Factors, Volume 1, Stationary and Area Point Source, U.S. EPA Office of Air Quality Planning and Standards (January 1995).

dilution tunnel test method. Other than the U.S collaborative project, AP-42 tests, and a handful of similar test results based on conventional test methods, review of available fine particulate emissions data and emission factors did not identify significant additional data. In an ongoing effort to improve $PM_{2.5}$ emission estimates for natural gas-fired combustion sources, this technical memorandum considers alternative $PM_{2.5}$ emission factors for natural gas-fired sources. The memo includes:

- Background on the U.S. EPA AP-42 emissions factor and similar data based on conventional test methods;
- Background on a U.S. collaborative project and its results, including a summary of test data acquired using a dilution tunnel test method, comparison to AP-42, and conclusions and recommendations regarding these results;
- Discussion and recommendations regarding alternative $PM_{2.5}$ emission factors for natural gas-fired turbines, boilers, and heaters.

Following this introductory section of the memo, Section 2 provides background on the AP-42 emission factors and potential biases in historical data. Section 3 provides a test methods overview, and also provides an overview of emissions data and emission factors from a collaborative multi-party project that included U.S. federal, state and industry participants. The U.S. collaborative project used a dilution tunnel to measure $PM_{2.5}$ emissions from gas-fired and oil-fired sources. Section 4 discusses alternative $PM_{2.5}$ emission factors for natural gas-fired sources and recommends alternatives based on available data.

2.0 Fine Particulate Emission Factors Background and U.S. EPA AP-42 Factors

$PM_{2.5}$ is typically comprised of a number of constituents that include sulfate, nitrate, ammonium, elemental carbon, semi-volatile organic compounds, and other inorganic materials (e.g., ash from solid and liquid fuels). Natural gas is comprised of simple hydrocarbons and is typically 90% by volume or more methane (CH_4) with ethane, ethylene, propane, butane, carbon dioxide and nitrogen comprising the balance. Trace levels of higher hydrocarbons and contaminants (e.g., hydrogen sulfide, benzene) may also be present. Since it is a gaseous and ash free fuel, natural gas combustion emits very low levels of particulate that challenge test method detection limits. Trace levels of $PM_{2.5}$ constituents including nitrate, sulfate, and semi-volatile organics can form in the byproducts from natural gas combustion.

Most available data on natural gas combustion $PM_{2.5}$ emissions was acquired using conventional test methods that measure the total mass of all constituents that comprise fine particulate, with "filterable" particulate (i.e., constituents captured on a sample system filter) measured separately from "condensable" particulate, which passes through the filter and is captured in a cooled impinger train. These methods are available on the U.S. Environmental Protection Agency (EPA) website (e.g., see Method 5, Method 5I, and Method 202 at http://www.epa.gov/ttn/emc/promgate.html). A measurement bias has been demonstrated when using Method 202 for natural gas-fired sources due to a sampling artifact that can inappropriately categorize trace levels of SO_2 from fuel sulfur (i.e., from H_2S and mercaptans used as an odorant) as sulfate. Although the absolute level of this bias (i.e., absolute mass emissions) is small, the relative bias can be significant due to the low overall $PM_{2.5}$ emissions. An advanced method used in recent testing can measure total mass from a *dilution tunnel system*, as well as the various constituents or species that comprise particulate.

“Dilution tunnel” methods simulate plume chemistry, and the method “separates” the resulting stream into a number of parallel sample lines and applies species-specific methods to measure and speciate the emissions using available refined sample collection and analytical techniques. For natural gas combustion, the trace emission levels challenge detection limits, even though methods analogous to ambient test methods are used for sample collection and analysis. As discussed in Section 3, the EPA supported a program that used a dilution tunnel to measure natural gas combustion $PM_{2.5}$ emissions.

The U.S. collaborative project dilution tunnel tests measured $PM_{2.5}$ emissions, and present $PM_{2.5}$ mass rates as well as speciated data that identify the chemical components that comprise $PM_{2.5}$ emissions. An understanding of combustion chemistry and the species measured indicates that particulate from gas-fired sources is fine particulate (<2.5 μm). Thus, coarser particulate was not measured in the collaborative project and results are not presented using protocol sometimes associated with conventional test methods (e.g., “filterable” or “condensable” emissions).

For estimating emissions for permitting, project analysis, or other related activities, emission factors are used. For more common natural gas combustion pollutants such as NOx or CO, equipment providers (e.g., turbine or engine manufacturers) provide emissions factors for new equipment. Emission factors for trace pollutants such as natural gas combustion $PM_{2.5}$ will typically not be available from the equipment manufacturer. In this case, the most common reference for industrial equipment emissions factors is the EPA “AP-42 document”. The document is titled “Compilation of Air Pollutant Emission Factors, Volume 1, Stationary Point and Area Sources,” and source-specific sections are updated periodically. On-line access is available at: http://www.epa.gov/ttnchie1/ap42/ .

For turbines and reciprocating engines, the most recent AP-42 updates were published in 2000, and 1998 for boilers and process heaters. Since the update process typically takes multiple years, this means the data and analysis are well over a decade old, and no revisions are anticipated in the next several years. The particulate emission factors include condensable and filterable fractions. Based on an understanding of natural gas constituents and combustion chemistry, condensable emissions should comprise the majority of fine particulate in natural gas combustion exhaust. That is, filterable particulate should be less than condensable particulate.

Previous memos discussed AP-42 $PM_{2.5}$ emission factors in more detail, and an AP-42 overview is provided in Appendix A. The AP-42 document rates the emission factors and data used to develop the factors. The AP-42 emission factors for natural gas-fired sources are presented in Appendix A along with a discussion of the emission factor rating and the rating scheme. Sections 3 compares AP-42 factors with other factors from the U.S. collaborative project and shows the implications for emission rates for example combustion sources.

3.0 Summary of the U.S. Collaborative $PM_{2.5}$ Test Program

3.1 Project Overview, Objectives and Summary of Conclusions

In response to uncertainties regarding $PM_{2.5}$ emission factors for gas-fired sources, a collaborative U.S. program investigating technical issues associated with fine particulate emission factors and measurement methods was initiated in 2001 and completed in 2005 (hereinafter referred to as the "collaborative project"). The collaborative project was funded by the California Energy Commission (CEC), New York State Energy Research and Development Authority (NYSERDA), and Gas Research Institute (GRI). The project was integrated with a similar effort that included the U.S. Department of Energy (DOE) and American Petroleum Institute (API). Thus, five funding agencies that include the U.S. federal government, state governments, and industry trade associations played a vital role in project oversight, management, and execution. The project team also included the U.S. EPA in an advisory role and academic and scientific leaders on fine particulate measurement as team members or technical advisors. This information is delineated in the project reports discussed below.

The collaboration was initiated because NYSERDA and GRI were generally concerned with emission factor and measurement issues, and additional data were desired to better characterize emissions and source apportionment to inform policy. For California, a need for additional data was identified following 2000 – 2001 electricity shortages in the state (i.e., brownouts and rolling blackouts). This resulted in a number of energy project applications for new in-state capacity, with the capacity primarily based on natural gas-fired turbines. CEC was concerned that the associated emissions may exacerbate fine particulate nonattainment. Using AP-42 $PM_{2.5}$ emission factors to estimate emissions raised concerns regarding marginal increases in in-state inventory that could result from larger turbines that would have replaced electricity imported from other states. There was also a concern that positive bias in AP-42 emission factors was artificially inflating the potential inventory and a better understanding of $PM_{2.5}$ emissions and the cause of turbine $PM_{2.5}$ emissions variability was desired.

The project objectives included:

- Development of improved dilution sampling methods for measuring total mass and speciated $PM_{2.5}$ emissions;
- Completing a field test campaign to gather emissions data for gas-fired and oil-fired sources;
- Comparison of results obtained with dilution tunnels and traditional EPA methods (e.g., compare to AP-42 and other available results);
- Identification and characterization of $PM_{2.5}$ emissions, and development of emission factors and speciation profiles, including precursors and organic aerosols, for use in source-receptor and source apportionment analysis; and
- Characterization of $PM_{2.5}$ emissions variability and uncertainty for gas-fired units, including understanding the sources of emissions variations and the contribution of test method artifacts.

The testing was completed over two years, and multiple detailed, peer-reviewed technical reports were developed. The reports are available at CEC and NYSERDA websites, and significant additional detail is available in the reports. There are thirteen primary project reports, technical memos, and host site test reports that comprise over 1,400 pages of material. The documents and weblinks to the CEC site are tabulated in Appendix B, and the general link to the CEC website is:

http://www.energy.ca.gov/pier/project_reports/CEC-500-2005-032_to_44.html

The primary reference used for this memo is the Final Report[2], which summarizes the program results. Additional documents (see Appendix B) include:

- A fine particulate dilution sampling test protocol.
- Four topical reports/memorandums addressing:
  - A literature review of source sampling and analysis methods for characterizing organic aerosols and fine particulate emission profiles;
  - The design and validation testing of a mini-dilution sampler;
  - An assessment of sources of $PM_{2.5}$ emissions data variability in gas turbines; and
  - An assessment of the impact of operating parameters on $PM_{2.5}$ emissions from natural gas-fired combined cycle and cogeneration power plants.
- Seven field test reports.

A summary of the project conclusions from the project reports and related summaries from the CEC and NYSERDA websites include:

- Traditional EPA test methods and the dilution tunnel method provide very different results;
- Data from traditional methods should not be mixed with speciation profiles from dilution sampling methods;
- $PM_{2.5}$ emissions from gas-fired sources are extremely low and challenge the capability of test methods;
- For traditional impinger-based methods, tests confirmed a positive bias from SO_2 capture for the condensable test method (i.e., from Method 202 impingers) and "dissolved SO_2 to sulfate" liquid-phase conversion, where SO_2 from trace sulfur in natural gas is inappropriately captured as $PM_{2.5}$;
- As expressed by NYSERDA, existing $PM_{2.5}$ inventories (based on AP-42 emission factors) are inadequate for developing air quality management plans;
- The multi-million dollar collaborative project provides significant data, and emission factors from that project are recommended as alternatives to AP-42 factors. Nevertheless, additional efforts may be desired to develop source emission profiles and mass emission rates that serve as a basis for scientifically sound emission inventories.

These conclusions, which are supported by state and federal agencies focused on protecting the public interest, include compelling conclusions regarding dilution tunnel test results and historical (e.g., AP-42) data. In Section 4 of this memo, additional discussion and more detailed conclusions are presented regarding collaborative project results that address the technical veracity of the emissions data and its use for emission factors.

[2] England, G.C., "Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas-fired Combustion Systems", Final Report (October 2004).

3.2 Fine Particulate Test Methods Overview

Supplemental technical reports from the collaborative project include detailed discussion of traditional “impinger based” test methods and dilution tunnel methods. An overview is provided here.

The conventional test methods for measuring $PM_{2.5}$ are EPA Method 5 and EPA Method 202 (or equivalent or derivative methods) to measure filterable and condensable particulate, respectively. Filterable particulate is in particulate form as a solid or liquid at the elevated temperatures within the exhaust stack. Condensable particulate are those chemical compounds that are gaseous at stack temperatures but condense at ambient temperature to form particulate. The Method 202 sample train is intended to condense and measure those emissions. According to the U.S. EPA, condensable particulate is all considered to be less than one micron (i.e., $PM_{1.0}$ or smaller).

It has been demonstrated that potential biases in the Method 202 can result in trace levels of sulfur in natural gas that is emitted as SO_2 being “measured” as sulfate particulate rather than as SO_2 (a gaseous, non-particulate pollutant). Exhaust SO_2 from natural gas combustion is very low and results from trace amounts of hydrogen sulfide and sulfur from mercaptans that are used to odorize natural gas being converted to SO_2 during combustion. Although the low level of SO_2 emissions is not a regulatory concern from combustion of pipeline quality natural gas, since fine particulate emissions are also very low, the bias from SO_2 can comprise a significant portion of $PM_{2.5}$ “measured” from natural gas combustion. This is explained further in the project reports.

In recent years, “dilution tunnel” methods have been developed that measure fine particulate by simulating plume chemistry in a holding chamber before measuring the sample where condensation of particulate species has occurred. The stream from the holding chamber can then be measured in multiple parallel samples that apply species-specific methods to measure $PM_{2.5}$ mass and/or speciate the emissions using available refined sample collection and analytical techniques, including ambient measurement methods.

The collaborative project test team included members from the Desert Research Institute (DRI), a primary developer of “laboratory scale” dilution tunnel hardware and test methods. A more compact dilution sampler was developed and utilized for the project. The compact dilution tunnel results agreed well with the larger laboratory-scale dilution sampler and showed much lower results than conventional test methods.

The collaborative project concluded that dilution sampling techniques are more appropriate for obtaining a representative particulate matter sample from combustion systems for determining $PM_{2.5}$ emission rate and chemical speciation. For natural gas combustion, the project also concluded that trace $PM_{2.5}$ emission levels challenge detection limits and results are often similar to ambient air.

3.3 Summary of $PM_{2.5}$ Test Results and Emission Factors

A primary goal of the collaborative project was to develop emission factors and speciation profiles using dilution sampling methods for $PM_{2.5}$ emissions. Precursor emissions (i.e., NOx, VOCs) were also measured, but those emissions are not addressed in this memo.

Dilution tunnel methods were used for tests at seven different sites to characterize fine particulate emission rates and speciation. Fuels tested include natural gas, refinery gas, low sulfur diesel, and residual (no. 6) fuel oil. This report focuses on gas-fired sources, specifically natural gas-fired sources (i.e., excluding refinery gas). The project tested 32 gas-fired units and in total included the following types of units:

- Gas-fired boilers and steam generators,
- Gas-fired combined cycle and cogeneration power plants,
- Gas-fired process heaters,
- No. 6 oil-fired boilers, and
- Diesel engines.

The testing program and units tested were dependent upon available host sites and the sources tested and associated emission controls are not an ideal list. For example, turbines tested included exhaust emission control (selective catalytic reduction, oxidation catalyst), and a natural gas-fired reciprocating engine was not tested due to funding limitations. A detailed description of the sites and units tested are provided in the project reports. As noted in those reports, particulate emissions are so low that operational factors do not appear consequential when considering emissions impacts, and the results indicate similar $PM_{2.5}$ emission rates for all gas-fired units tested. This is shown in results discussed below.

Although the list of tested sources is not ideal, the collaborative project provides the most robust emissions data available on trace $PM_{2.5}$ emissions from natural gas combustion. These data and results can be reviewed to identify appropriate emission factors.

Summary of Collaborative Project Results

Table 1 summarizes the $PM_{2.5}$ emissions data from dilution tunnel testing of natural gas and refinery gas-fired emission sources including boilers, steam generators, process heaters, and turbine combined cycle and cogeneration power plants. The table lists the data from the lowest to highest emission factor, presented in kilograms per gigajoule (kg/GJ) and grams per gigajoule (g/GJ) where gigajoules are based on the heat input using the higher heating value (HHV) of the fuel. HHV is the convention for emission factors.

Thirty-two gas-fired units were tested, including 20 natural gas-fired units and 12 refinery gas-fired units. Many of the units were equipped with air pollution control equipment as indicated in the table. Refer to the final project report and related host site-specific reports for additional detail on the tests and $PM_{2.5}$ emissions data for gas-fired combustion sources.

The purpose of this memorandum is to assess alternative $PM_{2.5}$ emission factors for *natural gas-fired* sources, but results for both natural gas and refinery gas are presented in Table 1 and Table 2. All gas-fired data are shown so that the effect of fuel type and source type on emission factors can be reviewed to assess whether there are significant differences in the data.

Table 1 indicates an average $PM_{2.5}$ emission factor of 9.0×10^{-5} kg/GJ (0.09 g/GJ) when considering all of the gas-fired tests and an emission factor based on the 95% confidence interval upper bound of 1.2×10^{-4} kg/GJ (0.12 g/GJ). The maximum from all tests is 2.7×10^{-4} kg/GJ

(0.27 g/GJ). Additional discussion is provided below on the range of emission factors and considerations for emission factor choice for emission estimates.

Table 1. Summary of $PM_{2.5}$ Emissions Data from Dilution Tunnel Tests for All Gas-Fired Units.

Source Category	Test Site	Source Description	$PM_{2.5}$ EF in kg/GJ and [g/GJ]
Process Heaters	Site B	RG-fired Process Heater	3.0×10^{-6} [0.0030]
Boilers & Steam Gens	Site C	NG-fired Steam Generator	7.3×10^{-6} [0.0073]
Process Heaters	Site B	RG-fired Process Heater	9.9×10^{-6} [0.0099]
Process Heaters	Site Charlie	NG-fired Process Heater w/SCR	1.1×10^{-5} [0.011]
Process Heaters	Site Alpha	RG-fired Process Heater	1.9×10^{-5} [0.019]
Process Heaters	Site Alpha	RG-fired Process Heater	2.1×10^{-5} [0.021]
Combined Cycle (CC) & Cogen PPs	Site Bravo	NG-fired CCPP w/ supp firing, Ox catalyst & SCR	2.2×10^{-5} [0.022]
Boilers & Steam Gens	Site C	NG-fired Steam Generator	2.4×10^{-5} [0.024]
Process Heaters	Site Alpha	RG-fired Process Heater	2.6×10^{-5} [0.026]
CC & Cogen PPs	Site Echo	NG-fired CCPP w/ lean premix comb, supp firing, Ox catalyst & SCR	3.6×10^{-5} [0.036]
Boilers & Steam Gens	Site C	NG-fired Steam Generator	4.1×10^{-5} [0.041]
CC & Cogen PPs	Site Echo	NG-fired CCPP w/ lean premix comb, supp firing, Ox catalyst & SCR	4.2×10^{-5} [0.042]
CC & Cogen PPs	Site Echo	NG-fired CCPP w/ lean premix comb, supp firing, Ox catalyst & SCR	4.7×10^{-5} [0.047]
Process Heaters	Site B	RG-fired Process Heater	5.6×10^{-5} [0.056]
CC & Cogen PPs	Site Echo	NG-fired CCPP w/ lean premix comb, supp firing, Ox catalyst & SCR	5.6×10^{-5} [0.056]
CC & Cogen PPs	Site Echo	NG-fired CCPP w/ lean premix comb, supp firing, Ox catalyst & SCR	6.4×10^{-5} [0.064]
CC & Cogen PPs	Site Echo	NG-fired CCPP w/ lean premix comb, supp firing, Ox catalyst & SCR	6.4×10^{-5} [0.064]
Process Heaters	Site Charlie	NG-fired Process Heater w/SCR	6.9×10^{-5} [0.069]
CC & Cogen PPs	Site Bravo	NG-fired CCPP w/ supp firing, Ox catalyst & SCR	6.9×10^{-5} [0.069]
CC & Cogen PPs	Site Echo	NG-fired CCPP w/ lean premix comb, supp firing, Ox catalyst & SCR	7.7×10^{-5} [0.077]
CC & Cogen PPs	Site Golf	RG-fired Cogen PP w/supp firing, Ox catalyst & SCR	9.0×10^{-5} [0.090]
Boilers & Steam Gens	Site A	RG-fired Boiler	1.2×10^{-4} [0.12]
Process Heaters	Site Charlie	NG-fired Process Heater w/SCR	1.3×10^{-4} [0.13]

Table 1. (continued)

Source Category	Test Site	Source Description	$PM_{2.5}$ EF in kg/GJ and [g/GJ]
CC & Cogen PPs	Site Golf	RG-fired Cogen PP w/supp firing, Ox catalyst & SCR	1.4×10^{-4} [0.14]
CC & Cogen PPs	Site Golf	RG-fired Cogen PP w/supp firing, Ox catalyst & SCR	1.5×10^{-4} [0.15]
Boilers & Steam Gens	Site Delta	Dual Fuel Boiler (NG)	1.6×10^{-4} [0.16]
Boilers & Steam Gens	Site A	RG-fired Boiler	1.6×10^{-4} [0.16]
Boilers & Steam Gens	Site A	RG-fired Boiler	1.8×10^{-4} [0.18]
CC & Cogen PPs	Site Bravo	NG-fired CCPP w/ supp firing, Ox catalyst & SCR	2.3×10^{-4} [0.23]
Boilers & Steam Gens	Site Delta	Dual Fuel Boiler (NG)	2.4×10^{-4} [0.24]
Boilers & Steam Gens	Site Delta	Dual Fuel Boiler (NG)	2.5×10^{-4} [0.25]
Boilers & Steam Gens	Site Delta	Dual Fuel Boiler (NG)	2.7×10^{-4} [0.27]
Average (mean)			**9.0×10^{-5}** [0.090]
Upper Bound (at 95% Confidence Level)			**1.2×10^{-4}** [0.12]

Table 1 includes all of the gas-fired units (i.e., boilers, process heaters and turbines with and without post-combustion controls) and includes both natural gas-fired and refinery gas-fired units. Table 2 segregates the results by fuel and unit type and presents the average emission factor, upper bound emission factor at a 95% confidence level, and maximum emission factor. The same AP-42 emission factor applies for boilers and process heaters, so those emission sources are presented grouped and individually in Table 2.

Since the dilution tunnel results are significantly lower than AP-42 emission factors and uncertainty is inherent to such low measurements, conservatism may be desired for $PM_{2.5}$ emission estimates. Tables below present *maximum* emission factors from the dataset, average emission factors, and/or emission factors based on a 95% confidence interval upper bound. The basis for the emission estimate (e.g., source permitting, national inventory, etc.) should be considered when evaluating the preferred emission factor for a particular analysis or estimate.

Table 2. Comparison of $PM_{2.5}$ Emission Factors from Dilution Tunnel Tests by Unit Type and Fuel Type for Gas-Fired Boilers, Process Heaters, and Turbines.

Type of Unit	Fuel	Test Count	Average $PM_{2.5}$ in kg/GJ and [g/GJ]	$PM_{2.5}$ (95% CI) in kg/GJ and [g/GJ]	Maximum $PM_{2.5}$ in kg/GJ and [g/GJ]
All	All Gas	32	9.0×10^{-5} [0.090]	1.2×10^{-4} [0.12]	2.7×10^{-4} [0.27]
All	Natural Gas	20	9.6×10^{-5} [0.096]	1.3×10^{-4} [0.13]	2.7×10^{-4} [0.27]
All	Refinery Gas	12	8.2×10^{-5} [0.082]	1.2×10^{-4} [0.12]	1.8×10^{-4} [0.18]
Boiler and Heater	All Gas	19	9.5×10^{-5} [0.095]	1.4×10^{-4} [0.14]	2.7×10^{-4} [0.27]
Boiler and Heater	Natural Gas	10	1.2×10^{-4} [0.12]	1.8×10^{-4} [0.18]	2.7×10^{-4} [0.27]
Boiler and Heater	Refinery Gas	9	6.7×10^{-5} [0.067]	1.1×10^{-4} [0.11]	1.8×10^{-4} [0.18]
Boiler	All Gas	10	1.5×10^{-4} [0.15]	2.1×10^{-4} [0.21]	2.7×10^{-4} [0.27]
Boiler	Natural Gas	7	1.4×10^{-4} [0.14]	2.3×10^{-4} [0.23]	2.7×10^{-4} [0.27]
Boiler	Refinery Gas	3	1.5×10^{-4} [0.15]	1.9×10^{-4} [0.19]	1.8×10^{-4} [0.18]
Process Heater	All Gas	9	3.7×10^{-5} [0.037]	6.2×10^{-5} [0.062]	1.3×10^{-4} [0.13]
Process Heater	Natural Gas	3	6.9×10^{-5} [0.069]	1.4×10^{-4} [0.14]	1.3×10^{-4} [0.13]
Process Heater	Refinery Gas	6	2.3×10^{-5} [0.023]	3.7×10^{-5} [0.04]	5.6×10^{-5} [0.056]
Turbine	All Gas	13	8.4×10^{-5} [0.084]	1.2×10^{-4} [0.12]	2.3×10^{-4} [0.23]
Turbine	Natural Gas	10	7.1×10^{-5} [0.071]	1.1×10^{-4} [0.11]	2.3×10^{-4} [0.23]
Turbine	Refinery Gas	3	1.3×10^{-4} [0.13]	1.6×10^{-4} [0.16]	1.5×10^{-4} [0.15]

To facilitate comparison, Table 3 summarizes the same information for natural gas-fired units (i.e., omits refinery gas). Table 4 compares the dilution tunnel average emission factor and 95% confidence upper bound emission factor to AP-42 emission factors for each unit type.

Table 3. Comparison of $PM_{2.5}$ Emission Factors from Dilution Tunnel Tests for Natural Gas-Fired Boilers, Process Heaters, and Turbines.

Type of Unit	Fuel	Test Count	Average $PM_{2.5}$ in kg / GJ and [g/GJ]	$PM_{2.5}$ (95% CI)[1] in kg / GJ and [g/GJ]
All	Natural Gas	20	9.6×10^{-5} [0.096]	1.3×10^{-4} [0.13]
Boiler and Heater	Natural Gas	10	1.2×10^{-4} [0.12]	1.8×10^{-4} [0.18]
Boiler	Natural Gas	7	1.4×10^{-4} [0.14]	2.3×10^{-4} [0.23]
Process Heater	Natural Gas	3	6.9×10^{-5} [0.069]	1.4×10^{-4} [0.14]
Turbine	Natural Gas	10	7.1×10^{-5} [0.071]	1.1×10^{-4} [0.11]

[1] Emission factor based on the 95% confidence interval upper bound is presented in Tables 3, 4 and 5.

Table 4. Comparison of Dilution Tunnel $PM_{2.5}$ Emission Factors to AP-42 Emission Factors.

Type of Unit	Fuel	Dilution Tunnel Emission Factor		AP-42 $PM_{2.5}$ EF in kg / GJ and [g/GJ]	EF Ratio: AP-42 / Dil. Tunnel (95% CI)
		Average $PM_{2.5}$ in kg / GJ and [g/GJ]	$PM_{2.5}$ (95% CI) in kg / GJ and [g/GJ]		
Boiler and Heater	Natural Gas	1.2×10^{-4} [0.12]	1.8×10^{-4} [0.18]	3.2×10^{-3} [3.2]	18
Boiler	Natural Gas	1.4×10^{-4} [0.14]	2.3×10^{-4} [0.23]	3.2×10^{-3} [3.2]	14
Process Heater	Natural Gas	6.9×10^{-5} [0.069]	1.4×10^{-4} [0.14]	3.2×10^{-3} [3.2]	23
Turbine	Natural Gas	7.1×10^{-5} [0.071]	1.1×10^{-4} [0.11]	2.8×10^{-3} [2.8]	25

Table 5 provides another comparison by presenting the annual “potential to emit” (i.e., based on 8,760 annual operating hours) $PM_{2.5}$ emissions in kilograms per year for types and sizes of typical equipment based on the AP-42 emission factor and 95% confidence upper bound emission factor from the collaborative project. This shows that emissions are much less than one metric ton annually for gas-fired units as large as 30 MW based on the dilution tunnel 95% confidence upper bound emission factor and lower if the average emission factor is used for the calculation.

Table 5. Annual $PM_{2.5}$ emissions (kg per year) for example natural gas-fired equipment based on dilution tunnel emission factors (average and 95% confidence upper bound) or AP-42.

Unit Type	Example Size	$PM_{2.5}$ Emissions[1] (kg/year) Dil.Tun. (Average) EF	$PM_{2.5}$ Emissions[1] (kg/year) Dil.Tun. (95% CI) EF	$PM_{2.5}$ Emissions[1] (kg/year) AP-42 EF
Natural gas-fired boiler	10 MW	147	242	3364
Natural gas-fired boiler	0.5 MW	7	12	168
Natural gas-fired process heater	10 MW	73	147	3364
Natural gas-fired process heater	0.5 MW	4	7	168
Natural gas-fired turbine	4 MW	30	46	1177
Natural gas-fired turbine	10 MW	75	116	2943
Natural gas-fired turbine	30 MW	224	347	8830

[1]Emission calculation based on potential to emit (8760 annual operating hours) and an assumed HHV-based heat rate of 12,000 kJ/kW-hr (8500 Btu/hp-hr).

These results demonstrate the significant difference between test results using dilution tunnel methods and conventional methods. Table 1 indicates relatively consistent emissions for boilers, process heaters, and turbines, including units with post-combustion emission controls – i.e., considering the challenges associated with measuring such low levels of particulate, the test data fall within a relatively narrow band and there are no outliers. The comparison to AP-42 demonstrates significantly different emission factors, and reinforces the conclusion in the collaborative project report on variability in gas-fired turbine test results. That report concluded that the most important factor affecting $PM_{2.5}$ variability is *not* equipment type, operating condition, or emission controls, but rather due to test methods, with the method choice (i.e., traditional impinger methods versus dilution tunnel) and artifacts related to sulfur species the most important factors affecting variability in $PM_{2.5}$ emission results. This is a significant conclusion, which confirms that the test method from which the emissions data is derived may be the primary basis for conclusions about the significance of $PM_{2.5}$ emissions. If unit or facility emissions are assessed based on the lower emission factor from dilution tunnel tests, different conclusions may be reached regarding the significance of a source. Or, considering this from another perspective, care should be taken to ensure that test method flaws do not erroneously impact regulatory decisions.

Detailed discussion is provided in the project reports on chemical speciation for the dilution tunnel results and data using conventional impinger-based methods. An example, which is typical for the dilution tunnel results, is shown in Figure 1. This figure shows the composite speciation profile for the average emissions factor for boilers and process heaters. The primary constituents are organic carbon species, which is a logical expectation for natural gas-fired sources. These speciation data show a much smaller sulfate percentage, which is typically reported as 50% to 70% of the total $PM_{2.5}$ from conventional impinger based methods. More detailed discussion of sulfur artifacts is available in the collaborative project final report and test methods report[3], and in the literature[4].

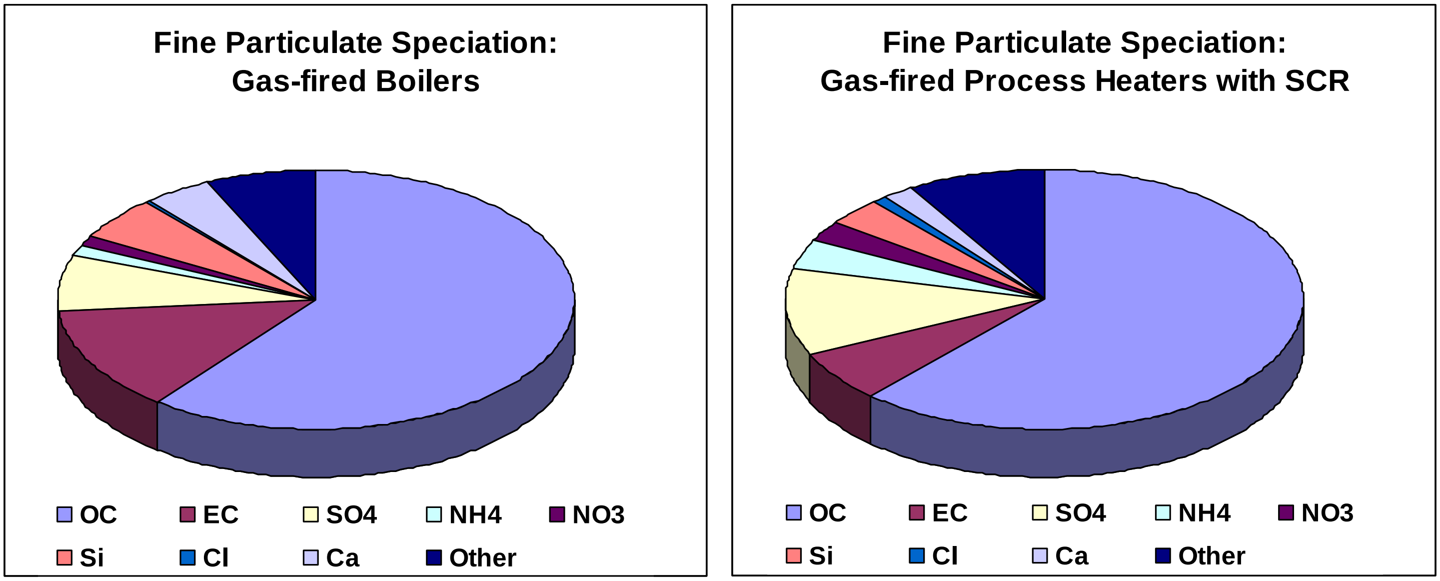


Figure 1. $PM_{2.5}$ Speciaton for Gas-fired Boilers and Process Heaters.

4.0 Discussion and Recommended $PM_{2.5}$ Emission Factors for Natural Gas-Fired Sources

4.1 Conclusions Regarding Dilution Tunnel Results

State and federal environmental and energy staff played a primary role in planning, managing, and executing the U.S. collaborative project, which supports the veracity of the results and conclusions. Government agencies that funded the project include CEC, NYSERDA, and DOE. EPA staff participated as advisors, and leading scientists in the field of PM emissions and measurement were team members or advisors. Findings, conclusions, and recommendations from the project reports: document the ultra-low levels of $PM_{2.5}$ emission from natural gas-fired sources; document the technical superiority of dilution tunnel methods and high bias from sulfur species with conventional impinger based methods; and, conclude that due to the low levels being measured and associated method limitations, dilution tunnel emission factors are more representative than emission factors, such as AP-42 factors, that are based on conventional methods.

The conclusions in the collaborative project reports provide the foundation to recommend dilution tunnel data as preferable to AP-42 emission factors. A number of key conclusions from

---

[3] Chang, O.M.C. and England, G.C., "Development of Fine Particulate Emission Factors and Speciation Profiles for Oil and Gas-fired Combustion Systems, Update: Critical Review of Source Sampling and Analysis Methodologies for Characterizing Organic Aerosol and Fine Particulate Source Emission Profiles." February 2004.

[4] Wien, S., England, G., Loos, K., and Ritter, K., "Investigation of Artifacts in Condensable Particulate Measurements for Stationary Combustion Sources". Proceedings of the Air & Waste Management Association's 94th Annual Conference and Exhibition, Orlando, Florida, June 2001.

the collaborative project reports which support the technical superiority of dilution tunnel test results are summarized here:

- $PM_{2.5}$ mass (for gas-fired sources).
  - **For gas-fired sources, dilution sampling indicates fine particulate mass emissions are extremely low and probably similar to ambient air $PM_{2.5}$ concentrations in many cases.** [emphasis added]
  - These levels are difficult to *quantify* with high confidence using available test methods. The "measured" data are far below both the estimated minimum detection limit (MDL) and lower quantification limit (LQL) of traditional hot filter/iced impinger methods, and generally between the estimated MDL and LQL of the dilution sampling method.
  - Traditional methods for measuring filterable and condensable particulate matter previously have been shown to be subject to small systematic and random biases (due to sampling artifacts and biases) that are very significant at the extremely low particulate concentrations typical of gas-fired sources.
  - The in-stack MDL and LQL achieved with dilution sampling are far lower than can be achieved by traditional hot filter/iced impinger methods due to the avoidance of such biases and greater analytical sensitivity.
  - **Therefore, the $PM_{2.5}$ concentration in stack gases from gas-fired sources measured using dilution sampling is far lower than that measured by traditional methods. While a degree of systematic and random bias in the dilution sampling measurements remains (primarily due to background $PM_{2.5}$ in the dilution air), these results for gas-fired sources are considered more representative of actual emissions.** [emphasis added]
  - Many of the stack $PM_{2.5}$ results could not be clearly distinguished from measurement background; in these cases, the true stack $PM_{2.5}$ is difficult to quantify by any of the methods used in this study.
  - Background $PM_{2.5}$ in the purified dilution air may be significant relative to the stack $PM_{2.5}$ for sources with extremely low stack $PM_{2.5}$ concentrations. This is more a consequence of the nature of the clean sources tested than of inherent limitations in the method.
  - The results from dilution sampling show that $PM_{2.5}$ differences due to size, load, gas fuel composition, duct burners, and various other differences (design, location, weather, etc.) are very small – especially in comparison to the wide $PM_{2.5}$ range exhibited in existing data.
- Particle Size. The test results for gas-fired units indicate that substantially all of the particulate matter in the stack was smaller than 2.5 micrometers. In-stack cyclones with 10 and 2.5 μm cutpoints were used in most tests; however, the results are generally below the MDL.
- Dilution Sampling Method Readiness. Tests comparing the dilution sampler to an existing benchmark dilution sampler showed that the two samplers yield results that are the same at the 95 percent confidence level. However, further testing is needed to better quantify systematic and random variation, especially for applications with extremely low (less than approximately 1 to 2 mg/dscm) particulate concentrations. Measurement background levels in the dilution air were found to be significant in some tests relative to stack concentrations for gas-fired sources.

- Use of $PM_{2.5}$ Emission Factors and Speciation Profiles.
  - The current population of data for each source category is small, but this project provided a good start toward developing robust emission factors and speciation profiles. To date, it is the most comprehensive study completed and similar projects have not been undertaken since this project was completed.
  - However, because of the small number of units tested (one to three), the emission factors may not be representative of either any individual unit or the entire population of units in each category (although this is frequently a limitation of many published emission factors).

  [Note that the data set from the collaborative project is larger and more robust than the data used for AP-42 emissions factors.]

4.2 Discussion and Recommended $PM_{2.5}$ Emission Factors

Based on the conclusions from the U.S. collaborative project, it is apparent that dilution tunnel results are the preferred data that provide an alternative to AP-42 emission factors. There are considerations that need to be addressed when defining the emission factor because the selection of the factor may have both policy and technical implications, and the context for data use is important. For example, AP-42 emission factors typically average the relevant emissions data, and EPA cautions against using AP-42 factors for establishing permit limits. EPA notes that if AP-42 factors truly represent the population, it would be expected that half of the sources would emit at a level higher than the AP-42 average factor.

This memorandum presents the 95% confidence upper bound and maximum emission factors from dilution tunnel data as alternatives to using an average factor or AP-42 factor, and recommends using maximum emission factors from dilution tunnel tests. Emission factors are presented for boilers, process heaters, and turbines, but it appears that there is little difference in the $PM_{2.5}$ emissions for different source types, and different values for source-specific emission factors likely include measurement uncertainty as a significant contributor. Although AP-42 factors are more than an order of magnitude higher than dilution tunnel-based factors (see Tables 4 and 5), the associated $PM_{2.5}$ emissions for gas-fired sources are still relatively low.

The context and subsequent requirements associated with the emission factor choice are important. For example, conducting dilution tunnel tests are very costly and the methods are not main stream. Thus, “compliance tests” to validate compliance with an emission limit would be a difficult if not infeasible proposition at this time. Similarly, test methods and data sources cannot be mixed – e.g., results from conventional impinger-based methods should not be used to assess whether a unit meets an emission level based on dilution tunnel emission factors.

The summary of dilution tunnel $PM_{2.5}$ emission factors (in kg/GJ) for natural gas-fired sources, as shown in Tables 2 and 3 follows, and use of the maximum emission factor by source type is recommended:

- Boilers: 2.7×10^{-4} kg/GJ (based on the maximum emission factor);
  - The average emission factor is 1.4×10^{-4} kg/GJ;
  - The 95% confidence interval upper bound emission factor is 2.3×10^{-4} kg/GJ;
- Process Heaters: 1.3×10^{-4} kg/GJ (based on the maximum emission factor);

  - The average emission factor is 6.9 x 10^{-5} kg/GJ;
  - The 95% confidence interval upper bound emission factor is 1.4 x 10^{-4} kg/GJ (note that the 95% confidence interval upper bound is larger than the maximum due to the small number of samples – i.e., three tests);
- Turbines: 2.3 x 10^{-4} kg/GJ (based on the maximum emission factor);
  - The average emission factor is 7.1 x 10^{-5} kg/GJ;
  - The 95% confidence interval upper bound emission factor is 1.1 x 10^{-4} kg/GJ;
- If all of the natural gas-fired data are considered as a single dataset, the maximum emission factor is 2.7 x 10^{-4} kg/GJ, the 95% confidence upper bound emission factor is 1.3 x 10^{-4} kg/GJ, and the average emission factor is 9.6 x 10^{-5} kg/GJ.

APPENDIX A

Summary of AP-42 Particulate Matter Emission Factors, Ratings, and Data Sources for Natural Gas-Fired Combustion

A summary of the emission factors (MMBtu is HHV based), ratings, and data sources follow:

- Natural gas-fired Turbine:
  - 4.7×10^{-3} lb/MMBtu condensable
  - 1.9×10^{-3} lb /MMBtu filterable
  - 6.6×10^{-3} lb /MMBtu total (2.8×10^{-3} kg/GJ)
  - “C” rating from EPA rating for both filterable and condensable
  - Particulate test data from three tests of one, 86 MW ABB turbine in Wisconsin
- Natural gas-fired boiler / process heater:
  - 5.7 lb/10^{6} SCF natural gas condensable
  - 1.9 lb/10^{6} SCF natural gas filterable
  - 7.6 lb/10^{6} SCF natural gas total (3.2×10^{-3} kg/GJ assuming 1020 Btu/SCF natural gas HHV)
  - “B” rating for filterable and “D” rating for condensable
  - Particulate test data: 21 tests from multiple units for filterable; four tests for condensable
- Natural gas-fired two-stroke lean burn reciprocating engine:
  - 9.91×10^{-3} lb/MMBtu condensable
  - 3.84×10^{-2} lb/MMBtu filterable
  - 4.83×10^{-2} lb/MMBtu total (2.1×10^{-2} kg/GJ)
  - “C” rating for filterable and “E” rating for condensable
  - Filterable particulate test data from three engine tests with one result more than an order of magnitude higher than the other two (note: based on the rating scheme discussed below, this should be D rather than C rating); condensable factor based on 4-stroke lean burn data
- Natural gas-fired four-stroke lean burn reciprocating engine:
  - 9.91×10^{-3} lb/MMBtu condensable
  - 7.71×10^{-5} lb/MMBtu filterable
  - 9.99×10^{-3} lb/MMBtu total (4.3×10^{-3} kg/GJ)
  - “D” rating for both filterable and condensable
  - Particulate test data from two tests at one site

The EPA rating scheme is subjective. In general, a factor rated lower than “B” is based on limited data and a limited source sample size. EPA describes these rating for the emission factor (A through E) and associated data (A through D), where the data ranking ranges from “sound methodology and validated results” for “A” data to “generally unaccepted methodology but may provide an order of magnitude estimate” for D quality data.

The ratings for data and emission factor ratings are described in the AP-42 document introduction (see http://www.epa.gov/ttn/chief/ap42/c00s00.pdf). For *data* ratings:

- A = Tests are performed by a sound methodology and are reported in enough detail for adequate validation.
- B = Tests are performed by a generally sound methodology, but lacking enough detail for adequate validation.
- C = Tests are based on an unproven or new methodology, or are lacking a significant amount of background information.
- D = Tests are based on a generally unacceptable method, but the method may provide an order-of-magnitude value for the source.

The related *emission factor* ratings are:

- A — Excellent. Factor is developed from A- and B-rated source test data taken from many randomly chosen facilities in the industry population. The source category population is sufficiently specific to minimize variability.
- B — Above average. Factor is developed from A- or 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. As with an A rating, the source category population is sufficiently specific to minimize variability.
- C — Average. Factor is developed from A-, B-, and/or C-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. As with the A rating, the source category population is sufficiently specific to minimize variability
- D — Below average. Factor is developed from A-, B- and/or C-rated test data from a small number of facilities, and there may be reason to suspect that these facilities do not represent a random sample of the industry. There also may be evidence of variability within the source population.
- E — Poor. Factor is developed from C- and D-rated test data, and there may be 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.

With the exception of the B rating for boiler *filterable* emissions, which is paired with a D rating for *condensable* emissions, the AP-42 emission factors for natural gas-fired sources are rated C or lower. Thus, there is considerable uncertainty associated with the AP-42 fine particulate emissions factors for gas-fired sources, and biases (e.g., from sulfur) are likely in at least some of the data. Because of measurement limitations (e.g., positive bias, measurement of mass differential that is near instrument detection limits), it is likely that the AP-42 emission factors provide a conservative estimate of $PM_{2.5}$ emissions for natural gas-fired sources. Caution should be used if it is concluded that equipment emissions based on AP-42 emission factors are significant enough to warrant further consideration. As discussed in this document, alternative emission factors based on a project that used dilution tunnel testing should be considered.

APPENDIX B

Primary Technical Documents from the U.S. Collaborative $PM_{2.5}$ Emissions Project (with links to documents on CEC's website)

Report / Document Title	Page Count	File Size
Final Report:		
Final Report – Development of Fine Particulate Emission Factors and Speciation Profiles for Oil- and Gas-Fired Combustion Systems	130	0.9 MB
Supplemental Technical Reports:		
Critical Review of Source Sampling and Analysis Methodologies for Characterizing Organic Aerosol and Fine Particulate Source Emission Profiles	165	1.4 MB
Pilot-Scale Dilution Sampler Design and Validation Tests (Laboratory Study)	81	1.4 MB
Topical Reports / Technical Memos:		
Technical Memorandum: Conceptual Model of Sources of Variability in Combustion Turbine PM10 Emissions Data	65	0.7 MB
Impact of Operating Parameters on Fine Particulate Emissions from Natural Gas-Fired Combined Cycle and Cogeneration Power Plants	51	0.5 MB
Fine Particulate Test Protocol	38	0.5 MB
Site Test Reports:		
Test Results for a Gas-Fired Process Heater (Site Alpha)	114	1.0 MB
Test Results for a Combined Cycle Power Plant with Supplementary Firing, Oxidation Catalyst and SCR at Site Bravo	159	1.1 MB
Test Results for a Gas-Fired Process Heater with Selective Catalytic NOx Reduction (Site Charlie)	119	1.1 MB
Test Results for a Dual-Fuel-Fired Commercial Boiler (Site Delta)	176	1.3 MB
Test Results for a Combined Cycle Power Plant with Oxidation Catalyst and SCR at Site Echo	141	1.0 MB
Test Results for a Diesel Fuel-Fired Compression Ignition Reciprocating Engine with a Diesel Particulate Filter at Site Foxtrot	86	0.7 MB
Test Results for a Cogeneration Plant with Supplementary Firing, Oxidation Catalyst and SCR at Site Golf	91	0.7 MB