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Updated Greenhouse Gas and Criteria Air Pollutant Emission Factors and Their Probability Distribution Functions for Electric Generating Units

Energy Systems Division

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ACRONYMS AND ABBREVIATIONS

AB	agricultural byproduct
AEO	Annual Energy Outlook
ARPD	Acid Rain Program Dataset
BEV	battery-powered electric vehicle
BF	biased firing
BFG	blast furnace gas
BIT	bituminous coal
BLQ	black liquor
BLR	boilers
BOOS	burners-out-of-service
CAP	criteria air pollutant
CI	carbon intensity
CC	combined cycle
CH_4	methane
CHP	combined heat and power
CO	carbon monoxide
CO_2	carbon dioxide
Com.Opt.	combustion optimization
CPM	condensable particulate matter
CT	combustion turbines
DFO	distillate fuel oil
DG	digester gas
eGRID	Emissions & Generation Resource Integrated Database
EGU	electric generating unit
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
EPA/CAMD	EPA's Clean Air Markets Division
ESP	electrostatic precipitator
FBC	fluidized bed combustion
FGD	flue gas desulfurization
FGR	flue gas recirculation
FPM	filterable particulate matter
GEO	geothermal energy
GHG	greenhouse gas
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model

HHV	higher heating value
ICE	internal combustion engines
IGCC	integrated gasification combined cycle
JF	jet fuel
KER	kerosene
lb	pound
LEA	low excess air
LFG	landfill gas
LHV	lower heating value
LIG	lignite coal
LNB	low nitrogen burners
MSB	biomass component of municipal solid waste
N_2O	nitrous oxide
NEG	net electricity generated
NEI	National Emission Inventory
NERC	North American Electric Reliability Council
NG	natural gas
NGCC	natural gas combined cycle
NO_x	nitrogen oxides
NSPS	New Source Performance Standards
OBL	other biomass liquid
OBS	other biomass solids
OFA	overfire air
OG	other gases
OTH	other unknown
PC	pulverized coal
PDF	probability distribution function
PetCoke	petroleum coke
PHEV	plug-in hybrid electric vehicle
$PM_{2.5}$	particulate matter up to 2.5 micrometers in size
PM10	particulate matter up to 10 micrometers in size
PTW	pump-to-wheels
PUR	purchased steam
RFO	residual fuel oil
SC	syncoal
Scf	one cubic foot of volume at 60°F and 101.325 kPa of pressure
SCR	selective catalytic reduction
SNCR	selective noncatalytic reduction

SO_x	sulfur oxides
SUB	subbituminous coal
SUN	solar energy
T&D	transmission and distribution
TDF	tire-derived fuel
VOC	volatile organic compounds
WAT	hydropower
WC	waste coal
WDL	woody biomass liquid
WDS	woody biomass solid
WebFIRE	Web version of EPA’s Factor Information Retrieval Data System
WH	waste heat
WI	water injection
WND	wind power
WO	waste oil
WTW	well-to-wheels
WTP	well-to-pump

UPDATED GREENHOUSE GAS AND CRITERIA AIR POLLUTANT EMISSION FACTORS AND THEIR PROBABILITY DISTRIBUTION FUNCTIONS FOR ELECTRIC GENERATING UNITS

1 BACKGROUND

Greenhouse gas (CO_2, CH_4 and N_2O, hereinafter GHG) and criteria air pollutant (CO, NO_x, VOC, PM_{10}, $PM_{2.5}$ and SO_x, hereinafter CAP) emission factors for various types of power plants burning various fuels with different technologies are important upstream parameters for estimating life-cycle emissions associated with alternative vehicle/fuel systems in the transportation sector, especially electric vehicles. The emission factors are typically expressed in grams of GHG or CAP per kWh of electricity generated by a specific power generation technology. This document describes our approach for updating and expanding GHG and CAP emission factors in the GREET (Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation) model developed at Argonne National Laboratory (see Wang 1999 and the GREET website at http://greet.es.anl.gov/main) for various power generation technologies. These GHG and CAP emissions are used to estimate the impact of electricity use by stationary and transportation applications on their fuel-cycle emissions. The electricity generation mixes and the fuel shares attributable to various combustion technologies at the national, regional and state levels are also updated in this document. The energy conversion efficiencies of electric generating units (EGUs) by fuel type and combustion technology are calculated on the basis of the lower heating values of each fuel, to be consistent with the basis used in GREET for transportation fuels. On the basis of the updated GHG and CAP emission factors and energy efficiencies of EGUs, the probability distribution functions (PDFs), which are functions that describe the relative likelihood for the emission factors and energy efficiencies as random variables to take on a given value by the integral of their own probability distributions, are updated using best-fit statistical curves to characterize the uncertainties associated with GHG and CAP emissions in life-cycle modeling with GREET.

2 METHOD AND DATA

2.1 CO_2, CH_4, N_2O, NO_x AND SO_x EMISSION FACTORS

GHG and CAP emission factors by fuel type and combustion technology are required to perform life-cycle analyses using GREET. On the basis of the recent release of the Emissions & Generation Resource Integrated Database, known as eGRID[1] (EPA, 2011a), which contains comprehensive unit-level emission data and plant performance data like the heat input and electricity generation for year 2007, we calculate the CO_2, CH_4, N_2O, NO_x and SO_x emission factors for each plant in the power generation sector. The version that we used, eGRID2010, provided the best available and most recent (2007) comprehensive data to meet our study objectives when this study began. However, eGRID2012, which incorporates the 2009 dataset, has just been released. Therefore, we are aware that we may have missed some recent trends in the evolution of the combustion technology for each type of power plant, which will eventually result in variations in their GHG and CAP emission factors. This assumption will be validated in a follow-up study using the latest available data from EIA and EPA, in comparison with the 2007 data addressed in this report.

The emissions of CO_2, CH_4, N_2O, NO_x and SO_x in eGRID are based on data from a variety of sources, but its primary source for CO_2, SO_x, and NO_x emissions is the unit-level data from the Clean Air Markets Division (EPA/CAMD) (EPA, 2007a; Pechan, 2010a). If any of the emissions data are not reported, which is the case for 1076 out of 5172 EGUs, the emissions are estimated by eGRID as follows: CO_2 emission factors are estimated using fuel consumption data from EIA-923 (EIA, 2007a), fuel carbon intensity, and the fraction of carbon oxidized to CO_2 (a uniform oxidation fraction of 1 is used for all fossil fuels); SO_x emission factors are estimated using fuel consumption data from EIA-923, EPA-approved uncontrolled-emission factors (Pechan, 2010b) are based on EPA's AP-42 emission factors (EPA, 2004), sulfur content, and control efficiencies, if available; and NO_x emission factors for steam prime movers are estimated using fuel consumption data from EIA-923 and EPA-approved uncontrolled emissions factors for steam prime movers. For combined-cycle plants, turbines and internal combustion engines, NO_x emission factors are developed on the basis of the prime mover technology, size, and location, and using data from the EPA Reasonably Available Control Technology/Best Available Control Technology/Lowest Achievable Emission Rate Clearinghouse (EPA, 2010a). The term "prime mover" refers to the machine (e.g., engine, turbine, water wheel) that drives the electric generator in the power plant.

In this work, the averaged CO_2, CH_4, N_2O, NO_x and SO_x emission factors by fuel type and combustion technology are calculated by dividing the annual total emissions by the annual total net electricity generated (NEG) from that technology, as shown in Equation (1). The NEG in this

[1] A comprehensive emission inventory of the electric power sector in the U.S.

report refers to the generated electricity supplied to the grid, i.e., electricity directly consumed by EGUs is excluded.

$$EF_{p,f,ct} = \frac{\sum_i Emission_{p,f,ct,i}}{\sum_i NEG_{f,ct,i}} \tag{1}$$

where

$EF_{p,f,ct}$	(expressed in g/kWh) is the averaged emission factor of a GHG species or pollutant *p* (e.g., NO_x or SO_x) emitted by all power plants burning fuel *f* using combustion technology *ct*;
$Emission_{p,f,ct,i}$	(expressed in grams) is the emissions of a GHG species or pollutant *p* from power plant *i* burning fuel *f* using combustion technology *ct*; and
$NEG_{f,ct,i}$	(expressed in kWh) is the net electricity generated by power plant *i* burning fuel *f* using combustion technology *ct*.

To obtain $Emission_{p,f,ct,i}$, we first sort the plants in eGRID by fuel type based on the primary fuel type indicated by eGRID. This report explicitly updates the GHG and CAP emission factors for use in GREET on the basis of a total of 3394 combustion-based EGUs fired by four major fuel types: (1) coal, including the subtypes of bituminous coal (BIT), subbituminous coal (SUB), lignite (LIG), syncoal[2] (SC), waste coal[3] (WC), petroleum coke (PetCoke) and tire-derived fuel (TDF); (2) natural gas (NG), including the subtypes of NG, landfill gas (LFG), blast furnace gas (BFG), digester gas (DG), other gases (OG), and other unknown (OTH); (3) oil, including the subtypes of residual fuel oil (RFO), distillate fuel oil (DFO), jet fuel (JF), kerosene (KER), and waste oil (WO); and (4) biomass, including the subtypes of woody biomass solid (WDS), woody biomass liquid (WDL), black liquor (BLQ), agricultural byproduct (AB), biomass component of municipal solid waste (MSB), other biomass solid (OBS), and other biomass liquid (OBL). These combustion-based EGUs accounted for 75.0% of the total net electricity generated in the U.S., while 60 nuclear-power EGUs and 1718 renewable-power EGUs, including solar energy (SUN), hydropower (WAT), wind (WND), geothermal (GEO) and waste heat (WH), account for another 18.0% and 7.0% of the national generation, respectively.

While most power plants employ a single fuel type, a small percentage of power plants burn multiple fuel types. For multiple-fuel-fired plants, the primary fuel type employed by the prime mover with the largest nameplate capacity is recognized as the primary fuel type for that plant. Multiple-fuel-fired plants with the primary fuel types BIT, SUB, NG and DFO represent 6.5%, 4.3%, 5.4% and 4.2%, respectively, of the total. Aggregating the different fuel types under one

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[2] Syncoal includes briquettes, pellets, or extrusions, which are formed by binding materials or by processes that recycle materials. Syncoal has reduced sulfur and ash contents and increased heating value.

[3] Waste coal includes anthracite culm, bituminous gob, fine coal and lignite waste.

primary fuel type leads to a small error that is due to the difference in fuel properties and their combustion characteristics. We noticed that a few plants in eGRID, i.e., plants with DOE/EIA Office of the Regulatory Information System PLant (ORISPL) codes 30, 1225, 2390, 10437, 50241 and 54406, show inconsistent plant-level and generator-level primary fuel types. We made corrections to these minor discrepancies in eGRID and identified the true primary fuel types of these plants through personal communication with S. Rothschild (2012).

Next, we sort plants of the same fuel type by combustion technology, using information on the prime mover type of each generator within each power plant as provided in eGRID. For example, natural gas is used in power plants employing various prime mover technologies such as steam turbines, gas turbines, or both. Since many plants have multiple generators driven by different prime mover types, the prime mover type of the generators whose summed capacities represent the largest fraction of the entire capacity of a power plant is recognized as the prime mover type of that plant. For these plants, the $NEG_{f,ct,i}$ is determined by the annual electricity generation of power plant *i* burning fuel type *f* with the combustion technology *ct* that defines the prime mover type of that plant.

A few combustion-based power plants with zero heat inputs or zero emissions and NEG that is a very small fraction of their nameplate capacities, which account for 0.53% of the national total NEG, are excluded from the calculation of GHG and CAP emission factors, since they are not representative of typical emission characteristics of EGUs. EGUs employing boilers, combustion turbines or engines with efficiency higher than 45%, and combined-cycle plants with efficiency higher than 60%, are regarded as unrealistic for current non-CHP[4] efficiency levels (EVA, 2007; Bellman et al., 2007; Ishikawa et al., 2008), and are therefore excluded. Moreover, EGUs that have negative electricity generations in eGRID (possibly because of their operations in spinning reserve mode) are excluded, since no electricity is supplied by such EGUs to meet the downstream demand. Those CHP facilities that usually have higher efficiencies than EGUs producing electricity alone are also excluded, owing to the lack of consensus on how to allocate emissions between the electricity and heat co-products. Table 1 shows the number and electricity generation share of both CHP and non-CHP facilities by fuel type, in addition to the basic characteristics of EGUs by fuel type.

[4] Combined heat and power

Table 1 The number and electricity generation share of CHP and non-CHP facilities, and basic characteristics of EGUs by fuel type

	Number of facilities	Electricity generation share (percentage of total or subtotal)	Total installed capacity (MW)	Capacity factor
Biomass	**271**	**1.34%**	43.9	0.587
Non-CHP facilities	88	29.15%	39.0	0.596
CHP facilities	183	70.85%	46.2	0.584
Coal	**604**	**49.15%**	629.9	0.625
Non-CHP facilities	427	95.42%	844.4	0.628
CHP facilities	177	4.58%	112.4	0.569
NG	**1744**	**24.00%**	253.4	0.235
Non-CHP facilities	1162	75.30%	323.6	0.200
CHP facilities	582	24.70%	113.3	0.438
Nuclear	**60**	**17.41%**	1,633.0	0.871
Non-CHP facilities	60	100.00%	1,633.0	0.871
Oil	**775**	**1.58%**	50.7	0.199
Non-CHP facilities	709	96.14%	53.9	0.196
CHP facilities	66	3.86%	15.7	0.314
Renewable	**1718**	**6.52%**	67.9	0.285
Non-CHP facilities	1707	99.26%	68.1	0.284
CHP facilities	11	0.74%	41.8	0.528
Sum	**5172**	**100.00%**	**210.4**	**0.437**

Note: The numbers at the bottoms of columns 1 and 2 are sums; the numbers at the bottoms of columns 3 and 4 are the averages of the columns 3 and 4.

To avoid the biases caused by individual EGUs with unrealistically high or low emission factors, these potential outliers are detected using the modified Z-score, which is defined by Equation (2) (Iglewicz and Hoaglin, 1993):

$$M_i = \frac{0.6745 \times (x_i - \tilde{x})}{median(|x_i - \tilde{x}|)} \tag{2}$$

where

M_i is the modified Z-score;

x_i are the GHG and CAP emission factors of an individual EGU_i;

$\tilde{x}$ is the median GHG and CAP emission factor of all EGUs; and

$median(|x_i - \tilde{x}|)$ is the median absolute deviation.

x_i is calculated from Equation (3):

$$x_i = \frac{Emission_i}{NEG_i} \tag{3}$$

where

$Emission_i$ is the annual GHG or CAP emission of an individual EGU$_i$; and

NEG_i is the annual net electricity generation of an individual EGU$_i$.

Equation (2) was performed for each specific GHG and CAP emission factor of EGUs using the same fuel subtype and combustion technology. Potential outliers are detected when the modified Z-scores have an absolute value of greater than 3.5. Although the median absolute deviation has been recognized to be a robust measure for outlier detection, there is a possibility that the detected outliers could be due to real fluctuation in the data. Therefore, an additional rejection threshold for outlier detection was set at 1.96 standard deviations (σ) of the observations, to allow for real fluctuation in the data. Emission factors with Z-scores larger than 3.5 and exceeding the rejection threshold are removed before Equations (1) and (4-1 or 4-2) are employed to calculate the GHG and CAP emission factors by fuel subtype and combustion technology.

2.2 CO, VOC, PM_{10} AND $PM_{2.5}$ EMISSION FACTORS

Owing to the lack of direct information on CAP emissions other than NO_x and SO_x in eGRID, we utilized the internet version of the Factor Information Retrieval Data System (WebFIRE[5]) (EPA, 2011b) and data in the open literature, in conjunction with heat input and NEG data in eGRID, to derive the emission factors of CO, VOC, PM_{10} and $PM_{2.5}$.

We employed the fuel-use-related information from eGRID (annual heat input by plant) and the emission factors (expressed in g/unit fuel use) from WebFIRE or the open literature for each specific fuel and combustion technology to calculate CO, VOC, PM_{10} and $PM_{2.5}$ emission factors using Equation (4) (Wang, 1999):

5 WebFIRE is a database management system containing EPA's recommended emission factors for criteria and hazardous air pollutants (http://cfpub.epa.gov/webfire).

$$EF_{out,p,f,ct} = \frac{\sum_i \sum_{ec} \frac{HI_{f,ct,i}}{HHV_f} \times EF_{in,f,ct,p} \times (1 - ER_{p,ec})}{\sum_i NEG_{f,ct,i}} \tag{4a}$$

$$EF_{out,p,f,ct} = \frac{\sum_i \sum_{ec} HI_{f,ct,i} \times EF'_{in,f,ct,p} \times (1 - ER_{p,ec})}{\sum_i NEG_{f,ct,i}} \tag{4b}$$

where

$EF_{in,f,ct,p}$	is the uncontrolled emission factor of CAP *p* for EGUs burning fuel type *f* using combustion technology *ct* in grams per ton of coal or WDS, per 1000 gallons of oil, or per million standard cubic feet of NG;
$EF'_{in,f,ct,p}$	is the uncontrolled emission factor of CAP *p* for EGUs burning fuel type *f* using combustion technology *ct* in g/mmBtu;
$ER_{p,ec}$	is the emission reduction efficiency of CAP *p* using control technology *ec*;
$HI_{f,ct,i}$	is the annual heat input (based on the fuel's higher heating value, HHV) to plant *i* from the burning of fuel type *f* using combustion technology ct, in mmBtu;
HHV_f	is the HHV of fuel type *f*, in mmBtu;
$NEG_{f,ct,i}$	is the annual net electricity generation by plant *i* burning fuel type *f* using combustion technology *ct*; and
$EF_{out,p,f,ct}$	is the emission factor of CAP *p* for EGUs burning fuel type *f* using combustion technology *ct*, in g/kWh of NEG.

For EGUs fired by a specific fuel type, $HI_{f,ct,i}$ and $NEG_{f,ct,i}$ are obtained from eGRID. For BIT-, SUB-, LIG-, NG-, RFO-, DFO-, JF- and WDS-fired EGUs, the HHV_f values are obtained from the fuel specifications incorporated in GREET 1_2011. The HHV, rather than the lower heating value (LHV), is adopted because HHV is used for calculating the heat input in eGRID, which is originally obtained from EPA's CAMD (EPA, 2007a) or EIA's Form 923 data (EIA, 2007a) when the former is not available. For other fuel-fired EGUs which account for a small percentage of the total generation, e.g., SC-, WC- and LFG-fired EGUs, the term $\frac{HI_{f,ct,i}}{HHV_f}$ in Equation (4-1), representing the quantity of fuel consumption, is obtained from EIA's Form 923 data (EIA, 2007a).

As mentioned earlier, $EF_{in,f,ct,p}$ and $EF'_{in,f,ct,p}$ are mainly obtained from WebFIRE. WebFIRE includes information about various industries and their processes, the chemicals emitted, and the associated emission factors. WebFIRE allows easy access to criteria and hazardous air pollutant emission factors obtained from the Compilation of Air Pollutant Emission Factors (AP-42) (EPA, 2011c), the Locating and Estimating documents (EPA, 2010b), and the retired Aerometric Facility Subsystem Emission Factors and Crosswalk/Air Toxics Emission Factors documents.

We used a four-step procedure (described below) to determine the emission factors from WebFIRE for each type of EGU burning a specific type of fuel using a certain combustion technology with a particular control technology. For example, the CAP emission factors of a BIT-fired power plant using a cyclone furnace can be obtained by following these four steps:

- Step 1: Identify the combustion technology, e.g., external combustion boilers;
- Step 2: Identify the emission source category, i.e., electricity generation sector;
- Step 3: Identify the fuel type, e.g., bituminous/subbituminous coal;
- Step 4: Identify the combustion technology type and emission control technology, e.g., pulverized coal, cyclone furnace.

Usually, the above four-step procedure narrows down the emission factors to one set of CAPs reflecting the effects of the boiler type, the firing type and the specific emission control measures in operation. It is therefore necessary to identify the combustion technology type and the emission control measures in operation at each EGU covered in eGRID in order to obtain the appropriate emission factor from WebFIRE. Here, the boiler type and firing type of individual EGUs are obtained from EPA's CAMD (2007a). Furthermore, EPA's CAMD unit-level data, including information on emission control equipment at existing EGUs (EPA, 2007a), are used to identify the different emission control measures adopted by each EGU.

PM_{10} and $PM_{2.5}$ emission factors are complex functions of boiler bottom and firing configuration, boiler operation, pollution control equipment, and fuel properties. Here, the plant-level-controlled PM emission factors are calculated using Equation (5), which accounts for the emission reduction efficiency of the emission control technology and the prime mover-level heat input as obtained from EPA's CAMD. The uncontrolled emission factors and some controlled emission factors are obtained from WebFIRE. The emission reduction efficiencies of control technologies are based on AP-42 and open-literature data, and the fuel quality data are from EIA (2007b).

$$EF_{PM_{controlled,f,ct,i}} = EF_{PM_{uncontrolled,f,ct,i}} \times \sum_j \left[(1 - ER_j) \times HI(\%)_j \right] \tag{5}$$

where

$EF_{PM_{controlled,f,ct,i}}$ and $EF_{PM_{uncontrolled,f,ct,i}}$ are the controlled and uncontrolled PM emission factors, respectively, for plant i burning fuel type f using combustion technology ct;

ER_j is the emission reduction efficiency of control technology j, such as electrostatic precipitator or baghouse; and

$HI(\%)_j$ is the heat input share of generators that are employing control technologies j within the same plant.

When multiple emission factors for a particular CAP are available for the same fuel type and combustion technology using the same emission control technology, the technology with a higher quality grade and the post-NSPS (New Source Performance Standards) boilers are adopted. The CO, VOC, PM_{10} and $PM_{2.5}$ emission factors chosen from WebFIRE for power plants are given in Tables 2–5 for various fuel types, combustion technologies, boiler bottom and firing types, and emission control technologies.

TABLE 2 CO emission factors of EGUs by fuel type, combustion technology, boiler bottom and firing type, and emission control technology

	Uncontrolled	OFA[a]	LNB[b]	FGR[c]	WI[d]	Combustion optimization
Coal (unit: lb/ton)						
BIT, BLR[e], PC[f], dry bottom	0.5		0.5			
BIT, BLR, PC, wet bottom	0.5					
BIT, BLR, tangential	0.5		0.5			
BIT, FBC[g]	18					
BIT, Stoker	5					
BIT, Cyclone	0.5					
SUB, BLR, PC, dry bottom	0.5					
SUB, BLR, PC, wet bottom	0.5					
SUB, BLR, tangential	0.5					
SUB, FBC	18					
SUB, Stoker	5					
SUB, Cyclone	0.5					
SUB, Cell	0.5					
LIG, BLR, PC, dry bottom	0.25	0.48	0.48			
LIG, BLR, tangential	0.6	0.1				
LIG, Cyclone	0.6					
LIG, FBC	0.15					
PetCoke, BLR	0.6					
NG (unit: lb/million scf[h])						
NG, BLR	84					
NG, BLR, tangential	24			98		
NG, ICE[i]	399					
NG, CT[j,k]	0.082				0.03	0.015
LFG, CT[k]	0.44					
BFG, BLR	13.7					
DG, BLR	84					
DG, CT[k]	0.017					
Oil (unit: lb/1000 gal)						
RFO, BLR	5					
DFO, BLR	5					
DFO, CT	0.459				10.56	
DFO, ICE	0.95					
KER, CT[k]	0.0033					
WO, BLR	5					
Biomass (unit: lb per mmBtu)						
Dry WDS, BLR, ≤20% moisture	0.6					
Wet WDS, BLR, ≥20% moisture	0.6					
BLQ, BLR	0.0165					

[a] OFA stands for overfire air.
[b] LNB stands for low nitrogen burners.
[c] FGR stands for flue gas recirculation.
[d] WI stands for water injection.
[e] BLR stands for boilers.
[f] PC stands for pulverized coal.
[g] FBC stands for fluidized bed combustion.
[h] scf refers to a cubic foot of volume at 60°F and 101.325 kPa of pressure.
[i] ICE stands for internal combustion engines.
[j] CT stands for combustion turbines.
[k] Unit is lb/mmBtu.

TABLE 3 VOC emission factors of EGUs by fuel type, combustion technology, boiler bottom and firing type, and emission control technology

	Uncontrolled	Wet scrubber	ESP[a]
Coal (unit: lb/ton)			
BIT, BLR, PC, dry bottom	0.06		
BIT, BLR, PC, wet bottom	0.04		
BIT, BLR, tangential	0.06		
BIT, FBC	0.05		
BIT, Stoker	0.05		
BIT, Cyclone	0.11		
SUB, BLR, PC, dry bottom	0.06		
SUB, BLR, PC, wet bottom	0.04		
SUB, BLR, tangential	0.06		
SUB, FBC	0.05		
SUB, Stoker	0.05		
SUB, Cyclone	0.06		
SUB, Cell	0.06		
LIG, BLR, PC, dry bottom	0.07		
LIG, BLR, tangential	0.07		
LIG, Cyclone	0.07		
LIG, FBC	0.07		
PetCoke, BLR	0.07		
NG (unit: lb/million scf)			
NG, BLR	5.5		
NG, BLR (tangential)	5.5		
NG, ICE	116		
NG, CT[b]	0.0021		
LFG, CT[b]	0.013		
BFG, BLR	0.4457[c]		
DG, BLR	5.5		
DG, CT[a]	0.0058		
Oil (unit: lb/1000 gal)			
RFO, BLR	0.76		
DFO, BLR	0.2		
DFO, CT	0.057		
DFO, ICE	0.36		
JF, CT	0.0033		
KER, CT[b]	0.004		
WO, BLR	1		
Biomass (unit: lb/mmBtu)			
Dry WDS, BLR, <u><</u>20% moisture	0.017		
Wet WDS, BLR, <u>></u>20% moisture	0.017		
BLQ, BLR[c]	0.4237	0.114[d]	0.0138[d]

[a] ESP is electrostatic precipitator.
[b] Unit is lb/mmBtu.
[c] Unit is lb/ton.`
[d] From Pechan (2003)

TABLE 4 PM_{10} emission factors of EGUs by fuel type, combustion technology, boiler bottom and firing type, and emission control technology

	Uncontrolled	ESP	Baghouse[a]	Multiple cyclones	Scrubber
Coal (unit: lb/ton)					
BIT, BLR, PC, dry bottom, w/ FGD	2.3*A+0.469	0.054*A+0.469	0.02*A+0.469	0.58*A+0.469	0.42*A+0.469
BIT, BLR, PC, dry bottom, w/o FGD	2.3*A+(0.1*S-0.03)*23.44	0.054*A+(0.1*S-0.03)*23.44	0.02*A+(0.1*S-0.03)*23.44	0.58*A+(0.1*S-0.03)*23.44	0.42*A+(0.1*S-0.03)*23.44
BIT, BLR, PC, wet bottom, w/ FGD	2.6*A+0.469	0.042*A+0.469		1.3*A+0.469	
BIT, BLR, PC, wet bottom, w/o FGD	2.6*A+(0.1*S-0.03)*23.44	0.042*A+(0.1*S-0.03)*23.44		1.3*A+(0.1*S-0.03)*23.44	
BIT, BLR, tangential, w /FGD	2.3*A+0.469	0.054*A+0.469	0.02*A+0.469	0.58*A+0.469	0.42*A+0.469
BIT, BLR, tangential, w/o FGD	2.3*A+(0.1*S-0.03)*23.44	0.054*A+(0.1*S-0.03)*23.44	0.02*A+(0.1*S-0.03)*23.44	0.58*A+(0.1*S-0.03)*23.44	0.42*A+(0.1*S-0.03)*23.44
BIT, FBC	12.9				
BIT, Stoker	14.2	1.48	1.11	10.9	
BIT, Cyclone	0.26*A+(0.1*S-0.03)*23.44	0.011*A+(0.1*S-0.03)*23.44		0.112*A+(0.1*S-0.03)*23.44	
SUB, BLR, PC, dry bottom, w/ FGD	2.3*A+0.4	(**0.01**)*2.3*A+0.4	(**0.001**)*2.3*A+0.4	(**0.075**)*2.3*A+0.4	(**0.03**)*2.3*A+0.4
SUB, BLR, PC, dry bottom, w/o FGD	2.3*A+(0.1*S-0.03)*20	(**0.01**)*2.3*A+(0.1*S-0.03)*20	(**0.001**)*2.3*A+(0.1*S-0.03)*20	(**0.075**)*2.3*A+(0.1*S-0.03)*20	(**0.03**)*2.3*A+(0.1*S-0.03)*20
SUB, BLR, PC, wet bottom	2.6*A+(0.1*S-0.03)*20				
SUB, BLR, tangential	2.3*A+(0.1*S-0.03)*20				
SUB, FBC	16.6				
SUB, Stoker	14				
SUB, Cyclone	0.26*A+(0.1*S-0.03)*20				
SUB, Cell	2.3*A+(0.1*S-0.03)*20				
LIG, BLR, PC, dry bottom, w/ FGD	0.79*2.3*A+0.29		0.00018*A+0.29	0.79*0.88*A+0.29	0.000945*A+0.29
LIG, BLR, PC, dry bottom, w/o FGD	0.79*2.3*A+(0.1*S-0.03)*14.5		0.00018*A+(0.1*S-0.03)*14.5	0.79*0.88*A+(0.1*S-0.03)*14.5	0.000945*A+(0.1*S-0.03)*14.5
LIG, BLR, tangential, w/ FGD	2.3*A+0.29		0.00018*A+0.29	0.88*A+0.29	0.000945*A+0.29
LIG, BLR, tangential, w/o FGD	2.3*A+(0.1*S-0.03)*14.5		0.00018*A+(0.1*S-0.03)*14.5	0.88*A+(0.1*S-0.03)*14.5	0.000945*A+(0.1*S-0.03)*14.5

TABLE 4 (Cont.)

	Uncontrolled	ESP	Baghouse[a]	Multiple cyclones	Scrubber
Coal (unit: lb/ton)					
LIG, Cyclone	0.871*A+(0.1*S-0.03)*14.5				
LIG, FBC	100[b]*0.07*A+0.32	0.07*A+0.32	0.07*A+0.32		30[c]*0.07*A+0.32
PetCoke, BLR	7.9*A				
NG (unit: lb/million scf)					
NG, BLR	7.6	0.076[d]		0.57[d]	0.19[d]
NG, BLR, tangential	7.6				
NG, ICE	49.3				
NG, CT[e]	0.0066				
LFG, CT[e]	0.02484				
BFG, BLR	8.6				
DG, BLR	7.6				
DG, CT[e]	0.01477				
Oil (unit: lb/1000 gal)					
RFO, BLR	5.9*(1.12*S+0.37)+1.5	0.042*(1.12*S+0.37)+1.5			0.5*(1.12*S+0.37)+1.5
DFO, BLR	2.3				
DFO, CT	8.54				1.57
DFO, ICE	0.31				
JF, CT	0.0615[f]				0.0113
KER, CT	8.54[g]				0.012[e]
WO, BLR	51*A				
Biomass (unit: lb/mmBtu)					
Dry WDS, BLR, $\leq$20% moisture	0.377	0.057		0.287	
Wet WDS, BLR, $\geq$20% moisture	0.327		0.091	0.217	
BLQ, BLR	9.322[h,i]				0.184[h]

Notes: A is the as-fired coal ash weight percentage (%).
S is the as-fired coal sulfur weight percentage (%).
The numbers in bold in parentheses reflect the emission reduction efficiency of the corresponding emission control device in operation, obtained from AP-42 on an average basis.

TABLE 4 (Cont.)

[a] PM removal efficiency for baghouse technology is assumed the same as that of ESP.
[b] FPM removal efficiency of 99% for ESP is adopted, and the uncontrolled PM emission factors are scaled on the basis of the ESP-equipped ones (EPA, 1995b).
[c] FPM removal efficiencies of 70% and 99% for wet scrubber and ESP, respectively, are adopted, and the scrubber-equipped PM emission factors are scaled on the basis of the ESP-equipped ones (EPA, 1995b).
[d] From AP-42, Chapter 1.1 (EPA, 1995a).
[e] Unit is lb/mmBtu.
[f] The uncontrolled PM_{10} emission factor is calculated assuming that the emission reduction efficiency of steam or water injection treatment for PM_{10} emissions from JF-fired turbines is equivalent to that for PM emissions from DFO-fired turbines.
[g] The uncontrolled PM_{10} emission factor for DFO is used.
[h] Unit is lb/ton.
[i] From Pechan (2003)

TABLE 5 PM$_{2.5}$ emission factors of EGUs by fuel type, combustion technology, boiler bottom and firing type, and emission control technology

	Uncontrolled	ESP	Baghouse	Multiple cyclones	Scrubber
Coal (unit: lb/ton)					
BIT, BLR, PC, dry bottom, w/ FGD	0.6*A+0.469	0.024*A+0.469	0.01*A+0.469	0.06*A+0.469	0.3*A+0.469
BIT, BLR, PC, dry bottom, w/o FGD	0.6*A+(0.1*S–0.03)*23.44	0.024*A+(0.1*S–0.03)*23.44	0.01*A+(0.1*S–0.03)*23.44	0.06*A+(0.1*S–0.03)*23.44	0.3*A+(0.1*S–0.03)*23.44
BIT, BLR, PC, wet bottom, w/ FGD	1.48*A+0.469	0.022*A+0.469		0.86*A+0.469	
BIT, BLR, PC, wet bottom, w/o FGD	1.48*A+(0.1*S–0.03)*23.44	0.022*A+(0.1*S–0.03)*23.44		0.86*A+(0.1*S–0.03)*23.44	
BIT, BLR, tangential, w/ FGD	0.6*A+0.469	0.024*A+0.469	0.01*A+0.469	0.06*A+0.469	0.3*A+0.469
BIT, BLR, tangential, w/o FGD	0.6*A+(0.1*S–0.03)*23.44	0.024*A+(0.1*S–0.03)*23.44	0.01*A+(0.1*S–0.03)*23.44	0.06*A+(0.1*S–0.03)*23.44	0.3*A+(0.1*S–0.03)*23.44
BIT, FBC	1.88				
BIT, Stoker	5.64	0.44	0.072	3.34	
BIT, Cyclone	0.11*A+(0.1*S–0.03)*23.44	0.0006*A+(0.1*S–0.03)*23.44		0.11*A+(0.1*S–0.03)*23.44	
SUB, BLR, PC, dry bottom, w/ FGD	0.6*A+0.4	(**0.01**)*0.6*A+0.4	(**0.001**)*0.6*A+0.4	(**0.075**)*0.6*A+0.4	(**0.03**)*0.6*A+0.4
SUB, BLR, PC, dry bottom, w/o FGD	0.6*A+(0.1*S–0.03)*20	(**0.01**)*0.6*A+(0.1*S–0.03)*20	(**0.001**)*0.6*A+(0.1*S–0.03)*20	(**0.075**)*0.6*A+(0.1*S–0.03)*20	(**0.03**)*0.6*A+(0.1*S–0.03)*20
SUB, BLR, PC, wet bottom	1.48*A+(0.1*S–0.03)*20				
SUB, BLR, tangential	0.6*A+(0.1*S–0.03)*20				
SUB, FBC	1.88				
SUB, Stoker	5.4				
SUB, Cyclone furnace	0.11*A+(0.1*S–0.03)*20				
SUB, Cell	0.6*A+(0.1*S–0.03)*20				
LIG, BLR, PC, dry bottom, w/ FGD	0.79*0.66*A+0.29		0.00008*A+0.29	0.79*0.36*A+0.29	0.0005*A+0.29
LIG, BLR, PC, dry bottom, w/o FGD	0.79*0.66*A+(0.1*S–0.03)*14.5		0.00008*A+(0.1*S–0.03)*14.5	0.79*0.36*A+(0.1*S-0.03)*14.5	0.0005*A+(0.1*S–0.03)*14.5

TABLE 5 (Cont.)

	Uncontrolled	ESP	Baghouse	Multiple cyclones	Scrubber
Coal (unit: lb/ton)					
LIG, BLR, tangential, w/ FGD	0.66*A+0.29		0.00008*A+0.29	0.36*A+0.29	0.0005*A+0.29
LIG, BLR, tangential, w/o FGD	0.66*A+(0.1*S–0.03)*14.5		0.00008*A+(0.1*S–0.03)*14.5	0.36*A+(0.1*S–0.03)*14.5	0.0005*A+(0.1*S–0.03)*14.5
LIG, Cyclone	0.369*A+(0.1*S–0.03)*14.5				
LIG, FBC	0.27[a]*(100[b]*0.07*A+0.32)	0.27[a]*(0.07*A+0.32)	0.27[a]*(0.07*A+0.32)		0.27[a]*(30[c]*0.07*A+0.32)
PetCoke, BLR	4.5*A				
NG (unit: lb/million scf)					
NG, BLR	7.6	0.19[d]		0.57[d]	0.076[d]
NG, BLR, tangential	7.6				
NG, ICE	49.3				
NG, CT[e]	0.0066				
LFG, CT	0.02484[e]				
BFG, BLR	8.6				
DG, BLR	7.6				
DG, CT[e]	0.01477				
Oil (unit: lb/1000 gal)					
RFO, BLR	4.3*(1.12*S+0.37)+1.5	0.028*(1.12*S+0.37)+1.5			0.48*(1.12*S+0.37)+1.5
DFO, BLR	1.55				
DFO, CT	2.05[f]				1.54
DFO, ICE	0.31				
JF, CT	0.0148[g]				0.0111
KER, CT	2.05[h]				0.01107[e]
WO, BLR	28.8*A				
Biomass (unit: lb/mmBtu)					
Dry WDS, BLR, ≤20% moisture	0.267	0.052		0.137	
Wet WDS, BLR, ≥20% moisture	0.307		0.082	0.177	
BLQ, BLR[i,j]	2.3305				0.184[i]

Notes: A is the as-fired coal ash weight percentage (%).
S is the as-fired coal sulfur weight percentage (%).
The numbers in bold in parentheses reflect the emission reduction efficiency of the corresponding emission control device in operation, obtained from AP-42 on an average basis.

TABLE 5 (Cont.)

[a] A PM cumulative $PM_{2.5}$ mass percentage out of PM_{10} for pulverized lignite (0.27) is adopted (EPA, 1995b).
[b] FPM removal efficiency of 99% for ESP is adopted, and the uncontrolled PM emission factors are scaled on the basis of the ESP-equipped ones (EPA, 1995b).
[c] FPM removal efficiencies of 70% and 99% for wet scrubber and ESP, respectively, are adopted, and the scrubber-equipped PM emission factors are scaled on the basis of the ESP-equipped ones (EPA, 1995b).
[d] From AP-42, Chapter 1 (EPA, 1995a).
[e] Unit is lb/mmBtu;
[f] The $PM_{2.5}$ emission factor is calculated on the basis of the size-specific mass percentage of $PM_{2.5}$ and PM_{10} for uncontrolled industrial boilers.
[g] The uncontrolled $PM_{2.5}$ emission factor is calculated assuming that the emission reduction efficiency of steam or water injection treatment for PM emissions from JF-fired turbines is equivalent to that for $PM_{2.5}$ emissions from DFO-fired turbines.
[h] The uncontrolled $PM_{2.5}$ emission factor for DFO is used.
i Unit is lb/ton.
[j] From Pechan (2003)

Special attention was given to the estimation of primary (total) PM_{10} and $PM_{2.5}$ emission factors. Particulate matter consists of filterable particulate matter (FPM) that is trapped by the glass fiber filter plus condensable particulate matter (CPM) that is emitted in the vapor state but later condenses to form homogeneous and/or heterogeneous aerosol particles (EPA, 1995a). The CPM emission factors of coal- and oil-fired EGUs are dependent on the sulfur content of coal and oil and on whether a flue gas desulfurization (FGD) control is in place or not. Thus, the primary PM_{10} and $PM_{2.5}$ emission factors of FPM and FGD-dependent CPM for coal-fired EGUs are estimated by separate terms in Tables 4 and 5, with the first and the second terms representing FPM and CPM emission factors, respectively.

Tables 4 and 5 show that the FPM and CPM portions of the PM_{10} and $PM_{2.5}$ emission factors for BIT-, SUB-, LIG- and RFO-fired EGUs are determined by the ash content (A) and the sulfur content (S), respectively. A default condensable PM_{10} and $PM_{2.5}$ emission factor of 0.01 lb/mmBtu rather than the emission equation (0.1*S–0.03) is used when the sulfur content of coal is 0.4% or less (EPA, 1995a). Since the FGD control determines the condensable PM emission factors, these factors are calculated by applying the FGD deployment rate weighted by the generator-level heat input for each plant, as shown in Equation (6).

$$CPM_{f,i,j} = FGD\_rate_i \times CPM_{f,FGD\_w/,j} + (1 - FGD\_rate_i) \times CPM_{f,FGD\_w/o,j} \tag{6}$$

where

$CPM_{f,i,j}$	is the CPM emission factor of plant *i* burning fuel type *f* with emission control technology *j*;
FGD_rate_i	is the heat-input-weighted FGD deployment rate of plant *i*;
$CPM_{f,FGD\_w/,j}$	is the CPM emission factor for fuel type *f* with emission control technology *j* with FGD control; and
$CPM_{f,FGD\_w/o,j}$	is the CPM emission factor for fuel type *f* with emission control technology *j* without FGD control.

The FGD_rate_i is calculated on the basis of the deployment of SO_x emission control devices as obtained from EPA's CAMD (EPA, 2007a). From CAMD, the FGD deployment rate by U.S. EGUs is 33.2% (nameplate capacity basis), which agrees well with the 33% deployment rate reported by EPA (EPA, 2009a).

$CPM_{f,FGD\_w/,j}$ and $CPM_{f,FGD\_w/o,j}$ are derived from WebFIRE and AP-42, as shown in Tables 4 and 5. It is clear that $CPM_{f,FGD\_w/o,j}$ for coal-fired EGUs are dependent on the fuel sulfur contents. A high-sulfur coal would result in significantly higher CPM than FPM, and eventually a high total primary PM emission factor. With reported measurements of both FPM and CPM emission factors for coal-fired EGUs (Corio and Sherwell, 2000; Farber et al., 2004), EPA developed refined FPM/CPM ratios, which split the primary PM_{10} and $PM_{2.5}$ emission factors by 40/60 and 20/80 for the FPM and CPM, respectively. These split ratios were used for the development of refined PM emission estimates in the National Emission Inventory (Pechan, 2005). In the present report, the WebFIRE- and AP-42-based PM_{10} and $PM_{2.5}$ emission factors for coal-fired EGUs are first calculated, and then checked against the FPM/CPM split using Equations 7a and 7b for PM_{10} and $PM_{2.5}$ emission factors, respectively:

$$PM_{10,adjusted} = FPM_{10} + \min(CPM_{10}, 1.5 \times FPM_{10}) \tag{7a}$$

$$PM_{2.5,adjusted} = FPM_{2.5} + \min(CPM_{2.5}, 4.0 \times FPM_{2.5}) \tag{7b}$$

where

$PM_{10,adjusted}$ and $PM_{2.5,adjusted}$	are adjusted PM_{10} and $PM_{2.5}$ emission factors, respectively;
FPM_{10} and $FPM_{2.5}$	are the WebFIRE and AP-42-based filterable PM_{10} and $PM_{2.5}$ emission factors, respectively; and
CPM_{10} and $CPM_{2.5}$	are the WebFIRE and AP-42-based condensable PM_{10} and $PM_{2.5}$ emission factors, respectively.

For RFO-fired boilers, removal efficiencies of 77.96% and 92.93% for PM_{10} and $PM_{2.5}$, respectively, are assigned to the multiple-cyclone-controlled boilers according to AP-42 (EPA, 1995c).

To evaluate whether the reported data for woody biomass-fired boilers are dry-basis or wet-basis, the heating value of the woody biomass as obtained from the EIA's monthly fuel consumption and heat content data at the plant level (EIA, 2007a) is used. We made the assumption that woody biomass with HHV greater than 15 mmBtu/ton is considered dry and otherwise it is considered wet. This assumption is based on the heating value, which ranges from 9 mmBtu/ton for wet-basis to 16 mmBtu/ton for dry-basis woody biomass (EPA, 1995d).

For the coal-fired integrated gasification combined cycle (IGCC) technology, there is only one EGU (ORIS code 7242) reported in eGRID that employs bituminous coal-fired IGCC components. However, the IGCC component of that plant has a very low generator capacity factor (0.0055 and 0.1109 for the steam turbine and the combustion turbine part, respectively), with a very low combined efficiency of 5%, which does not represent the performance of this type of advanced combustion technology, expected to be in the range of 41.2%–44.5% (NETL, 2010). As a result, we have not calculated the GHG and CAP emission factors of coal-fired IGCC plants based on eGRID. Nevertheless, we estimated the CAP emission factor on the basis of the modeled performances of three hypothetical IGCC power plant configurations, assuming that they use technologies available today (NETL, 2010), and the CAP emission factors for BIT, SUB and LIG using equipment and processes available for deployment in the 2010 time period (EPA, 2006).

For natural gas combined cycle (NGCC) plants, 0.000242 and 0.0004973 lb/mmBtu are adopted as the emission factors of PM and VOC, respectively, on the basis of the in-stack flue gas measurement of one NGCC plant (England et al., 2004). A CO emission factor of 0.02669 g/kWh, which was modeled on an energy balance and mass balance basis from an NGCC plant with an LHV-based efficiency of 54.1% (Spath and Mann, 2000), is used in this work for estimation of the CO emission factors for individual NGCC plants, using Equation (8). As for other types of power plants, the NO_x and SO_x emission data from eGRID are used to calculate their emission factors for NGCC plants.

$$EF_{co,i} = EF_{co,NREL} \times \frac{\eta_{NERL}}{\eta_i} \tag{8}$$

where

$EF_{co,i}$ and $EF_{co,NREL}$	are the CO emission factors in g/kWh for NGCC plant *i* and for the NREL NGCC plant, respectively; and
η_i and	are the LHV-based efficiencies for NGCC plant *i* and for the NREL NGCC plant, respectively.

The CAP emissions are approximated for SC-, WC-, TDF-, AB-, MSB-, OBS-, OBL-, WDL-, OG-, OTH- and purchased steam (PUR)-fired EGUs, whose net electricity generation accounts for a small fraction of the total and for which no data are available for the estimation of their CAP emissions. The emission factors of BIT-fired EGUs are applied to SC-fired EGUs after accounting for the difference in fuel properties, e.g., decreased ash and sulfur contents, and increased heating value. For WC-fired EGUs, with a much higher ash content, the CAP emissions are calculated using the emission factors of LIG-fired EGUs and adjusted by the ash and sulfur contents of WC. The BIT-fired emission factors are used to approximate the CAP emissions for TDF-fired EGUs. Emission factors of NG-fired EGUs are used to estimate the CAP emissions of OG-, OTH- and PUR-fired EGUs. The dry-basis WDS emission factors are used to estimate the CAP emissions of AB-, MSB- and OBS-fired EGUs, while the wet-basis WDS emission factors are used to estimate the CAP emissions of OBL- and WDL-fired EGUs.

For PC-, BLQ-, BFG-, DG-, KER- and WO-fired EGUs, the CAP emissions are calculated from the CAP emission factors compiled in Tables 2-5, based on WebFIRE.

In Tables 2-5, only uncontrolled or LNB emission factors for CO and VOC are available for most EGUs. Also, we noticed that some EGUs, like the BIT-fired EGUs that utilize FBC or stokers, have only uncontrolled PM_{10} and $PM_{2.5}$ emission factors, since no particular control technologies are deployed there.

2.3 SULFUR CONTENTS AND ASH CONTENTS OF VARIOUS FUELS BY STATE

As mentioned earlier, the ash content and sulfur content of the fuels are needed to calculate the PM_{10} and $PM_{2.5}$ emission factors for various combustion technologies. On the basis of 2007 EIA FERC-423 data (EIA, 2007b), the sulfur contents and ash contents of BIT, SUB, LIG, NG, RFO, DFO, JF, KER, PC, SC, WC and WO by state are calculated on the basis of the weighted average fuel consumption of each fuel. For those states where no relevant data are available, the weighted averages of all other states are used. Tables 6 and 7 summarize the sulfur contents and ash contents, respectively, of BIT-, SUB-, LIG-, SC-, WC-, PC-, NG-, RFO-, DFO- and JF-fired EGUs by state on an as-received basis in year 2007.

TABLE 6 Sulfur contents (weight %) of various fuels on an as-received basis in each state in year 2007

	BIT	SUB	LIG	SC	WC	PC	NG	RFO	DFO	JF
AL	1.26090	0.31310	0.90642	1.34802	1.72178	4.51377	0.00000	0.89493	0.26332	0.01394
AK	1.53553	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.14995	0.01394
AZ	0.55001	0.58052	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.35438	0.01394
AR	1.53553	0.25751	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.46635	0.01394
CA	1.53553	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.14995	0.01394
CO	0.53468	0.33827	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.03131	0.01394
CT	1.53553	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.14995	0.01394
DE	1.53553	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	0.95000	0.14995	0.01394
FL	1.48598	0.35683	0.90642	3.14408	1.72178	4.30807	0.00000	1.06578	0.06772	0.01000
GA	1.07063	0.28258	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.50000	0.01394
HI	1.53553	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.14995	0.01394
ID	1.53553	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.14995	0.01394
IL	2.70687	0.23075	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.24445	0.01394
IN	2.39468	0.24698	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.15868	0.01394
IA	1.16898	0.32982	0.90642	1.61427	1.72178	5.52308	0.00000	0.89493	0.00607	0.01394
KS	3.94230	0.35337	0.90642	1.61427	1.72178	4.38849	0.00000	0.89493	0.17568	0.01394
KY	2.10738	0.30744	0.90642	3.28095	1.72178	4.51377	0.00000	0.89493	0.22587	0.01394
LA	1.53553	0.34188	0.73408	1.61427	1.72178	4.51377	0.00000	0.27317	0.40900	0.01394
ME	1.53553	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.14995	0.01394
MD	1.53553	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.14995	0.01394
MA	1.53553	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	1.00000	0.18563	0.01394
MI	1.24906	0.28792	0.90642	1.61427	1.72178	5.91466	0.00000	0.86012	0.12412	0.01394
MN	0.92025	0.45544	0.90642	1.61427	1.72178	6.21600	0.00000	0.89493	0.17070	0.01394
MS	0.66092	0.30000	0.90642	1.61427	1.72178	4.51377	0.00000	3.00000	0.41902	0.01394
MO	2.19901	0.29295	0.90642	1.61427	1.72178	3.68000	0.00000	0.89493	0.23704	0.01394
MT	1.53553	0.64510	0.54058	1.61427	1.72178	4.51377	0.00000	0.89493	0.50000	0.01394
NE	1.53553	0.31387	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.00280	0.01394
NV	0.48912	0.37624	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.14995	0.01394
NH	1.27203	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	0.96758	0.27000	0.01394

TABLE 6 (Cont.)

	BIT	SUB	LIG	SC	WC	PC	NG	RFO	DFO	JF
NJ	1.84110	0.24000	0.90642	1.61427	1.72178	4.51377	0.00000	0.27887	0.09414	0.01394
NM	1.53553	0.77066	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.00000	0.01394
NY	1.98194	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	0.49495	0.12181	0.01394
NC	0.88395	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.15886	0.01394
ND	1.53553	0.34086	0.76337	1.61427	1.72178	4.51377	0.00000	0.89493	0.34074	0.01394
OH	2.24325	0.24741	0.90642	0.92187	1.72178	4.51377	0.00000	0.89493	0.03600	0.01394
OK	1.53553	0.31549	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.49185	0.01394
OR	1.53553	0.30722	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.10000	0.01394
PA	1.53553	0.35683	0.90642	1.61427	1.72754	4.51377	0.00000	0.89493	0.14995	0.01394
RI	1.53553	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.14995	0.01394
SC	1.25032	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.16600	0.01394
SD	1.53553	0.30252	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.14995	0.01394
TN	1.47505	0.28534	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.50000	0.01394
TX	1.53553	0.28545	1.48026	1.61427	1.72178	4.51377	0.00000	0.89493	0.35093	0.01394
UT	0.59183	0.35683	0.90642	0.56035	0.61829	4.51377	0.00000	0.89493	0.25290	0.01394
VT	1.53553	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.14995	0.01394
VA	0.96706	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	0.20000	0.13946	0.01394
WA	1.53553	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.14995	0.01394
WV	1.67058	0.41969	0.90642	1.61427	2.23463	4.51377	0.00000	0.89493	0.07500	0.20000
WI	0.85987	0.29734	0.90642	1.61427	1.72178	5.46855	0.00000	0.89493	0.08440	0.01394
WY	1.53553	0.49376	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.30696	0.01394
DC	1.53553	0.35683	0.90642	1.61427	1.72178	4.51377	0.00000	0.89493	0.14995	0.01394

TABLE 7 Ash contents (weight %) of various fuels on an as-received basis in each state in year 2007

	BIT	SUB	LIG	SC	WC	PC	NG	RFO	DFO	JF
AL	9.23965	5.02859	12.31063	11.38480	44.85893	0.62183	0.00000	0.10845	0.00000	0.00208
AK	10.31529	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.01849	0.00208
AZ	9.76459	11.42902	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.02498	0.00208
AR	10.31529	4.83484	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.10154	0.00208
CA	10.31529	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.01849	0.00208
CO	12.49913	5.61162	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.00000	0.00208
CT	10.31529	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.01849	0.00208
DE	10.31529	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.00000	0.01849	0.00208
FL	8.86764	6.31810	12.31063	8.36190	44.85893	0.66469	0.00000	0.03626	0.00000	0.00000
GA	10.54668	4.65973	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.09984	0.00208
HI	10.31529	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.01849	0.00208
ID	10.31529	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.01849	0.00208
IL	12.75097	4.72037	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.00000	0.00208
IN	8.81044	4.90242	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.00000	0.00208
IA	8.02722	5.10792	12.31063	12.06472	44.85893	0.32030	0.00000	0.10845	0.00000	0.00208
KS	15.96029	5.07091	12.31063	12.06472	44.85893	0.19301	0.00000	0.10845	0.01010	0.00208

TABLE 7 (Cont.)

	BIT	SUB	LIG	SC	WC	PC	NG	RFO	DFO	JF
KY	10.69417	5.52078	12.31063	11.64207	44.85893	0.62183	0.00000	0.10845	0.00000	0.00208
LA	10.31529	5.11206	13.02603	12.06472	44.85893	0.62183	0.00000	0.32683	0.17050	0.00208
ME	10.31529	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.01849	0.00208
MD	10.31529	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.01849	0.00208
MA	10.31529	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.00000	0.00668	0.00208
MI	9.04486	4.85436	12.31063	12.06472	44.85893	1.28831	0.00000	0.06516	0.01783	0.00208
MN	8.03758	6.82404	12.31063	12.06472	44.85893	0.43711	0.00000	0.10845	0.01765	0.00208
MS	9.49872	5.62637	12.31063	12.06472	44.85893	0.62183	0.00000	0.10000	0.00440	0.00208
MO	8.82249	5.09978	12.31063	12.06472	44.85893	0.20000	0.00000	0.10845	0.00631	0.00208
MT	10.31529	9.50765	8.73848	12.06472	44.85893	0.62183	0.00000	0.10845	0.00000	0.00208
NE	10.31529	5.06339	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.00000	0.00208
NV	9.51760	8.59164	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.01849	0.00208
NH	6.55862	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.25283	0.07987	0.00208
NJ	6.79610	4.70000	12.31063	12.06472	44.85893	0.62183	0.00000	0.62482	0.00075	0.00208
NM	10.31529	22.05481	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.00000	0.00208
NY	8.53282	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.26162	0.10000	0.00208
NC	11.94970	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.00000	0.00208
ND	10.31529	4.92592	10.11939	12.06472	44.85893	0.62183	0.00000	0.10845	0.00000	0.00208
OH	10.69418	5.33234	12.31063	13.86773	44.85893	0.62183	0.00000	0.10845	0.00000	0.00208
OK	10.31529	5.12851	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.00000	0.00208
OR	10.31529	4.71792	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.10000	0.00208
PA	10.31529	6.31810	12.31063	12.06472	45.33218	0.62183	0.00000	0.10845	0.01849	0.00208
RI	10.31529	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.01849	0.00208
SC	10.00471	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.00000	0.00208
SD	10.31529	5.46386	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.01849	0.00208
TN	9.89217	5.24092	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.00000	0.00208
TX	10.31529	5.08348	20.21746	12.06472	44.85893	0.62183	0.00000	0.10845	0.00000	0.00208
UT	12.59826	6.31810	12.31063	10.83886	46.83715	0.62183	0.00000	0.10845	0.00000	0.00208
VT	10.31529	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.01849	0.00208
VA	10.14313	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.10000	0.06516	0.00208
WA	10.31529	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.01849	0.00208
WV	11.79668	5.28451	12.31063	12.06472	38.79951	0.62183	0.00000	0.10845	0.01253	0.10000
WI	8.50051	5.09154	12.31063	12.06472	44.85893	0.48613	0.00000	0.10845	0.01688	0.00208
WY	10.31529	7.40841	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.00000	0.00208
DC	10.31529	6.31810	12.31063	12.06472	44.85893	0.62183	0.00000	0.10845	0.01849	0.00208

Using data in Tables 2-7, the CO, VOC, PM_{10} and $PM_{2.5}$ emission factors (in g/kWh) by fuel subtype and combustion technology per unit of net electricity generation output from each EGU are calculated using Equation (4). The emission factors for coal-fired, NG-fired, oil-fired and biomass-fired EGUs are combined to calculate the national average emission factors using the weighted average of net electricity generation by these EGUs.

2.4 EFFICIENCIES

Since the LHVs of fuels are used by default in GREET to evaluate transportation fuels, we calculate the LHV-based energy efficiencies for EGUs employing the same fuel type and combustion technology, using Equation (9):

$$\eta_{LHV,f,ct} = \frac{elec.gen._{f,ct} \times kWh2mmBtu}{heatinput_{f,ct} \times \frac{LHV_f}{HHV_f}} \times 100\% \tag{9}$$

where

$\eta_{LHV,f,ct}$	is the LHV-based energy efficiency (%) by fuel type and combustion technology;
$elec.gen._{f,ct}$	is the net electricity generation (kWh) by fuel type and combustion technology;
$kWh2mmBtu$	is the unit converter of per-kWh electricity to mmBtu, which is 3412 Btu per kWh;
$heatinput_{f,ct}$	is the heat input (mmBtu) by fuel type and combustion technology; and
LHV_f and HHV_f	are the LHV and HHV, respectively, of the fuel type.

Since the heat input of each EGU in eGRID is calculated on the basis of the HHV of the burning fuel on an as-received basis, the LHV-based heat input of each EGU for BIT, SUB, LIG, NG and biomass is estimated using Equation (10) (FR, 2007), with HHV_f, $mst\%$, and $H\%$ measured via typical ultimate analyses of such fuels obtained from EPA (2006):

$$LHV_f = HHV_f - 10.55 \times (mst\% + 9 \times H\%) \tag{10}$$

where

LHV_f	is the lower heating value in Btu/lb of fuel type *f*;
HHV_f	is the higher heating value in Btu/lb of fuel type *f*;
$mst\%$	is the moisture weight percentage of fuel type *f*; and
$H\%$	is the hydrogen weight percentage of fuel type *f*.

Owing to the lack of H% data, the LHVs for RFO, DFO, JF and PC are not calculated using Equation (10). Instead, their LHVs are obtained from GREET 1_2011. For SC, WC, TDF, AB, MSB, OBS, OBL, WDL, OG, OTH, PUR, BLQ, LFG, KER, WO, DG and BFG, the $\frac{LHV_f}{HHV_f}$

ratios are approximated by that of the major fuel type with which they are associated (see section 2.2 above), as shown in Table 8.

2.5 PROBABILITY DISTRIBUTION FUNCTIONS OF GHG AND CAP EMISSION FACTORS AND EFFICIENCIES

To address the uncertainty associated with GHG and CAP emission estimation, which is partly due to variations in plant vintages and usages, the PDFs of GHG and CAP emission factors, as well as energy efficiencies of EGUs by fuel type and combustion technology, were developed on the basis of the performance of individual EGUs. The PDFs serve as functions that describe the relative likelihood for the emission factors and energy efficiencies as random variables to take on a given value by the integral of their own probability distributions, which reflect the fluctuation, variability and uncertainty of the real-world performance of EGUs. To be considered in the data set that was used to develop the PDF, the energy efficiencies had to be both positive and not higher than 45%, 45%, 60% and 45% for boilers, CTs, combined-cycle (CC) plants and ICEs, respectively. The potential outliers among GHG and CAP emission factors for individual EGUs and the corresponding efficiencies were detected using the modified Z-score defined by Equation (2), and EGUs associated with these outliers were removed from the data set before the PDF was developed.

TABLE 8 $\frac{LHV_f}{HHV_f}$ **ratios, on an as-received basis, of various fuels burned by EGUs**

	$\frac{LHV_f}{HHV_f}$		$\frac{LHV_f}{HHV_f}$		$\frac{LHV_f}{HHV_f}$		$\frac{LHV_f}{HHV_f}$
BIT	0.95332[a]	NG	0.90133[a]	RFO	0.93500[b]	WDS	0.89408[c]
SUB	0.93036[a]	LFG	0.90133[a]	DFO	0.93500[b]	WDL	0.83922[d]
LIG	0.91138[a]	BFG	0.90133[a]	JF	0.93500[b]	MSB	0.89408[c]
SC	0.95332[a]	DG	0.90133[a]	KER	0.93500[b]	BLQ	0.83922[d]
WC	0.95332[a]	OG	0.90133[a]	WO	0.93500[b]	AB	0.83922[d]
PC	0.94242[b]	PUR	0.90133[a]			OBS	0.89408[c]
TDF	0.95332[a]	OTH	0.90133[a]			OBL	0.83922[d]

[a] Based on the ultimate analysis of coal properties from EPA (2006).

[b] From GREET1-2011.

[c] Based on the ultimate analysis of biomass properties from EPA (2007b), assuming a moisture content of 20%.

[d] Based on the ultimate analysis of biomass properties from EPA (2007b), assuming a moisture content of 45%.

Upon detection and exclusion of outliers, a toolbox called EasyFit Professional (developed by Mathwaves) was used to develop a number of PDFs for each of the GHG and CAP emission factors, as well as efficiencies based on multiple commonly used statistical goodness-of-fit criteria (e.g., Kolmogorov Smirnov and Anderson Darling). We used the calculated emission factors of individual EGUs for each fuel/combustion technology as sample data values and used the net electricity generation of each EGU as the corresponding probability density value. Subsequently, the best-fit PDF based on the goodness-of-fit criteria was selected from a gallery of built-in PDFs in EasyFit and in GREET (Subramanyan and Diwekar, 2005). Once developed, the PDFs were used to quantify the uncertainty associated with each GHG and CAP emission factor and efficiency of EGUs.

3 RESULTS

3.1 DATA QUALITY EVALUATION

3.1.1 Detection of Outliers

By applying the efficiency thresholds, the Z-scores, and the "1.96 standard deviations" criteria defined in Section 2.1, a number of potential outliers by fuel type and combustion technology are ruled out, as shown in Table 9, before the remaining good-quality data are processed for the GHG and CAP emission factors and the efficiencies.

TABLE 9 Number of outliers detected by fuel type and combustion technology

Fuel type/ com-bustion tech-nology	No. of outliers by efficiency thresholds/ total no. of EGUs	No. of outliers by Z-scores and standard deviations/total no. of EGUs								
		CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
Coal/BLR	4/419	18/415	18/415	12/415	21/415	6/415	29/415	27/415	21/415	15/415
NG/BLR	48/257	16/209	21/209	4/209	17/209	51/209	2/209	2/209	2/209	2/209
NG/CT	151/569	33/418	38/418	7/418	43/418	91/418	6/418	6/418	6/418	6/418
NG/CC	47/275	31/228	31/228	31/228	40/228	60/228	29/228	29/228	29/228	1/228
NG/ICE	34/262	16/228	7/228	7/228	7/228	7/228	7/228	7/228	7/228	7/228
Oil/BLR	0/28	2/28	0/28	0/28	0/28	2/28	1/28	1/28	2/28	0/28
Oil/CT	7/146	2/139	14/139	14/139	17/139	8/139	14/139	2/139	6/139	6/139
Oil/ICE	33/424	61/381	61/381	26/381	24/381	19/381	31/381	26/381	35/381	63/381
Biomass/ BLR	0/87	3/87	3/87	2/87	7/87	5/87	4/87	3/87	3/87	1/87

There are quite a few outliers, particularly for NG-fired and oil-fired EGUs, as shown in Table 9. Therefore, the detection and removal of such outliers is necessary and substantially improves the quality of the data used and the final results of this report.

3.1.2 Comparison of GHG and CAP Emissions with EPA's NEI Data

The accuracy of the GHG and CAP emission factors per unit electricity generated is largely dependent on the accuracy of the estimation of GHG and CAP emissions. Thus, to evaluate the data quality of our calculated emission factors, the total GHG and CAP emissions calculated from this study were compared with EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks (EPA, 2009b) and EPA's National Emission Inventory (NEI) Air Pollutant Emissions Trends Data (EPA, 2011d), as shown in Table 10.

TABLE 10 Comparison of total GHG and CAP emissions (thousand tons) calculated in the present study for the electric power sector with EPA's NEI data for the year 2007

	CO_2	CH_4	N_2O	PM_{10}	$PM_{2.5}$	VOC	CO	NO_x	SO_x
This study	2440542*	47*	37*	660	376	44	716	3343*	8913*
NEI 2007	2412800	33	33	479	398	44	699	3223	8472
Percentage difference	1.10	41.00	12.12	37.76	-5.64	-0.33	2.43	3.70	5.20

*Based on eGRID 2010.

Table 10 shows that with the exception of CH_4 and PM_{10} emissions, the GHG and CAP emissions from this study agree well with the EPA's NEI estimates. Both eGRID and NEI estimated CH_4 emissions by multiplying the fuel-specific heat input in MMBtu by appropriate Tier 2 technology- and fuel-specific emission factors from the Intergovernmental Panel on Climate Change, such as 1.0 g/GJ for coal boiler combustion, 3.0 g/GJ for petroleum boiler combustion, 1.0 g/GJ for natural gas boiler combustion, and 30.0 g/GJ for wood boiler combustion, which are also the default CH_4 emission factors in GREET (except for wood boiler combustion). The emission differences shown in Table 10 are ascribed to two factors. The first is the difference in fuel-specific heat input. The NEI obtained the heat input data from the EPA's Acid Rain Program Dataset (ARPD, EPA 2009c), whereas eGRID obtained the heat input data from both the EPA's CAMD continuously monitored data, which is basically the same as the ARPD, and the EIA 923 heat input data when the former are not available. As the NEI does not mention where the heat input data are obtained for those power plants that are not included in the ARPD, this indicates that eGRID was likely to account for a more complete list of power plants than the NEI, and therefore the CH_4 emissions estimated by eGRID were higher than the NEI estimation. The second reason is that the NEI data for year 2007 are a simple interpolation between the NEI 2005 data and the NEI 2008 data, which could have higher uncertainty than the emissions originally estimated with eGRID. Therefore, we believe the observed difference is plausible and the CH_4 estimation from eGRID is credible.

We could not find the source of the PM_{10} discrepancy. However, we note that the NEI PM_{10} and $PM_{2.5}$ data for 2007 were simple interpolations between the 2005 and 2008 data. Moreover, the $PM_{2.5}/PM_{10}$ emission ratio for EPA's NEI is much higher, at 83.1%, than ours at 57.0%. Upon checking the AP-42 PM emission factors for coal-fired EGUs, we found the $PM_{2.5}/PM_{10}$ emission ratios to be 26.1%, 10.3%, 71.8%, 43.3% and 57.6% for uncontrolled, cyclone-controlled, scrubber-controlled, ESP-controlled and baghouse-controlled facilities, respectively. Therefore, we concluded that NEI's $PM_{2.5}/PM_{10}$ emission ratio of 83.1% is less realistic than ours, especially when a large share (approximately 50%) of the total electric generation in the U.S. comes from coal-fired EGUs. Furthermore, our estimates of PM_{10} and $PM_{2.5}$ are based on rigorous evaluation of fuel types and specifications, combustion technologies, emission control technologies, unit-level FGD deployment rate, and the recommended 40/60 and 20/80 split of FPM and CPM for PM_{10} and $PM_{2.5}$, respectively. Moreover, our PM_{10} emissions estimates incorporate the high PM_{10} emission contributions from WC, SC, WDS, MSB, BLQ, and PetCoke combustion, which together account for 31.6% of the total PM_{10} emissions despite their low contribution to the total generation mix (4.3%). The higher PM_{10} emissions from EGUs that employ these fuels are due to the absence of PM control devices (e.g., baghouse or electrostatic precipitator), as indicated in the EPA's CAMD database.

3.1.3 Carbon Intensities by Fuel Type

Fuel quantities consumed are calculated on the basis of plant-level heat input, which could involve errors for multiple-fuel-burning EGUs because of the lumping of the minor fuel types with the primary fuel type. To reduce this potential bias, the plant-level carbon intensities (CIs) of the primary fuel types are calculated using Equation (11), and those with significant bias are recognized using the modified Z-score approach and removed as outliers.

$$CI = \frac{\frac{12}{44} \times E_{CO_2} + \frac{12}{28} \times E_{CO} + \frac{12}{16} \times E_{CH_4} + 0.85 \times E_{VOC}}{Q} \tag{11}$$

where

CI	is carbon intensity;
E_{CO_2}	is the CO_2 emissions, in tons;
E_{CO}	is the CO emissions, in tons;
E_{CH_4}	is the CH_4 emissions, in tons;
E_{VOC}	is the VOC emissions, in tons; and
Q	is the quantities of fuels consumed, in tons.

Table 11 summarizes the percentages of CI outliers detected by fuel type and combustion technology for multiple-fuel-burning EGUs on the basis of their nameplate capacities. With the removal of these detected outliers, the potential bias associated with our methodology is minimized.

TABLE 11 Percentage of CI outliers detected by fuel type and generation technology

Fuel type	Combustion technology	Outlier no. (Total no. of EGUs)	Outlier nameplate capacity share (%)
BIT	Boiler	14 (388)	0.76
SUB	Boiler	6 (198)	1.80
LIG	Boiler	0 (16)	0
NG	Boiler	1 (228)	0.0050
	Combined-Cycle Plant	1 (424)	0.000088
	Combustion Turbine	3 (609)	0.0042
	Internal Combustion Engine	3 (157)	0.0033
RFO	Boiler	2 (37)	0.32
DFO	Internal Combustion Engine	21 (489)	1.53
	Combustion Turbine	2 (127)	3.90
JF	Combustion Turbine	0 (6)	0

3.2 NATIONAL AVERAGE GHG AND CAP EMISSION FACTORS AND EFFICIENCIES BY FUEL TYPE AND GENERATION TECHNOLOGY

The national-average GHG and CAP emission factors, LHV-based efficiencies, and generation technology shares (determined by the ratio of their generated electricity to the total generated electricity) for non-CHP EGUs are summarized in Table 12. Aggregating the generation from all fuel subtypes for each fuel gives the GHG and CAP emission factors, as well as the efficiencies, shown in Table 13. The zero CO_2 emission factors for biomass, including WDS, WDL, BLQ, AB, MSB, OBS, and OBL, reflect the fact that the carbon in biomass is originally from the atmosphere, and thus the net CO_2 emission to the atmosphere is zero.

TABLE 12 GHG and CAP emission factors (g/kWh) by fuel subtype and combustion technology for the electricity power sector in the U.S.

	Fuel subtype (share)	Combustion technology (share)	Effi-ciency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
Coal	BIT (50.3%)	BLR (100.0%)	35.2%	939.7	0.01078	0.01583	1.46424	4.73676	0.21297	0.17863	0.01166	0.09826
	SUB (40.2%)	BLR (100.0%)	33.6%	1009.9	0.01148	0.01711	1.33016	2.83006	0.04787	0.02596	0.01451	0.12215
	LIG (4.4%)	BLR (100.0%)	34.4%	1085.1	0.01161	0.01723	1.28867	3.62487	0.23722	0.23652	0.02304	0.14917
	SC (4.6%)	BLR (100.0%)	37.4%	887.4	0.01009	0.01509	1.09157	6.10972	0.17456	0.14437	0.00793	0.06608
	WC (0.2%)	BLR (100.0%)	32.3%	1044.4	0.01171	0.01753	0.85223	4.32689	2.15083	0.60515	0.02934	0.10478
	PC (0.3%)	BLR (100.0%)	33.0%	1003.4	0.01164	0.01515	0.94548	2.40568	0.96453	0.54942	0.00862	0.07392
	TDF (0.01%)	BLR (100.0%)	22.2%	968.4	0.50346	0.06707	5.73916	19.6564	3.90010	1.10953	0.01591	0.13262
NG	NG (99.1%)	BLR (13.4%)	31.9%	631.2	0.01253	0.00143	0.83724	0.00449	0.03528	0.03528	0.02714	0.40760
		CT (5.9%)	32.9%	622.6	0.01237	0.00134	0.35089	0.00648	0.03435	0.03435	0.01093	0.42682
		CC (80.5%)	49.8%	408.7	0.00793	0.00080	0.06295	0.00203	0.00083	0.00083	0.00170	0.02797
		ICE (0.2%)	37.6%	530.9	0.01128	0.00124	5.45417	0.03715	0.20483	0.20483	0.48195	1.65775
	LFG (0.8%)	BLR (15.1%)	30.7%	0.8	0.00003	0.00001	2.05681	0.00015	0.09433	0.09433	0.06575	1.12598
		CT (19.0%)	24.3%	0.0	0.00000	0.00000	0.79253	0.00000	0.17581	0.17581	0.09201	3.11421
		CC (10.9%)	30.3%	140.5	0.00109	0.00011	0.29449	0.00107	0.14097	0.14097	0.07378	0.04765
		ICE (55.0%)	29.9%	6.5	0.00091	0.00013	2.42821	0.00250	0.57210	0.57210	1.34612	4.63018
	BFG (0.02%)	BLR (100.0%)	12.0%	1491.0	0.02972	0.00297	2.44007	0.44474	0.03233	0.03233	0.00168	0.05150
	DG (0.01%)	BLR (21.1%)	17.6%	200.4	0.00404	0.00041	2.30531	0.00846	0.10728	0.10728	0.07764	1.18570
		ICE (78.9%)	25.7%	9.1	0.00039	0.00008	1.58177	0.01188	0.47648	0.47648	1.12112	3.85626
	OG (0.04%)	BLR (26.0%)	18.2%	1100.3	0.02196	0.00220	18.1677	0.35812	0.77565	0.77565	0.56133	8.57301
		CT (9.8%)	13.7%	1463.1	0.02916	0.00292	1.15154	0.04448	0.08261	0.08261	0.02629	1.02637
		ICE (64.2%)	10.1%	1980.9	0.03949	0.00395	2.76143	0.06316	0.88853	0.88853	2.09066	7.19114
Oil	RFO (89.4%)	BLR (100.0%)	32.8%	791.1	0.03058	0.00590	1.35301	3.29910	0.13979	0.11591	0.02555	0.02557
	DFO (8.0%)	BLR (2.4%)	22.8%	1179.3	0.05075	0.01018	1.79151	4.81600	0.11794	0.07948	0.03897	0.25638
		CT (67.9%)	31.1%	869.3	0.03683	0.00739	2.74862	0.67096	0.31780	0.06812	0.00264	0.02123
		ICE (29.7%)	34.8%	768.6	0.03288	0.00662	9.70863	0.82745	0.09806	0.04777	0.01968	0.08508

TABLE 12 (Cont.)

	Fuel subtype (share)	Combustion technology (share)	Effi-ciency	CO2	CH4	N2O	NOx	SOx	PM10	PM2.5	VOC	CO
Biomass	JF (2.4%)	CT (100.0%)	37.9%	704.8	0.03047	0.00611	1.33929	1.24463	0.26848	0.06461	0.00011	0.01441
	WO (0.01%)	ICE (100.0%)	41.5%	653.2	0.27500	0.03666	5.39524	0.28884	0.00340	0.00275	0.00052	0.00339
	KER (0.2%)	CT (100.0%)	25.4%	1051.6	0.04549	0.00912	1.64269	0.46794	0.40203	0.40203	0.02607	0.02151
	WDS (37.6%)	BLR (100.0%)	22.5%	0.0	0.51546	0.06932	1.74266	0.18924	2.51730	2.34353	0.12970	4.57770
	MSB (59.0%)	BLR (100.0%)	20.9%	0.0	0.57671	0.07684	7.04769	19.7043	3.12365	2.21224	0.14085	4.97133
	BLQ (2.1%)	BLR (100.0%)	8.5%	0.0	0.38503	0.10657	3.62878	8.93050	1.22254	0.30564	0.05557	0.35805
	AB (0.7%)	BLR (100.0%)	30.6%	0.0	0.42090	0.05608	0.60302	0.04020	2.27335	1.61004	0.10251	3.61807
	OBS (0.6%)	BLR (100.0%)	15.3%	0.0	0.79178	0.10549	1.86746	1.29146	4.27651	3.02872	0.19284	6.80612
	OBL (0.02%)	BLR (100.0%)	37.7%	0.0	0.03419	0.00686	6.63204	0.05393	1.84659	1.30780	0.08327	2.93887

Note: BLR, CT, CC and ICE represent boilers, combustion turbines, combined-cycle plants and internal combustion engines, respectively.

TABLE 13 GHG and CAP emission factors (g/kWh) by fuel type and combustion technology for the electricity power sector in the U.S.

	Combustion technology	Efficiency	Technology share	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
Coal	BLR	34.5%	100.0%	973.5	0.0111	0.0164	1.3843	3.9377	0.1504	0.1182	0.0133	0.1092
	IGCC[a]	42.2%	0.0%	716.6	NA	NA	0.2150	0.0044	0.0258	NA	NA	NA
	IGCC[b]	43.8%	0.0%	653.6	NA	NA	0.1610	0.1411	0.0231	NA	0.0054	0.0984
	IGCC[c]	43.0%	0.0%	699.0	NA	NA	0.1479	0.0404	0.0236	NA	0.0059	0.1007
	IGCC[d]	43.0%	0.0%	718.5	NA	NA	0.1701	0.0680	0.0240	NA	0.0059	0.1021
NG	BLR	31.9%	13.5%	625.4	0.0124	0.0014	0.8608	0.0048	0.0364	0.0364	0.0279	0.4201
	CT	32.6%	6.0%	600.8	0.0119	0.0013	0.3616	0.0062	0.0394	0.0394	0.0138	0.5231
	CC	49.8%	79.9%	408.7	0.0079	0.0008	0.0629	0.0020	0.0008	0.0008	0.0017	0.0281
	ICE	29.0%	0.6%	208.3	0.0049	0.0005	3.1366	0.0132	0.4868	0.4868	1.1454	3.9398
Oil	BLR	32.8%	89.6%	791.1	0.0306	0.0059	1.3530	3.2991	0.1398	0.115	0.0256	0.1682
	CT	32.7%	8.0%	822.9	0.0351	0.0070	2.2708	0.5939	0.3045	0.0740	0.0021	0.0178
	ICE	34.8%	2.4%	759.1	0.0352	0.0069	9.5561	0.8121	0.0958	0.0467	0.0192	0.0816
Biomass	BLR	20.8%	100.0%		0.5509	0.0748	5.0041	12.977	2.8757	2.2239	0.1352	4.7373
	IGCC	40.0%[e]	0.0%	0.0	Negligible[f]	Negligible[f]	0.078[e]	0.322[e]	0.024[e]	0.012[g]	0.070[f]	0.071[f]

Note: IGCC represents integrated gasification combined cycle, and NA denotes not available.

[a] Data from NETL (2010).

[b] Data from EPA (2006), representing BIT-fired IGCC plants.

[c] Data from EPA (2006), representing SUB-fired IGCC plants.

[d] Data from EPA (2006), representing LIG-fired IGCC plants.

[e] From GREET 1-2011.

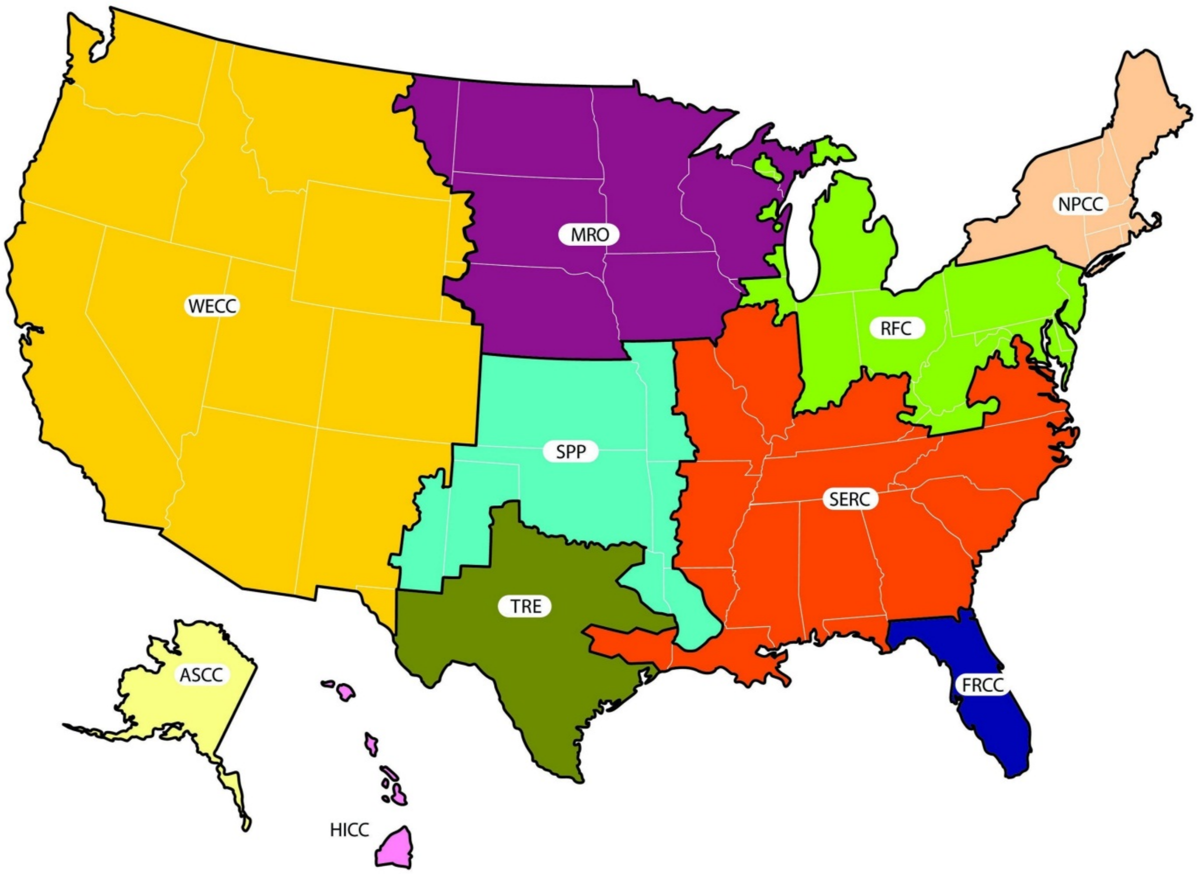
[f] From Mann (2001).

[g] Calculated from the ratio of PM_{10} and $PM_{2.5}$ emission factors for biomass IGCC plants in GREET 1-2011.

It needs to be mentioned that the CO_2 emission factors calculated from the methodology described in Section 2.1 are not used by GREET, which actually uses an alternative approach based on the carbon content of fuels, assuming a 100% carbon oxidation rate (Wang, 1999). In comparison with the CO_2 emission factor (973.5 g/kWh) for coal-fired power plants calculated from eGRID2010, the CO_2 emission factor (1084 g/kWh) calculated by the previous version of GREET is about 11.4% higher, which indicates that the previous coal property parameters, particularly the carbon and heat content of various subtypes of coal in GREET, might be inaccurate for recent years. So we also made an effort to update the coal property parameters in this study: we used EIA's unit-level fuel quality data (EIA-423) to update the HHVs of various subtypes of coal, including BIT, SUB, LIG, SC, WC, PC, and TDF, and we used USGS's Coal Quality database (USGS, 2006) to update the carbon contents of the three major subtypes of coal (BIT, SUB and LIG) on a state coal production weighted-average basis, taking into account the interstate variation in coal properties, and to convert the EIA-based HHVs to LHVs based on the LHV/HHV ratios by coal subtype, also calculated on the basis of the USGS database. With the updated coal property parameters, GREET calculates a new CO_2 emission factor of 989 g/kWh for coal-fired power plants, which is an 8.8% reduction compared to the previous CO_2 emission factor. Consequently, this new CO_2 emission factor is much more consistent with the flue gas measurement-based number (973.5 g/kWh) from eGRID.

3.3 REGIONAL GHG AND CAP EMISSION FACTORS AND EFFICIENCIES BY FUEL TYPE AND GENERATION TECHNOLOGY

GHG and CAP emission factors, efficiencies, and combustion technology shares in the ten North American Electric Reliability Council (NERC) regions shown in Figure 1 are summarized in Table 14. These estimates facilitate life cycle analysis of the GHG and CAP emissions of various vehicle/fuel systems at the regional level.



This Is a representational map; many of the boundaries shown on this map are approximate because they are based on companies, not on strictly geographical boundaries.
USEPA eGRID2010 Version 1.0
December 2010

FIGURE 1   NERC region representational map from eGRID 2010 (EPA, 2011a).

TABLE 14 GHG and CAP emission factors (g/kWh), efficiencies, and combustion technology shares by NERC region

	Fuel type (Share)	Combustion technology (Share)	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
ASCC	NG (62.1%)	CC (97.2%)	36.0%	557.3	0.0111	0.0011	0.9152	0.0166	0.0012	0.0012	0.0024	0.0401
		CT (2.8%)	23.5%	854.9	0.0171	0.0017	2.0208	0.0272	0.0483	0.0483	0.0154	0.5995
	Oil (19.4%)	BLR (14.9%)	17.1%	1602.9	0.0676	0.0136	3.2793	7.3504	0.5714	0.4427	0.0491	0.3227
		CT (67%)	36.7%	731.9	0.0315	0.0063	1.5096	1.7450	0.2772	0.0666	0.0002	0.0156
		ICE (32.1%)	36.9%	731.9	0.0313	0.0063	10.9435	0.9276	0.3650	0.3476	0.3795	1.0710
	Renewable (23.0%)											
FRCC	Biomass (1.6%)	BLR (100%)	18.5%	0.0	0.6523	0.0869	7.1656	19.5981	3.4773	2.5525	0.1595	5.6289
	Coal (28.7%)	BLR (100%)	38.1%	866.1	0.0100	0.0143	1.7538	2.3667	0.5281	0.2543	0.0101	0.0885
	NG (54.6%)	BLR (0.5%)	29.7%	740.7	0.0201	0.0030	0.9373	1.8034	0.0403	0.0403	0.0292	0.4453
		CC (94.2%)	49.0%	432.6	0.0097	0.0012	0.2112	0.2524	0.0010	0.0010	0.0018	0.0248
		CT (5.1%)	32.6%	651.3	0.0139	0.0016	0.4813	0.3056	0.0348	0.0348	0.0111	0.4324
		ICE (0.2%)	30.9%	605.1	0.0137	0.0017	7.8771	0.0543	0.2819	0.2819	0.6633	2.2815
	Oil (7.2%)	BLR (98.9%)	32.3%	808.1	0.0301	0.0058	1.8445	4.7224	0.1825	0.1475	0.0259	0.1706
		CT (0.8%)	26.3%	1026.5	0.0439	0.0088	1.9517	0.5748	0.3792	0.0910	0.0025	0.0204
		ICE (0.3%)	32.8%	834.0	0.0353	0.0071	12.3126	6.1956	0.0770	0.0530	0.0530	0.1410
	Nuclear (7.1%)											
	Renewable (0.8%)											
HICC	Biomass (3.9%)	BLR (100%)	27.8%	0.0	0.4319	0.0576	5.0604	13.0940	2.3436	1.6598	0.1057	3.7299
	Coal (17.6%)	BLR (100%)	38.4%	864.4	0.0140	0.0151	4.2348	14.1123	4.7987	1.6375	0.0108	0.0901
	Renewable (7.1%)											
MRO	Biomass (0.6%)	BLR (100%)	21.1%	0.0	0.5075	0.0703	4.8511	10.0371	2.2520	1.6394	0.1396	4.9273
	Coal (68.8%)	BLR (100%)	32.5%	1064.7	0.0120	0.0179	1.8142	3.6044	0.2247	0.0751	0.0168	0.1931
	NG (5.2%)	BLR (2.3%)	28.0%	749.5	0.0146	0.0015	2.5679	0.3650	0.0377	0.0377	0.0348	0.5308
		CC (70.9%)	48.2%	418.1	0.0082	0.0008	0.0636	0.0037	0.0022	0.0022	0.0024	0.0298
		CT (24.5%)	30.2%	693.1	0.0149	0.0017	0.5968	0.0188	0.0375	0.0375	0.0119	0.4658
		ICE (2.4%)	29.9%	78.3	0.0020	0.0003	6.3403	0.0198	0.5119	0.5119	1.2044	4.1427
	Oil (0.1%)	CT (83%)	22.5%	1208.2	0.0513	0.0103	2.2815	1.9150	0.4432	0.1064	0.0030	0.0238
		ICE (17%)	31.1%	867.1	0.0370	0.0074	12.9216	0.7968	0.1323	0.0389	0.0098	0.0349

TABLE 14 (Cont.)

	Fuel type (Share)	Combustion technology (Share)	Efficiency	CO2	CH4	N2O	NOx	SOx	PM10	PM2.5	VOC	CO
	Nuclear (18.0%)											
	Renewable (7.3%)											
NPCC	Biomass (2.8%)	BLR (100%)	22.1%	0.0	0.5454	0.0727	4.6645	11.1070	2.6982	2.2025	0.1331	4.6982
	Coal (16.2%)	BLR (100%)	35.8%	932.0	0.0126	0.0160	0.8733	4.1888	0.1475	0.0974	0.0129	0.2563
	NG (29.8%)	BLR (13.5%)	33.6%	649.8	0.0149	0.0019	0.6403	0.4175	0.0312	0.0312	0.0259	0.3949
		CC (83%)	50.5%	406.1	0.0079	0.0008	0.0447	0.0321	0.0008	0.0008	0.0017	0.0283
		CT (2.8%)	32.6%	590.4	0.0125	0.0014	0.3462	0.0157	0.0419	0.0419	0.0153	0.5707
		ICE (0.7%)	31.0%	19.9	0.0006	0.0001	1.3221	0.0025	0.5199	0.5199	1.2233	4.2078
	Oil (4.9%)	BLR (97.2%)	33.2%	753.4	0.0288	0.0055	0.7491	2.3168	0.0555	0.0542	0.0252	0.1658
		CT (2.7%)	27.0%	998.1	0.0429	0.0086	2.6288	0.2918	0.3706	0.1249	0.0052	0.0199
		ICE (0.2%)	32.3%	836.3	0.0358	0.0072	6.9454	0.8070	0.2010	0.0514	0.0060	0.0232
	Nuclear (33.3%)											
	Renewable (13.0%)											
RFC	Biomass (0.3%)	BLR (100%)	22.3%	0.0	0.5388	0.0718	6.1191	16.2785	2.8387	2.1352	0.1317	4.6495
	Coal (68.7%)	BLR (100%)	35.6%	939.6	0.0108	0.0159	1.4753	5.6119	0.2412	0.1566	0.0121	0.1080
	NG (5.0%)	BLR (2.5%)	23.7%	840.8	0.0138	0.0015	1.3211	0.5961	0.0568	0.0568	0.0385	0.6235
		CC (79.9%)	48.6%	417.2	0.0082	0.0008	0.0699	0.0031	0.0017	0.0017	0.0022	0.0296
		CT (15.4%)	31.7%	610.9	0.0122	0.0013	0.3884	0.0113	0.0412	0.0412	0.0146	0.5515
		ICE (2.2%)	28.9%	32.5	0.0007	0.0001	2.7549	0.0066	0.5566	0.5566	1.3096	4.5045
	Oil (0.04%)	BLR (45.9%)	26.6%	1044.3	0.0435	0.0087	1.5655	5.0382	0.2689	0.2045	0.0322	0.2120
		CT (42.4%)	23.7%	1152.2	0.0487	0.0098	1.6385	0.9399	0.4223	0.1303	0.0050	0.0226
		ICE (11.7%)	31.9%	848.0	0.0362	0.0073	8.0963	1.3231	0.1254	0.0359	0.0092	0.0301
	Nuclear (25.2%)											
	Renewable (0.8%)											
SERC	Biomass (0.2%)	BLR (100%)	16.4%	0.0	0.5034	0.0795	5.2167	13.3054	2.4654	1.7274	0.1145	3.6799
	Coal (62.2%)	BLR (100%)	35.4%	941.6	0.0109	0.0159	1.2030	4.0612	0.1777	0.1394	0.0126	0.1107
	NG (9.2%)	BLR (20.3%)	30.7%	666.3	0.0143	0.0016	1.3967	0.2118	0.0415	0.0415	0.0303	0.4653
		CC (66.5%)	49.8%	411.5	0.0082	0.0009	0.0728	0.0308	0.0008	0.0008	0.0017	0.0290

TABLE 14 (Cont.)

	Fuel type (Share)	Combustion technology (Share)	Efficiency	CO2	CH4	N2O	NOx	SOx	PM10	PM2.5	VOC	CO
		CT (12.9%)	34.2%	598.6	0.0119	0.0012	0.3651	0.0124	0.0335	0.0335	0.0108	0.4197
		ICE (0.3%)	33.4%	40.9	0.0077	0.0011	2.6405	0.0228	0.4941	0.4941	1.1626	3.9990
	Oil (0.01%)	BLR (26.9%)	18.0%	1537.3	0.0641	0.0129	3.1721	17.4138	0.9499	0.7172	0.0465	0.3061
		CT (27.7%)	17.8%	1518.4	0.1227	0.0203	3.9247	1.5320	0.5053	0.1217	0.0035	0.0279
		ICE (45.4%)	33.4%	806.7	0.0345	0.0069	10.8156	0.8403	0.2194	0.0621	0.0139	0.0513
	Nuclear (26.6%)											
	Renewable (1.8%)											
SPP	Coal (66.6%)	BLR (100%)	33.7%	1012.9	0.0115	0.0171	1.5206	2.8341	0.1451	0.0648	0.0151	0.1267
	NG (22.0%)	BLR (48.3%)	32.9%	620.2	0.0121	0.0012	1.0705	0.0448	0.0300	0.0300	0.0264	0.4026
		CC (48.5%)	48.2%	422.8	0.0083	0.0008	0.2396	0.0037	0.0009	0.0009	0.0018	0.0299
		CT (3%)	30.8%	661.8	0.0131	0.0013	0.5433	0.0095	0.0368	0.0368	0.0117	0.4572
		ICE (0.1%)	29.8%	697.8	0.0158	0.0019	8.2308	0.1207	0.2612	0.2612	0.6145	2.1137
	Oil (0.003%)	CT (43%)	10.0%	2700.7	0.1156	0.0232	37.7720	3.4117	0.9976	0.2395	0.0067	0.0536
		ICE (57%)	32.8%	820.9	0.0350	0.0070	12.2543	0.9994	0.2020	0.1168	0.1052	0.2817
	Nuclear (5.6%)											
	Renewable (5.9%)											
TRE	Biomass (0.001%)	BLR (100%)	37.7%	0.0	0.0342	0.0069	6.6320	0.0539	1.8466	1.3078	0.0833	2.9389
	Coal (43.9%)	BLR (100%)	34.3%	1032.6	0.0114	0.0169	0.7068	3.2823	0.0117	0.0162	0.0177	0.2514
	NG (37.5%)	BLR (14.4%)	32.1%	634.1	0.0124	0.0012	0.6600	0.0067	0.0376	0.0376	0.0272	0.4151
		CC (84.2%)	50.7%	402.9	0.0079	0.0008	0.1001	0.0022	0.0008	0.0008	0.0017	0.0285
		CT (1.1%)	28.4%	718.0	0.0141	0.0014	0.1995	0.0040	0.0399	0.0399	0.0127	0.4956
		ICE (0.3%)	31.3%	112.0	0.0022	0.0002	1.2923	0.0035	0.4896	0.4896	1.1520	3.9625
	Oil (0.00004%)	ICE (100%)	29.1%	927.5	0.0397	0.0080	7.7019	2.8678	0.0923	0.0622	0.0305	0.2006
	Nuclear (15.2%)											
	Renewable (3.4%)											
WECC	Biomass (0.4%)	BLR (100%)	21.5%	0.0	0.5513	0.0739	2.1615	3.1468	2.7048	2.4202	0.1371	4.8372
	Coal (33.7%)	BLR (100%)	32.6%	1035.4	0.0118	0.0176	1.8544	1.3664	0.4074	0.1542	0.0143	0.1319
	NG (24.8%)	BLR (11.1%)	31.7%	635.2	0.0124	0.0012	0.3119	0.0079	0.0385	0.0385	0.0279	0.3943

TABLE 14 (Cont.)

Fuel type (Share)	Combustion technology (Share)	Efficiency	CO2	CH4	N2O	NOx	SOx	PM10	PM2.5	VOC	CO
	CC (84%)	50.4%	404.2	0.0079	0.0008	0.0722	0.0023	0.0010	0.0010	0.0018	0.0284
	CT (4%)	33.2%	555.1	0.0109	0.0011	0.3491	0.0065	0.0436	0.0436	0.0165	0.6103
	ICE (0.9%)	27.2%	460.3	0.0093	0.0009	3.7693	0.0186	0.4558	0.4558	1.0725	3.6889
Oil (0.01%)	CT (46.2%)	26.1%	1015.7	0.0443	0.0089	1.6736	0.3139	0.3823	0.0918	0.0026	0.0205
	ICE (53.8%)	34.1%	792.2	0.0339	0.0068	7.1531	1.0254	0.2876	0.0715	0.0053	0.0253
Nuclear (10.8%)											
Renewable (30.2%)											

Note: Totals of shares may not sum, owing to independent rounding.

3.4 GHG AND CAP EMISSION FACTORS AND EFFICIENCIES BY FUEL TYPE AND GENERATION TECHNOLOGY IN EACH STATE

GHG and CAP emission factors and efficiencies for EGUs in the 50 states and the Washington, D.C. area (DC) are summarized in Table 15. Significant variations in GHG and CAP emission factors among states are found, mostly because of differences among states in the efficiencies of EGUs and the fuel quality.

TABLE 15 GHG and CAP emission factors and efficiencies in each state

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
AK											
NG		35.5%	565.6	0.0113	0.0011	0.9460	0.0169	0.0025	0.0025	0.0027	0.0557
CC	97.21%	36.0%	557.3	0.0111	0.0011	0.9152	0.0166	0.0012	0.0012	0.0024	0.0401
CT	2.79%	23.5%	854.9	0.0171	0.0017	2.0208	0.0272	0.0483	0.0483	0.0154	0.5995
Oil		36.4%	739.2	0.0317	0.0064	4.5554	1.5293	0.3078	0.1600	0.1225	0.3572
Boiler	0.84%	17.1%	1602.9	0.0676	0.0136	3.2793	7.3504	0.5714	0.4427	0.0491	0.3227
CT	67.03%	36.7%	731.9	0.0315	0.0063	1.5096	1.7450	0.2772	0.0666	0.0002	0.0156
ICE	32.13%	36.9%	731.9	0.0313	0.0063	10.9435	0.9276	0.3650	0.3476	0.3795	1.0710
Renewable											
WAT	100.00%										
AL											
Coal		34.7%	948.4	0.0110	0.0158	1.3231	4.8614	0.1444	0.1322	0.0126	0.1046
Boiler	100.00%	34.7%	948.4	0.0110	0.0158	1.3231	4.8614	0.1444	0.1322	0.0126	0.1046
NG		49.6%	411.4	0.0081	0.0008	0.0681	0.0021	0.0023	0.0023	0.0021	0.0461
CC	95.40%	50.7%	402.4	0.0079	0.0008	0.0602	0.0020	0.0008	0.0008	0.0017	0.0285
CT	4.60%	34.3%	595.3	0.0117	0.0012	0.2274	0.0045	0.0330	0.0330	0.0105	0.4102
Nuclear											
Renewable											
WAT	100.00%										
AR											
Biomass		8.4%	333.1	0.4091	0.1096	3.6815	8.9086	1.3370	0.4159	0.0615	0.5743
Boiler	100.00%	8.4%	333.1	0.4091	0.1096	3.6815	8.9086	1.3370	0.4159	0.0615	0.5743
Coal		33.5%	1018.6	0.0116	0.0173	1.2935	2.5368	0.0657	0.0355	0.0147	0.1225
Boiler	100.00%	33.5%	1018.6	0.0116	0.0173	1.2935	2.5368	0.0657	0.0355	0.0147	0.1225

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
AR (cont.)											
NG		47.9%	424.5	0.0083	0.0008	0.1709	0.0593	0.0054	0.0054	0.0088	0.0717
Boiler	3.63%	28.1%	761.6	0.0142	0.0014	1.5766	1.5345	0.0426	0.0426	0.0309	0.4713
CC	93.57%	49.5%	412.2	0.0081	0.0008	0.0776	0.0037	0.0008	0.0008	0.0017	0.0287
CT	2.30%	42.3%	479.3	0.0095	0.0009	0.4256	0.0032	0.0268	0.0268	0.0085	0.3332
ICE	0.49%	30.8%	22.0	0.0004	0.0000	6.3742	0.0006	0.5052	0.5052	1.1888	4.0891
Nuclear											
Oil		35.8%	753.1	0.0322	0.0065	11.2614	0.9493	1.4319	1.4319	1.6629	4.3882
ICE	100.00%	35.8%	753.1	0.0322	0.0065	11.2614	0.9493	1.4319	1.4319	1.6629	4.3882
Renewable											
WAT	100.00%										
AZ											
Coal		30.7%	1094.7	0.0125	0.0185	1.7874	1.2365	0.1095	0.0802	0.0149	0.1246
Boiler	100.00%	30.7%	1094.7	0.0125	0.0185	1.7874	1.2365	0.1095	0.0802	0.0149	0.1246
NG		51.4%	397.0	0.0078	0.0008	0.0734	0.0021	0.0018	0.0018	0.0021	0.0384
Boiler	1.32%	31.2%	653.9	0.0128	0.0013	1.3514	0.0042	0.0384	0.0384	0.0278	0.4248
CC	97.40%	52.3%	389.9	0.0076	0.0008	0.0487	0.0020	0.0008	0.0008	0.0016	0.0276
CT	1.29%	30.6%	666.5	0.0132	0.0013	0.6340	0.0090	0.0370	0.0370	0.0118	0.4598
Nuclear											
Oil		17.1%	1562.3	0.0662	0.0132	14.3586	1.9171	0.3346	0.1198	0.0317	0.2111
CT	47.20%	19.3%	1396.4	0.0598	0.0120	2.6550	1.7512	0.5158	0.1238	0.0034	0.0277
ICE	52.80%	15.6%	1710.6	0.0719	0.0143	24.8222	2.0655	0.1725	0.1163	0.0570	0.3751
Renewable											
SUN	0.10%										
WAT	99.90%										

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
CA											
Biomass		21.7%	157.4	0.5470	0.0733	1.8362	2.0516	2.6666	2.4212	0.1362	4.8060
Boiler	100.00%	21.7%	157.4	0.5470	0.0733	1.8362	2.0516	2.6666	2.4212	0.1362	4.8060
Coal		31.8%	1162.3	0.0120	0.0180	3.8007	11.3622	6.4524	3.6754	0.0127	0.1086
Boiler	100.00%	31.8%	1162.3	0.0120	0.0180	3.8007	11.3622	6.4524	3.6754	0.0127	0.1086
NG		43.7%	453.3	0.0089	0.0009	0.0787	0.0037	0.0186	0.0186	0.0254	0.1964
Boiler	21.72%	31.5%	638.0	0.0124	0.0012	0.1348	0.0085	0.0388	0.0388	0.0281	0.3914
CC	73.80%	51.1%	399.0	0.0078	0.0008	0.0301	0.0020	0.0012	0.0012	0.0019	0.0279
CT	3.49%	33.2%	444.8	0.0088	0.0009	0.3000	0.0060	0.0600	0.0600	0.0263	0.9311
ICE	0.99%	20.1%	475.7	0.0095	0.0010	1.6870	0.0157	0.7280	0.7280	1.7130	5.8920
Nuclear											
Oil		30.7%	869.8	0.0377	0.0076	4.3230	0.5961	0.3251	0.0780	0.0022	0.0175
CT	43.65%	26.7%	988.5	0.0433	0.0087	1.5642	0.0655	0.3738	0.0897	0.0025	0.0201
ICE	56.35%	34.7%	777.9	0.0333	0.0067	6.4602	1.0071	0.2873	0.0690	0.0019	0.0154
Renewable											
SUN	0.01%										
GEO	28.00%										
WAT	59.55%										
WH	0.40%										
WND	12.04%										
CO											
Coal		32.7%	1030.3	0.0117	0.0175	1.6324	1.6601	0.1034	0.0583	0.0141	0.1989
Boiler	100.00%	32.7%	1030.3	0.0117	0.0175	1.6324	1.6601	0.1034	0.0583	0.0141	0.1989
NG		44.0%	464.9	0.0091	0.0009	0.1778	0.0033	0.0082	0.0082	0.0075	0.1108
Boiler	0.24%	27.5%	738.6	0.0155	0.0017	1.8573	0.0679	0.0435	0.0435	0.0315	0.4813
CC	81.88%	47.1%	433.5	0.0085	0.0009	0.0845	0.0023	0.0009	0.0009	0.0018	0.0307
CT	16.98%	34.0%	610.0	0.0118	0.0012	0.3068	0.0067	0.0334	0.0334	0.0106	0.4147
ICE	0.89%	39.8%	504.2	0.0101	0.0010	5.8419	0.0146	0.1953	0.1953	0.4594	1.5803

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
CO (cont.)											
Oil		25.2%	1069.5	0.0458	0.0092	4.2675	1.3491	0.4059	0.1077	0.0183	0.0624
CT	79.93%	24.0%	1123.9	0.0481	0.0097	2.1368	1.4085	0.4151	0.0997	0.0028	0.0223
ICE	20.07%	31.6%	853.0	0.0365	0.0073	12.7542	1.1125	0.3692	0.1397	0.0800	0.2221
Renewable											
SUN	0.08%										
WAT	53.91%										
WH	1.42%										
WND	44.59%										
CT											
Biomass		21.9%	1279.5	0.5522	0.0736	6.2365	17.2804	2.9823	2.1121	0.1345	4.7464
Boiler	100.00%	21.9%	1279.5	0.5522	0.0736	6.2365	17.2804	2.9823	2.1121	0.1345	4.7464
Coal		31.8%	1033.4	0.0423	0.0206	1.0040	2.2255	0.3269	0.1144	0.0151	0.1258
Boiler	100.00%	31.8%	1033.4	0.0423	0.0206	1.0040	2.2255	0.3269	0.1144	0.0151	0.1258
NG		50.9%	399.5	0.0078	0.0008	0.0387	0.0020	0.0021	0.0021	0.0021	0.0441
Boiler	0.15%	33.1%	0.0	0.0000	0.0000	1.1815	0.0000	0.0751	0.0751	0.0544	0.8305
CC	96.66%	51.6%	395.4	0.0077	0.0008	0.0349	0.0020	0.0008	0.0008	0.0017	0.0280
CT	3.19%	35.6%	543.2	0.0106	0.0011	0.0985	0.0029	0.0369	0.0369	0.0132	0.4955
Nuclear											
Oil		28.7%	898.2	0.0373	0.0073	1.0111	1.2739	0.0642	0.0612	0.0289	0.1892
Boiler	98.46%	28.7%	895.3	0.0372	0.0073	1.0019	1.2892	0.0586	0.0583	0.0292	0.1918
CT	1.48%	24.2%	1093.5	0.0477	0.0096	1.3993	0.2991	0.4266	0.2529	0.0128	0.0225
ICE	0.06%	33.4%	807.4	0.0346	0.0069	6.7054	0.2031	0.2983	0.0716	0.0020	0.0160
Renewable											
WAT	100.00%										

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
DC											
Oil		21.3%	1261.8	0.0542	0.0109	1.9254	4.5107	0.2147	0.0920	0.0317	0.2094
Boiler	79.14%	22.8%	1179.3	0.0508	0.0102	1.7915	4.8160	0.1179	0.0795	0.0390	0.2564
CT	20.86%	17.1%	1574.6	0.0674	0.0135	2.4336	3.3525	0.5816	0.1396	0.0039	0.0313
DE											
Coal		33.3%	989.1	0.0122	0.0166	1.5597	5.2623	0.7987	0.3835	0.0125	0.1039
Boiler	100.00%	33.3%	989.1	0.0122	0.0166	1.5597	5.2623	0.7987	0.3835	0.0125	0.1039
NG		46.4%	420.3	0.0083	0.0008	0.1937	0.0080	0.0083	0.0083	0.0153	0.0973
Boiler	1.84%	34.6%	0.0	0.0000	0.0000	1.1303	0.0000	0.0761	0.0761	0.0551	0.8409
CC	94.25%	47.3%	429.2	0.0085	0.0008	0.1675	0.0081	0.0009	0.0009	0.0018	0.0305
CT	2.87%	37.4%	550.0	0.0107	0.0011	0.0907	0.0100	0.0303	0.0303	0.0096	0.3762
ICE	1.03%	32.7%	0.0	0.0000	0.0000	1.1954	0.0000	0.5076	0.5076	1.1944	4.1084
Oil		31.3%	823.7	0.0369	0.0074	1.6615	4.3285	0.2785	0.2037	0.0248	0.1634
Boiler	95.97%	32.6%	786.5	0.0354	0.0071	1.6203	4.5014	0.2637	0.2059	0.0257	0.1689
CT	4.03%	15.8%	1709.1	0.0732	0.0147	2.6416	0.2127	0.6313	0.1515	0.0042	0.0339
FL											
Biomass		18.2%	1459.2	0.6613	0.0881	7.2660	19.8987	3.5280	2.5867	0.1617	5.7078
Boiler	100.00%	18.2%	1459.2	0.6613	0.0881	7.2660	19.8987	3.5280	2.5867	0.1617	5.7078
Coal		33.8%	964.5	0.0112	0.0157	1.5870	2.0949	0.3287	0.1959	0.0112	0.0995
Boiler	100.00%	33.8%	964.5	0.0112	0.0157	1.5870	2.0949	0.3287	0.1959	0.0112	0.0995
NG		47.6%	444.7	0.0100	0.0012	0.2353	0.2626	0.0031	0.0031	0.0028	0.0495
Boiler	0.57%	29.8%	688.3	0.0186	0.0028	1.3251	1.6759	0.0435	0.0435	0.0315	0.4809
CC	94.09%	49.0%	432.6	0.0097	0.0012	0.2112	0.2524	0.0010	0.0010	0.0018	0.0248
CT	5.16%	32.6%	650.1	0.0139	0.0016	0.4900	0.3024	0.0348	0.0348	0.0111	0.4318
ICE	0.19%	36.0%	158.8	0.0036	0.0004	2.0674	0.0142	0.0740	0.0740	0.1741	0.5988

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
FL (cont.)											
Nuclear											
Oil		32.3%	810.0	0.0303	0.0058	1.8766	4.6921	0.1838	0.1468	0.0258	0.1693
Boiler	98.86%	32.3%	808.1	0.0301	0.0058	1.8445	4.7224	0.1825	0.1475	0.0259	0.1706
CT	0.84%	26.3%	1026.5	0.0439	0.0088	1.9517	0.5748	0.3792	0.0910	0.0025	0.0204
ICE	0.30%	32.8%	834.0	0.0353	0.0071	12.3126	6.1956	0.0770	0.0530	0.0530	0.1410
Renewable											
WAT	10.85%										
WH	89.15%										
GA											
Coal		35.6%	942.0	0.0107	0.0160	1.0700	6.3986	0.2155	0.1850	0.0123	0.1024
Boiler	100.00%	35.6%	942.0	0.0107	0.0160	1.0700	6.3986	0.2155	0.1850	0.0123	0.1024
NG		48.0%	425.2	0.0083	0.0008	0.0768	0.0023	0.0048	0.0048	0.0029	0.0755
Boiler	1.06%	35.3%	525.8	0.0103	0.0010	0.6295	0.0027	0.0375	0.0375	0.0271	0.4146
CC	88.40%	51.2%	398.8	0.0078	0.0008	0.0434	0.0020	0.0008	0.0008	0.0017	0.0282
CT	10.54%	32.1%	636.9	0.0125	0.0012	0.3013	0.0042	0.0353	0.0353	0.0112	0.4382
Nuclear											
Oil		18.4%	1492.2	0.0628	0.0126	4.7588	11.8946	0.7979	0.5195	0.0332	0.2198
Boiler	66.77%	18.0%	1537.3	0.0641	0.0129	3.1721	17.4138	0.9499	0.7172	0.0465	0.3061
CT	15.97%	13.0%	2082.2	0.0891	0.0179	4.0666	1.1878	0.7691	0.1846	0.0051	0.0413
ICE	17.25%	35.0%	771.8	0.0330	0.0066	11.5401	0.4458	0.2361	0.0645	0.0074	0.0510
Renewable											
WAT	100.00%										

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
HI											
Biomass		27.8%	971.4	0.4319	0.0576	5.0604	13.0940	2.3436	1.6598	0.1057	3.7299
Boiler	100.00%	27.8%	971.4	0.4319	0.0576	5.0604	13.0940	2.3436	1.6598	0.1057	3.7299
Oil		33.9%	804.6	0.0341	0.0068	2.1589	1.9393	0.2224	0.1476	0.0242	0.1594
Boiler	77.97%	33.0%	830.1	0.0350	0.0070	1.5700	2.3432	0.2215	0.1750	0.0254	0.1671
CT	17.88%	38.4%	699.4	0.0301	0.0060	3.1956	0.4791	0.2602	0.0503	0.0186	0.1247
ICE	4.16%	34.7%	778.3	0.0333	0.0067	8.7450	0.6427	0.0764	0.0515	0.0254	0.1662
Renewable											
GEO	41.54%										
WAT	15.43%										
WND	43.04%										
IA											
Coal		32.7%	1039.4	0.0118	0.0177	1.2493	3.2466	0.0407	0.0287	0.0144	0.3995
Boiler	100.00%	32.7%	1039.4	0.0118	0.0177	1.2493	3.2466	0.0407	0.0287	0.0144	0.3995
NG		47.9%	417.0	0.0082	0.0008	0.2086	0.0043	0.0102	0.0102	0.0201	0.1110
Boiler	0.06%	26.4%	873.8	0.0265	0.0044	11.4634	0.4881	0.0454	0.0454	0.0329	0.5022
CC	93.62%	49.9%	409.1	0.0080	0.0008	0.0445	0.0023	0.0008	0.0008	0.0017	0.0289
CT	4.79%	30.5%	665.9	0.0133	0.0014	1.0540	0.0226	0.0372	0.0372	0.0118	0.4619
ICE	1.53%	29.2%	109.5	0.0031	0.0005	7.1557	0.0536	0.4964	0.4964	1.1681	4.0178
Nuclear											
Oil		23.7%	1149.9	0.0488	0.0098	3.5330	1.9573	0.4032	0.0974	0.0035	0.0237
CT	88.41%	23.0%	1182.6	0.0502	0.0101	2.2330	2.0660	0.4330	0.1041	0.0029	0.0233
ICE	11.59%	29.9%	900.4	0.0384	0.0077	13.4472	1.1284	0.1756	0.0467	0.0080	0.0273
Renewable											
WAT	25.87%										
WND	74.13%										

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
ID											
NG		50.0%	410.0	0.0080	0.0008	0.0950	0.0021	0.0057	0.0057	0.0029	0.0855
CC	84.14%	54.2%	376.6	0.0074	0.0007	0.0467	0.0019	0.0008	0.0008	0.0016	0.0266
CT	15.86%	35.4%	587.0	0.0113	0.0011	0.3514	0.0029	0.0321	0.0321	0.0102	0.3982
Oil		34.7%	778.2	0.0333	0.0067	11.6363	0.9688	0.0104	0.0104	0.0121	0.0320
ICE	100.00%	34.7%	778.2	0.0333	0.0067	11.6363	0.9688	0.0104	0.0104	0.0121	0.0320
Renewable											
WAT	98.13%										
WND	1.87%										
IL											
Coal		33.0%	1034.5	0.0118	0.0176	1.1526	2.7005	0.0711	0.0401	0.0150	0.1216
Boiler	100.00%	33.0%	1034.5	0.0118	0.0176	1.1526	2.7005	0.0711	0.0401	0.0150	0.1216
NG		39.7%	454.3	0.0089	0.0009	0.3169	0.0025	0.0419	0.0419	0.0611	0.4200
Boiler	1.52%	31.4%	29.2	0.0006	0.0001	2.4441	0.0018	0.0781	0.0781	0.0565	0.8635
CC	53.05%	47.4%	411.9	0.0081	0.0008	0.1089	0.0021	0.0048	0.0048	0.0038	0.0300
CT	41.18%	34.0%	569.0	0.0112	0.0011	0.3045	0.0030	0.0382	0.0382	0.0135	0.5093
ICE	4.24%	30.3%	24.7	0.0005	0.0001	2.2748	0.0024	0.5281	0.5281	1.2425	4.2739
Nuclear											
Oil		28.9%	932.2	0.0398	0.0080	11.5834	0.6986	0.1117	0.0335	0.0109	0.0324
CT	15.32%	23.9%	1128.9	0.0483	0.0097	1.7448	0.8485	0.4170	0.1001	0.0028	0.0224
ICE	84.68%	30.0%	896.6	0.0383	0.0077	13.3631	0.6715	0.0565	0.0214	0.0124	0.0343
Renewable											
WAT	12.19%										
WND	87.81%										

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
IN											
Coal		35.3%	953.4	0.0108	0.0162	1.4441	4.9113	0.1537	0.1144	0.0123	0.1042
Boiler	100.00%	35.3%	953.4	0.0108	0.0162	1.4441	4.9113	0.1537	0.1144	0.0123	0.1042
NG		36.6%	496.5	0.0098	0.0010	0.4455	0.0218	0.0289	0.0289	0.0418	0.2980
Boiler	6.14%	11.7%	1064.9	0.0213	0.0021	3.8156	0.3158	0.0970	0.0970	0.0495	1.0369
CC	70.00%	48.1%	423.9	0.0083	0.0008	0.0733	0.0021	0.0009	0.0009	0.0018	0.0300
CT	20.84%	31.7%	644.2	0.0126	0.0013	0.4009	0.0042	0.0358	0.0358	0.0114	0.4447
ICE	3.01%	31.0%	3.4	0.0001	0.0000	2.5320	0.0007	0.4953	0.4953	1.1654	4.0086
Oil		34.0%	794.6	0.0340	0.0068	11.8820	0.9893	0.0791	0.0533	0.0261	0.1718
ICE	100.00%	34.0%	794.6	0.0340	0.0068	11.8820	0.9893	0.0791	0.0533	0.0261	0.1718
Renewable											
WAT	55.33%										
WH	44.67%										
KS											
Coal		33.0%	1032.5	0.0117	0.0175	1.6656	2.8674	0.0436	0.0347	0.0147	0.1244
Boiler	100.00%	33.0%	1032.5	0.0117	0.0175	1.6656	2.8674	0.0436	0.0347	0.0147	0.1244
NG		30.6%	669.0	0.0132	0.0013	1.4620	0.0076	0.0435	0.0435	0.0383	0.4724
Boiler	85.34%	31.3%	653.3	0.0128	0.0013	1.3585	0.0039	0.0383	0.0383	0.0277	0.4229
CT	12.71%	26.7%	760.4	0.0150	0.0015	1.0064	0.0099	0.0424	0.0424	0.0135	0.5271
ICE	1.95%	27.5%	759.8	0.0176	0.0022	8.9752	0.1532	0.2824	0.2824	0.6645	2.2856
Nuclear											
Oil		33.5%	803.2	0.0342	0.0068	11.9819	0.9629	0.1359	0.0373	0.0080	0.0257
ICE	100.00%	33.5%	803.2	0.0342	0.0068	11.9819	0.9629	0.1359	0.0373	0.0080	0.0257
Renewable											
WAT	0.90%										
WND	99.10%										

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
KY											
Coal		34.0%	974.7	0.0111	0.0165	1.6806	3.6556	0.1943	0.1524	0.0139	0.1019
Boiler	100.00%	34.0%	974.7	0.0111	0.0165	1.6806	3.6556	0.1943	0.1524	0.0139	0.1019
NG		28.6%	632.7	0.0123	0.0012	0.5963	0.0067	0.0923	0.0923	0.1403	0.9293
Boiler	2.28%	30.6%	0.0	0.0000	0.0000	2.5581	0.0000	0.1396	0.1396	0.0730	2.4722
CT	87.16%	28.2%	725.9	0.0142	0.0014	0.3157	0.0077	0.0401	0.0401	0.0128	0.4985
ICE	10.56%	31.4%	0.0	0.0000	0.0000	2.4889	0.0000	0.5131	0.5131	1.2072	4.1525
Oil		27.9%	966.5	0.0414	0.0083	14.4518	2.2808	0.0130	0.0130	0.0150	0.0397
ICE	100.00%	27.9%	966.5	0.0414	0.0083	14.4518	2.2808	0.0130	0.0130	0.0150	0.0397
Renewable											
WAT	100.00%										
LA											
Coal		34.4%	997.5	0.0113	0.0165	1.1278	2.7651	0.0752	0.0479	0.0160	0.1343
Boiler	100.00%	34.4%	997.5	0.0113	0.0165	1.1278	2.7651	0.0752	0.0479	0.0160	0.1343
NG		34.5%	593.9	0.0120	0.0013	1.0035	0.0926	0.0252	0.0252	0.0181	0.2942
Boiler	55.82%	28.9%	712.7	0.0146	0.0016	1.6135	0.1630	0.0407	0.0407	0.0300	0.4585
CC	38.91%	50.5%	403.8	0.0079	0.0008	0.0870	0.0020	0.0008	0.0008	0.0017	0.0286
CT	5.27%	27.3%	739.3	0.0147	0.0015	1.3071	0.0151	0.0415	0.0415	0.0132	0.5157
ICE	0.00%	32.8%	728.4	0.0239	0.0042	9.8213	0.5386	0.2371	0.2371	0.5578	1.9186
Nuclear											
Oil		31.1%	868.4	0.0372	0.0075	12.9849	1.1202	0.0116	0.0116	0.0135	0.0357
ICE	100.00%	31.1%	868.4	0.0372	0.0075	12.9849	1.1202	0.0116	0.0116	0.0135	0.0357
Renewable											
WAT	97.68%										
WH	2.32%										

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
MA											
Biomass		22.5%	1265.2	0.5357	0.0714	6.2911	17.1006	2.8814	2.0775	0.1310	4.6247
Boiler	100.00%	22.5%	1265.2	0.5357	0.0714	6.2911	17.1006	2.8814	2.0775	0.1310	4.6247
Coal		37.5%	883.9	0.0105	0.0149	0.5623	3.3132	0.0890	0.0793	0.0111	0.0924
Boiler	100.00%	37.5%	883.9	0.0105	0.0149	0.5623	3.3132	0.0890	0.0793	0.0111	0.0924
NG		50.2%	406.7	0.0079	0.0008	0.0692	0.0866	0.0036	0.0036	0.0068	0.0546
Boiler	1.31%	32.1%	645.0	0.0150	0.0019	0.8774	0.4158	0.0385	0.0385	0.0278	0.4251
CC	98.15%	50.8%	405.6	0.0079	0.0008	0.0532	0.0826	0.0008	0.0008	0.0017	0.0284
CT	0.22%	31.9%	41.0	0.0013	0.0002	0.3644	0.0135	0.1281	0.1281	0.0666	2.2577
ICE	0.32%	27.0%	3.8	0.0001	0.0000	1.4596	0.0012	0.6256	0.6256	1.4719	5.0630
Nuclear											
Oil		32.6%	811.8	0.0347	0.0069	0.4477	2.6271	0.0688	0.0635	0.0257	0.1687
Boiler	99.71%	32.6%	810.4	0.0346	0.0069	0.4337	2.6328	0.0679	0.0632	0.0257	0.1691
CT	0.11%	13.1%	2050.2	0.0884	0.0177	3.2072	0.9765	0.7563	0.4139	0.0235	0.0414
ICE	0.18%	34.1%	791.2	0.0339	0.0068	6.5703	0.4925	0.1138	0.0324	0.0085	0.0264
MD											
Biomass		21.6%	1497.2	0.5571	0.0742	7.0676	20.1164	3.0275	2.1441	0.1365	4.8183
Boiler	100.00%	21.6%	1497.2	0.5571	0.0742	7.0676	20.1164	3.0275	2.1441	0.1365	4.8183
Coal		35.8%	911.2	0.0112	0.0151	1.5333	8.3590	0.6151	0.2957	0.0120	0.0944
Boiler	100.00%	35.8%	911.2	0.0112	0.0151	1.5333	8.3590	0.6151	0.2957	0.0120	0.0944
NG		29.2%	638.2	0.0131	0.0014	0.6636	0.0332	0.0840	0.0840	0.1255	0.8340
CT	93.96%	30.0%	679.2	0.0139	0.0015	0.5870	0.0353	0.0378	0.0378	0.0120	0.4694
ICE	6.04%	21.1%	0.0	0.0000	0.0000	1.8552	0.0000	0.8035	0.8035	1.8907	6.5033

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
MD (cont.)											
Nuclear											
Oil		25.8%	1043.4	0.0447	0.0090	3.8090	5.9970	0.3179	0.1693	0.0184	0.1111
Boiler	39.41%	22.7%	1184.2	0.0509	0.0102	2.0808	12.8241	0.4327	0.3351	0.0369	0.2430
CT	18.93%	21.5%	1256.3	0.0538	0.0108	1.9417	1.4064	0.4640	0.1114	0.0031	0.0249
ICE	41.66%	33.3%	813.5	0.0347	0.0070	6.2928	1.6238	0.1427	0.0387	0.0078	0.0254
Renewable											
WAT	100.00%										
ME											
Biomass		20.6%	234.2	0.5843	0.0779	2.5758	3.2744	2.8262	2.5159	0.1428	5.0406
Boiler	100.00%	20.6%	234.2	0.5843	0.0779	2.5758	3.2744	2.8262	2.5159	0.1428	5.0406
NG		52.6%	387.7	0.0076	0.0008	0.0419	0.0020	0.0008	0.0008	0.0016	0.0272
CC	100.00%	52.6%	387.7	0.0076	0.0008	0.0419	0.0020	0.0008	0.0008	0.0016	0.0272
Oil		33.4%	855.9	0.0346	0.0069	0.7455	3.9365	0.0670	0.0654	0.0249	0.1636
Boiler	99.18%	33.5%	854.2	0.0345	0.0069	0.7200	3.9505	0.0653	0.0653	0.0250	0.1647
CT	0.48%	21.6%	1251.4	0.0536	0.0107	1.9341	2.6554	0.4622	0.1110	0.0031	0.0248
ICE	0.34%	34.7%	776.7	0.0332	0.0067	6.4498	1.6579	0.0104	0.0104	0.0121	0.0319
Renewable											
WAT	97.22%										
WND	2.78%										
MI											
Biomass		26.0%	53.4	0.4638	0.0618	2.0917	1.3440	2.1736	2.0406	0.1130	3.9882
Boiler	100.00%	26.0%	53.4	0.4638	0.0618	2.0917	1.3440	2.1736	2.0406	0.1130	3.9882
Coal		34.5%	983.5	0.0113	0.0167	1.3722	4.4021	0.0732	0.0383	0.0142	0.1182
Boiler	100.00%	34.5%	983.5	0.0113	0.0167	1.3722	4.4021	0.0732	0.0383	0.0142	0.1182

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
MI (cont.)											
NG		37.6%	520.8	0.0094	0.0009	0.4227	0.1302	0.0509	0.0509	0.0893	0.4392
Boiler	14.21%	25.1%	1080.9	0.0154	0.0015	0.9379	0.8944	0.0502	0.0502	0.0363	0.5548
CC	64.03%	45.7%	416.4	0.0082	0.0008	0.1197	0.0021	0.0072	0.0072	0.0051	0.0306
CT	15.64%	32.1%	635.3	0.0125	0.0012	0.3263	0.0054	0.0353	0.0353	0.0112	0.4386
ICE	6.12%	30.5%	19.1	0.0005	0.0001	2.6439	0.0138	0.5496	0.5496	1.2931	4.4479
Nuclear											
Oil		23.0%	1174.2	0.0503	0.0101	10.1148	1.4783	0.2579	0.0669	0.0094	0.0338
CT	39.78%	19.3%	1401.3	0.0600	0.0120	2.2429	1.7555	0.5176	0.1243	0.0035	0.0278
ICE	60.22%	26.4%	1024.2	0.0438	0.0088	15.3148	1.2951	0.0864	0.0291	0.0133	0.0378
Renewable											
WAT	97.83%										
WND	2.17%										
MN											
Biomass		19.5%	1048.4	0.6146	0.0819	5.5020	14.2236	3.3537	2.3752	0.1512	5.3375
Boiler	100.00%	19.5%	1048.4	0.6146	0.0819	5.5020	14.2236	3.3537	2.3752	0.1512	5.3375
Coal		30.0%	1136.8	0.0129	0.0193	2.7691	3.4729	0.0973	0.0372	0.0164	0.1363
Boiler	100.00%	30.0%	1136.8	0.0129	0.0193	2.7691	3.4729	0.0973	0.0372	0.0164	0.1363
NG		37.7%	530.7	0.0114	0.0013	0.4623	0.0104	0.0249	0.0249	0.0143	0.2598
Boiler	2.16%	29.1%	694.5	0.0141	0.0015	5.0856	0.0310	0.0633	0.0633	0.0458	0.6994
CC	50.07%	47.7%	396.6	0.0077	0.0008	0.1333	0.0096	0.0085	0.0085	0.0057	0.0293
CT	47.38%	31.4%	668.1	0.0153	0.0019	0.5374	0.0103	0.0361	0.0361	0.0115	0.4490
ICE	0.40%	27.4%	163.4	0.0048	0.0008	7.8645	0.0072	0.5342	0.5342	1.2569	4.3233
Nuclear											
Oil		25.7%	1050.5	0.0450	0.0090	7.8479	0.0655	0.2727	0.0715	0.0084	0.0417
CT	43.71%	19.3%	1398.0	0.0598	0.0120	2.9939	0.0871	0.5164	0.1240	0.0034	0.0278
ICE	56.29%	34.6%	780.7	0.0334	0.0067	11.6172	0.0488	0.0835	0.0308	0.0123	0.0525

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
MN (cont.)											
Renewable											
WAT	18.35%										
WND	81.65%										
MO											
Coal		35.8%	950.6	0.0108	0.0161	1.2901	3.1571	0.0818	0.0409	0.0137	0.1159
Boiler	100.00%	35.8%	950.6	0.0108	0.0161	1.2901	3.1571	0.0818	0.0409	0.0137	0.1159
NG		45.6%	444.9	0.0087	0.0009	0.1437	0.0038	0.0074	0.0074	0.0052	0.1042
Boiler	0.51%	44.4%	0.0	0.0000	0.0000	0.2155	0.0000	0.0546	0.0546	0.0395	0.6034
CC	83.41%	50.1%	407.3	0.0080	0.0008	0.0536	0.0021	0.0008	0.0008	0.0017	0.0288
CT	15.74%	31.1%	655.9	0.0130	0.0013	0.4788	0.0123	0.0364	0.0364	0.0116	0.4521
ICE	0.34%	36.1%	564.3	0.0119	0.0013	6.6297	0.0504	0.2155	0.2155	0.5071	1.7441
Nuclear											
Oil		15.0%	1793.4	0.0768	0.0154	20.8556	2.2615	0.6299	0.1777	0.0445	0.1390
CT	61.48%	11.2%	2417.6	0.1035	0.0208	26.4538	3.0512	0.8930	0.2144	0.0060	0.0480
ICE	38.52%	33.8%	797.3	0.0341	0.0068	11.9220	1.0014	0.2100	0.1193	0.1061	0.2842
Renewable											
WAT	100.00%										
MS											
Coal		33.7%	960.0	0.0113	0.0152	1.7260	2.9583	0.2278	0.1871	0.0142	0.1191
Boiler	100.00%	33.7%	960.0	0.0113	0.0152	1.7260	2.9583	0.2278	0.1871	0.0142	0.1191
NG		43.4%	476.0	0.0106	0.0013	0.5531	0.1406	0.0106	0.0106	0.0082	0.1324
Boiler	24.41%	31.2%	675.8	0.0184	0.0027	2.0529	0.5695	0.0384	0.0384	0.0278	0.4244
CC	74.09%	50.4%	405.0	0.0079	0.0008	0.0626	0.0020	0.0008	0.0008	0.0017	0.0287
CT	1.51%	28.1%	728.2	0.0159	0.0018	0.3815	0.0078	0.0403	0.0403	0.0128	0.5011
Nuclear											

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
MT											
Coal		30.3%	1126.7	0.0128	0.0191	2.1002	1.4369	0.8217	0.2994	0.0166	0.1326
Boiler	100.00%	30.3%	1126.7	0.0128	0.0191	2.1002	1.4369	0.8217	0.2994	0.0166	0.1326
NG		37.5%	536.4	0.0108	0.0011	5.8776	0.0242	0.1962	0.1962	0.4579	1.5955
CT	3.16%	19.7%	1044.2	0.0229	0.0027	2.4228	0.3156	0.0575	0.0575	0.0183	0.7140
ICE	96.84%	38.6%	519.8	0.0104	0.0010	5.9902	0.0147	0.2007	0.2007	0.4722	1.6242
Renewable											
WAT	94.97%										
WND	5.03%										
NC											
Coal		37.6%	882.5	0.0101	0.0150	0.6795	4.3650	0.2764	0.2339	0.0110	0.0920
Boiler	100.00%	37.6%	882.5	0.0101	0.0150	0.6795	4.3650	0.2764	0.2339	0.0110	0.0920
NG		38.8%	522.7	0.0105	0.0011	0.3040	0.0075	0.0293	0.0293	0.0097	0.3707
Boiler	0.16%	38.8%	109.7	0.0047	0.0009	3.3477	0.0208	0.0814	0.0814	0.0589	0.8999
CC	2.24%	29.6%	679.6	0.0137	0.0014	0.5480	0.0208	0.0014	0.0014	0.0029	0.0488
CT	97.60%	39.1%	519.8	0.0104	0.0011	0.2935	0.0072	0.0298	0.0298	0.0097	0.3772
Nuclear											
Oil		22.1%	1222.0	0.0523	0.0105	14.2174	0.2269	0.3003	0.0804	0.0109	0.0537
CT	16.51%	14.7%	1831.6	0.0784	0.0157	2.8310	0.3391	0.6766	0.1624	0.0045	0.0364
ICE	83.49%	24.5%	1101.4	0.0472	0.0095	16.4697	0.2047	0.2259	0.0642	0.0122	0.0571
Renewable											
WAT	100.00%										
ND											
Coal		34.0%	1081.6	0.0116	0.0174	2.1884	4.2500	0.2448	0.2442	0.0228	0.0920
Boiler	100.00%	34.0%	1081.6	0.0116	0.0174	2.1884	4.2500	0.2448	0.2442	0.0228	0.0920

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
ND (cont.)											
Oil		18.4%	1465.4	0.0627	0.0126	3.7865	1.7777	0.5359	0.1288	0.0038	0.0294
CT	91.01%	17.7%	1525.9	0.0653	0.0131	2.9012	1.8474	0.5636	0.1353	0.0038	0.0303
ICE	8.99%	31.7%	852.6	0.0365	0.0073	12.7485	1.0717	0.2553	0.0630	0.0043	0.0205
Renewable											
WAT	67.77%										
WND	32.23%										
NE											
Coal		32.5%	1051.2	0.0119	0.0179	1.8677	3.1770	0.0258	0.0194	0.0152	0.1265
Boiler	100.00%	32.5%	1051.2	0.0119	0.0179	1.8677	3.1770	0.0258	0.0194	0.0152	0.1265
NG		35.7%	548.7	0.0107	0.0011	0.6653	0.0729	0.0409	0.0409	0.0686	0.4024
Boiler	10.17%	29.0%	743.3	0.0138	0.0014	1.4036	0.6607	0.0413	0.0413	0.0299	0.4566
CC	55.46%	40.3%	507.4	0.0099	0.0010	0.0687	0.0036	0.0010	0.0010	0.0021	0.0358
CT	29.16%	32.7%	626.5	0.0122	0.0012	0.3772	0.0079	0.0346	0.0346	0.0110	0.4301
ICE	5.21%	28.9%	173.0	0.0038	0.0005	7.1904	0.0261	0.4997	0.4997	1.1757	4.0441
Nuclear											
Oil		26.1%	1031.7	0.0441	0.0088	8.8264	1.2866	0.1952	0.0522	0.0094	0.0317
CT	31.67%	16.9%	1593.0	0.0682	0.0137	3.0288	1.9625	0.5884	0.1412	0.0039	0.0316
ICE	68.33%	34.9%	771.6	0.0329	0.0066	11.5139	0.9733	0.0130	0.0109	0.0120	0.0317
Renewable											
WAT	79.13%										
WND	20.87%										
NH											
Biomass		24.4%	287.0	0.4960	0.0661	2.9846	4.0552	2.4007	2.1212	0.1208	4.2650
Boiler	100.00%	24.4%	287.0	0.4960	0.0661	2.9846	4.0552	2.4007	2.1212	0.1208	4.2650
Coal		32.4%	1028.3	0.0117	0.0175	0.8884	10.0655	0.0386	0.0042	0.0235	0.1069
Boiler	100.00%	32.4%	1028.3	0.0117	0.0175	0.8884	10.0655	0.0386	0.0042	0.0235	0.1069

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
NH (cont.)											
NG		51.1%	390.2	0.0076	0.0008	0.0405	0.0031	0.0042	0.0042	0.0062	0.9731
CC	98.64%	51.8%	395.6	0.0077	0.0008	0.0296	0.0032	0.0008	0.0008	0.0016	0.0279
CT	1.13%	24.9%	0.0	0.0000	0.0000	0.7392	0.0000	0.1715	0.1715	0.0897	3.0370
ICE	0.23%	30.2%	0.0	0.0000	0.0000	1.2963	0.0000	0.6574	0.6574	1.5469	5.3208
Nuclear											
Oil		26.2%	1009.9	0.0442	0.0089	1.2228	6.6472	0.0667	0.0648	0.0319	0.2100
Boiler	99.75%	26.2%	1008.4	0.0441	0.0088	1.2196	6.6618	0.0653	0.0646	0.0320	0.2104
CT	0.25%	16.7%	1592.4	0.0691	0.0139	2.4938	0.9380	0.6031	0.1450	0.0019	0.0324
Renewable											
WAT	100.00%										
NJ											
Biomass		20.2%	1666.0	0.5980	0.0797	7.8853	22.4732	3.2300	2.2876	0.1457	5.1406
Boiler	100.00%	20.2%	1666.0	0.5980	0.0797	7.8853	22.4732	3.2300	2.2876	0.1457	5.1406
Coal		32.0%	1042.3	0.0122	0.0176	1.3711	4.4643	0.1487	0.1517	0.0155	0.1141
Boiler	100.00%	32.0%	1042.3	0.0122	0.0176	1.3711	4.4643	0.1487	0.1517	0.0155	0.1141
NG		45.4%	448.4	0.0088	0.0009	0.1216	0.0121	0.0094	0.0094	0.0150	0.1117
Boiler	1.30%	23.8%	821.2	0.0204	0.0028	0.8577	0.4329	0.0561	0.0561	0.0406	0.6195
CC	89.58%	48.1%	428.7	0.0083	0.0008	0.0743	0.0034	0.0009	0.0009	0.0018	0.0300
CT	8.43%	33.4%	631.2	0.0130	0.0014	0.4586	0.0405	0.0339	0.0339	0.0108	0.4214
ICE	0.70%	21.0%	72.3	0.0014	0.0001	0.7601	0.0021	0.7285	0.7285	1.7141	5.8961
Nuclear											
Oil		21.4%	1254.6	0.0539	0.0108	2.0617	0.6033	0.4743	0.2559	0.0137	0.0252
Boiler	0.37%	21.8%	1226.6	0.0531	0.0106	1.9156	0.5668	0.4868	0.4868	0.0304	0.0251
CT	99.63%	21.4%	1254.7	0.0539	0.0108	2.0622	0.6034	0.4742	0.2550	0.0137	0.0252
Renewable											
WAT	100.0%										

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
NM											
Coal		36.5%	935.9	0.0106	0.0159	2.2477	0.8737	0.0084	0.0041	0.0135	0.1126
Boiler	100.00%	36.5%	935.9	0.0106	0.0159	2.2477	0.8737	0.0084	0.0041	0.0135	0.1126
NG		40.1%	508.7	0.0100	0.0010	0.4474	0.0030	0.0176	0.0176	0.0131	0.2053
Boiler	46.09%	33.2%	614.8	0.0121	0.0012	0.8830	0.0040	0.0361	0.0361	0.0262	0.3994
CC	52.43%	49.4%	413.4	0.0081	0.0008	0.0625	0.0021	0.0008	0.0008	0.0017	0.0292
CT	1.48%	35.1%	581.7	0.0114	0.0011	0.5181	0.0032	0.0323	0.0323	0.0103	0.4014
Renewable											
WAT	16.13%										
WND	83.87%										
NV											
Coal		31.0%	1073.3	0.0122	0.0183	1.8151	1.0836	0.1064	0.1001	0.0134	0.1118
Boiler	100.00%	31.0%	1073.3	0.0122	0.0183	1.8151	1.0836	0.1064	0.1001	0.0134	0.1118
NG		46.9%	434.2	0.0085	0.0009	0.3483	0.0036	0.0065	0.0065	0.0117	0.0800
Boiler	4.62%	35.7%	562.9	0.0112	0.0011	1.8379	0.0054	0.0335	0.0335	0.0243	0.3705
CC	92.33%	48.0%	424.2	0.0083	0.0008	0.1563	0.0033	0.0009	0.0009	0.0018	0.0301
CT	1.00%	29.8%	683.8	0.0134	0.0013	0.7111	0.0057	0.0381	0.0381	0.0121	0.4728
ICE	2.05%	42.5%	472.3	0.0094	0.0009	5.4713	0.0139	0.1829	0.1829	0.4304	1.4805
Renewable											
SUN	0.08%										
GEO	38.44%										
WAT	61.47%										
NY											
Biomass		22.6%	1275.0	0.5340	0.0711	6.3128	17.2303	2.8332	2.0834	0.1301	4.5901
Boiler	100.00%	22.6%	1275.0	0.5340	0.0711	6.3128	17.2303	2.8332	2.0834	0.1301	4.5901
Coal		35.0%	958.7	0.0110	0.0163	1.0593	3.5782	0.1683	0.1281	0.0125	0.1433
Boiler	100.00%	35.0%	958.7	0.0110	0.0163	1.0593	3.5782	0.1683	0.1281	0.0125	0.1433

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
NY (cont.)											
NG		39.8%	528.6	0.0113	0.0013	0.3206	0.1772	0.0207	0.0207	0.0238	0.2489
Boiler	41.71%	33.7%	650.9	0.0149	0.0019	0.6321	0.4182	0.0309	0.0309	0.0258	0.3934
CC	50.00%	49.0%	420.5	0.0082	0.0008	0.0327	0.0026	0.0008	0.0008	0.0017	0.0279
CT	7.25%	32.5%	639.5	0.0137	0.0016	0.3746	0.0187	0.0349	0.0349	0.0111	0.4335
ICE	1.03%	32.8%	39.5	0.0012	0.0002	1.3094	0.0047	0.4731	0.4731	1.1132	3.8290
Nuclear											
Oil		34.7%	697.9	0.0246	0.0045	0.8685	2.0566	0.0615	0.0513	0.0231	0.1519
Boiler	96.05%	35.0%	686.6	0.0239	0.0043	0.7889	2.1308	0.0494	0.0491	0.0239	0.1573
CT	3.90%	27.7%	973.8	0.0417	0.0084	2.7429	0.2553	0.3599	0.1075	0.0041	0.0194
ICE	0.05%	31.6%	854.5	0.0366	0.0073	7.0962	0.2149	0.0118	0.0116	0.0134	0.0357
Renewable											
WAT	96.70%										
WND	3.30%										
OH											
Coal		36.0%	928.8	0.0105	0.0158	1.6302	6.4398	0.3531	0.2025	0.0114	0.0970
Boiler	100.00%	36.0%	928.8	0.0105	0.0158	1.6302	6.4398	0.3531	0.2025	0.0114	0.0970
NG		40.9%	497.8	0.0099	0.0010	0.1521	0.0034	0.0104	0.0104	0.0047	0.1435
Boiler	0.29%	27.2%	0.0	0.0000	0.0000	2.8728	0.0000	0.0873	0.0873	0.0632	0.9654
CC	76.47%	47.8%	427.3	0.0084	0.0008	0.0851	0.0022	0.0009	0.0009	0.0018	0.0302
CT	23.21%	27.9%	735.9	0.0150	0.0016	0.3352	0.0076	0.0406	0.0406	0.0129	0.5045
ICE	0.03%	36.2%	575.7	0.0131	0.0016	3.4211	0.0466	0.2150	0.2150	0.5058	1.7399
Nuclear											
Oil		17.6%	1515.0	0.0640	0.0127	7.2056	0.6694	0.5582	0.1342	0.0040	0.0308
CT	54.53%	12.6%	2111.9	0.0888	0.0177	3.2477	0.9333	0.7906	0.1898	0.0053	0.0425
ICE	45.47%	33.8%	799.3	0.0342	0.0069	11.9515	0.3529	0.2795	0.0675	0.0026	0.0168

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
OH (cont.)											
Renewable											
WAT	96.53%										
WND	3.47%										
OK											
Coal		33.4%	1013.5	0.0116	0.0172	1.6136	2.4763	0.0553	0.0378	0.0147	0.1229
Boiler	100.00%	33.4%	1013.5	0.0116	0.0172	1.6136	2.4763	0.0553	0.0378	0.0147	0.1229
NG		42.0%	485.9	0.0095	0.0010	0.6345	0.0336	0.0081	0.0081	0.0100	0.1559
Boiler	33.35%	32.9%	622.5	0.0122	0.0012	1.3993	0.0943	0.0222	0.0222	0.0264	0.4029
CC	66.18%	49.0%	416.2	0.0082	0.0008	0.2512	0.0032	0.0008	0.0008	0.0017	0.0295
CT	0.47%	33.5%	608.1	0.0119	0.0012	0.2866	0.0048	0.0338	0.0338	0.0108	0.4200
Oil		23.8%	1136.2	0.0486	0.0098	16.9882	1.4246	0.1588	0.0456	0.0124	0.0381
ICE	100.00%	23.8%	1136.2	0.0486	0.0098	16.9882	1.4246	0.1588	0.0456	0.0124	0.0381
Renewable											
WAT	61.06%										
WND	38.94%										
OR											
Coal		34.0%	1002.6	0.0114	0.0171	2.2198	2.9240	0.0654	0.0341	0.0145	0.1206
Boiler	100.00%	34.0%	1002.6	0.0114	0.0171	2.2198	2.9240	0.0654	0.0341	0.0145	0.1206
NG		50.7%	399.6	0.0079	0.0008	0.1211	0.0037	0.0013	0.0013	0.0019	0.0337
Boiler	0.38%	37.6%	0.0	0.0000	0.0000	5.2006	0.0000	0.0687	0.0687	0.0497	0.7591
CC	98.92%	50.9%	399.9	0.0079	0.0008	0.1012	0.0037	0.0008	0.0008	0.0017	0.0284
CT	0.70%	36.0%	566.2	0.0111	0.0011	0.1562	0.0032	0.0315	0.0315	0.0100	0.3908
Renewable											
WAT	96.42%										
WND	3.58%										

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
PA											
Biomass		21.4%	1587.0	0.5613	0.0748	7.4879	21.3252	3.0468	2.1578	0.1374	4.8490
Boiler	100.00%	21.4%	1587.0	0.5613	0.0748	7.4879	21.3252	3.0468	2.1578	0.1374	4.8490
Coal		36.6%	906.6	0.0104	0.0153	1.3913	7.4888	0.1992	0.1672	0.0107	0.0838
Boiler	100.00%	36.6%	906.6	0.0104	0.0153	1.3913	7.4888	0.1992	0.1672	0.0107	0.0838
NG		48.0%	413.7	0.0081	0.0008	0.0691	0.0032	0.0086	0.0086	0.0162	0.1033
Boiler	0.30%	28.2%	0.0	0.0000	0.0000	1.1487	0.0000	0.0866	0.0866	0.0627	0.9573
CC	95.19%	49.3%	414.6	0.0081	0.0008	0.0436	0.0031	0.0008	0.0008	0.0017	0.0293
CT	3.47%	32.7%	519.0	0.0102	0.0010	0.3534	0.0031	0.0507	0.0507	0.0206	0.7448
ICE	1.04%	28.8%	98.2	0.0023	0.0003	1.1422	0.0143	0.5545	0.5545	1.3048	4.4881
Nuclear											
Oil		27.7%	1024.5	0.0417	0.0084	1.4178	1.9103	0.3625	0.1893	0.0170	0.1138
Boiler	58.78%	31.0%	956.6	0.0373	0.0075	1.1966	2.5659	0.3263	0.2523	0.0271	0.1780
CT	41.22%	24.1%	1121.4	0.0480	0.0096	1.7332	0.9752	0.4142	0.0994	0.0028	0.0223
Renewable											
WAT	76.30%										
WND	23.70%										
RI											
NG		47.8%	410.6	0.0081	0.0008	0.0915	0.0046	0.0126	0.0126	0.0295	0.1247
CC	97.77%	48.4%	419.9	0.0083	0.0008	0.0644	0.0047	0.0009	0.0009	0.0018	0.0298
ICE	2.23%	30.5%	0.0	0.0000	0.0000	1.2809	0.0000	0.5294	0.5294	1.2456	4.2845
Oil		31.5%	856.7	0.0367	0.0074	7.1147	1.0806	0.3165	0.0760	0.0021	0.0170
ICE	100.00%	31.5%	856.7	0.0367	0.0074	7.1147	1.0806	0.3165	0.0760	0.0021	0.0170
Renewable											
WAT	100.00%										

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
SC											
Coal		35.0%	950.6	0.0108	0.0161	0.9534	3.5053	0.2265	0.1428	0.0097	0.0808
Boiler	100.00%	35.0%	950.6	0.0108	0.0161	0.9534	3.5053	0.2265	0.1428	0.0097	0.0808
NG		42.3%	474.8	0.0093	0.0009	0.1358	0.0043	0.0184	0.0184	0.0105	0.2329
Boiler	0.71%	31.1%	0.0	0.0000	0.0000	2.5167	0.0000	0.0840	0.0840	0.0608	0.9287
CC	48.88%	49.5%	412.7	0.0081	0.0008	0.0423	0.0022	0.0008	0.0008	0.0017	0.0292
CT	50.04%	37.2%	545.6	0.0106	0.0011	0.1783	0.0065	0.0313	0.0313	0.0102	0.3955
ICE	0.37%	36.0%	0.0	0.0000	0.0000	2.1724	0.0000	0.4705	0.4705	1.1070	3.8076
Nuclear											
Oil		16.1%	1675.8	0.0717	0.0144	10.5608	4.3579	0.6190	0.1486	0.0041	0.0333
CT	28.54%	7.1%	3788.8	0.1622	0.0325	5.8559	9.8296	1.3995	0.3359	0.0093	0.0752
ICE	71.46%	32.4%	831.9	0.0356	0.0071	12.4400	2.1725	0.3073	0.0738	0.0021	0.0165
Renewable											
WAT	100.00%										
SD											
Coal		31.7%	1078.3	0.0122	0.0183	3.6718	3.3057	0.3085	0.1235	0.0155	0.1295
Boiler	100.00%	31.7%	1078.3	0.0122	0.0183	3.6718	3.3057	0.3085	0.1235	0.0155	0.1295
NG		29.4%	734.4	0.0136	0.0014	0.4557	0.0179	0.0393	0.0393	0.0143	0.4848
CT	99.85%	29.4%	732.9	0.0136	0.0014	0.4235	0.0167	0.0385	0.0385	0.0122	0.4782
ICE	0.15%	13.0%	1708.9	0.0478	0.0074	21.8124	0.7860	0.5962	0.5962	1.4029	4.8255
Oil		25.0%	1080.6	0.0463	0.0093	2.7801	1.3464	0.3951	0.0950	0.0028	0.0217
CT	93.25%	24.6%	1099.2	0.0471	0.0094	2.0899	1.3724	0.4060	0.0975	0.0027	0.0218
ICE	6.75%	32.8%	823.4	0.0352	0.0071	12.3116	0.9863	0.2439	0.0603	0.0042	0.0199
Renewable											
WAT	94.21%										
WND	5.79%										

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
TN											
Coal		35.1%	955.3	0.0109	0.0162	1.4948	3.0442	0.1944	0.1542	0.0124	0.1033
Boiler	100.00%	35.1%	955.3	0.0109	0.0162	1.4948	3.0442	0.1944	0.1542	0.0124	0.1033
NG		30.9%	625.8	0.0124	0.0012	0.3407	0.0070	0.0577	0.0577	0.0642	0.6192
CT	95.76%	30.9%	653.5	0.0130	0.0013	0.2438	0.0074	0.0367	0.0367	0.0117	0.4561
ICE	4.24%	30.9%	0.0	0.0000	0.0000	2.5275	0.0000	0.5314	0.5314	1.2504	4.3011
Nuclear											
Oil		37.8%	713.8	0.0306	0.0061	10.6738	0.8945	0.2637	0.0633	0.0018	0.0142
ICE	100.00%	37.8%	713.8	0.0306	0.0061	10.6738	0.8945	0.2637	0.0633	0.0018	0.0142
Renewable											
WAT	98.83%										
WND	1.17%										
TX											
Biomass		37.7%	0.0	0.0342	0.0069	6.6320	0.0539	1.8466	1.3078	0.0833	2.9389
Boiler	100.00%	37.7%	0.0	0.0342	0.0069	6.6320	0.0539	1.8466	1.3078	0.0833	2.9389
Coal		34.3%	1029.6	0.0114	0.0170	0.7637	3.0292	0.0988	0.0953	0.0173	0.2277
Boiler	100.00%	34.3%	1029.6	0.0114	0.0170	0.7637	3.0292	0.0988	0.0953	0.0173	0.2277
NG		44.2%	459.9	0.0090	0.0009	0.2386	0.0031	0.0110	0.0110	0.0105	0.1340
Boiler	22.93%	32.8%	620.5	0.0122	0.0012	0.6319	0.0059	0.0383	0.0383	0.0277	0.4233
CC	75.70%	50.0%	408.6	0.0080	0.0008	0.1166	0.0022	0.0008	0.0008	0.0017	0.0289
CT	1.13%	28.7%	710.0	0.0139	0.0014	0.2055	0.0042	0.0395	0.0395	0.0126	0.4902
ICE	0.24%	31.3%	112.0	0.0022	0.0002	1.2923	0.0035	0.4896	0.4896	1.1520	3.9625
Nuclear											
Renewable											
WAT	15.10%										
WH	2.22%										
WND	82.69%										

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
UT											
Coal		33.7%	987.6	0.0112	0.0168	1.8269	0.6535	0.3258	0.1115	0.0123	0.1026
Boiler	100.00%	33.7%	987.6	0.0112	0.0168	1.8269	0.6535	0.3258	0.1115	0.0123	0.1026
NG		46.6%	438.2	0.0086	0.0009	0.1452	0.0035	0.0116	0.0116	0.0107	0.1398
Boiler	11.08%	29.5%	692.7	0.0136	0.0014	0.3419	0.0035	0.0407	0.0407	0.0294	0.4495
CC	75.05%	55.3%	368.8	0.0072	0.0007	0.0303	0.0019	0.0008	0.0008	0.0015	0.0245
CT	13.08%	33.7%	603.9	0.0119	0.0012	0.1616	0.0038	0.0336	0.0336	0.0107	0.4172
ICE	0.78%	28.8%	727.9	0.0170	0.0022	8.1533	0.1609	0.2697	0.2697	0.6346	2.1830
Oil		36.0%	749.5	0.0321	0.0064	11.2078	0.9963	0.2769	0.0665	0.0018	0.0149
ICE	100.00%	36.0%	749.5	0.0321	0.0064	11.2078	0.9963	0.2769	0.0665	0.0018	0.0149
Renewable											
GEO	23.33%										
WAT	76.67%										
VA											
Biomass		23.8%	1016.1	0.5065	0.0675	5.3845	13.7280	2.6561	2.0173	0.1238	4.3710
Boiler	100.00%	23.8%	1016.1	0.5065	0.0675	5.3845	13.7280	2.6561	2.0173	0.1238	4.3710
Coal		35.8%	914.9	0.0112	0.0152	1.3939	4.8710	0.2048	0.1804	0.0116	0.0966
Boiler	100.00%	35.8%	914.9	0.0112	0.0152	1.3939	4.8710	0.2048	0.1804	0.0116	0.0966
NG		43.3%	479.9	0.0109	0.0013	0.2238	0.2118	0.0131	0.0131	0.0180	0.1543
Boiler	0.23%	28.8%	0.0	0.0000	0.0000	1.3585	0.0000	0.1482	0.1482	0.0776	2.6258
CC	81.04%	46.4%	454.1	0.0104	0.0013	0.1673	0.2500	0.0009	0.0009	0.0018	0.0311
CT	17.42%	33.4%	634.8	0.0127	0.0014	0.3606	0.0486	0.0339	0.0339	0.0108	0.4214
ICE	1.31%	37.7%	95.7	0.0198	0.0028	1.6956	0.0559	0.4682	0.4682	1.1017	3.7894
Nuclear											
Oil		32.9%	856.5	0.0495	0.0089	2.3765	0.3421	0.2589	0.0634	0.0032	0.0188
CT	72.91%	31.9%	896.6	0.0363	0.0073	0.9521	0.2916	0.3129	0.0751	0.0021	0.0168
ICE	27.09%	36.1%	748.6	0.0851	0.0131	6.2104	0.4778	0.1135	0.0318	0.0063	0.0243

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
VA (cont.)											
Renewable											
WAT	100.00%										
VT											
Biomass		24.0%	5.8	0.5028	0.0670	1.2047	0.0180	0.0236	1.9234	0.1225	4.3223
Boiler	100.00%	24.0%	5.8	0.5028	0.0670	1.2047	0.0180	0.0236	1.9234	0.1225	4.3223
Nuclear											
Oil		23.8%	1127.5	0.0486	0.0098	1.7551	0.7910	0.4272	0.3263	0.0199	0.0228
CT	100.00%	23.8%	1127.5	0.0486	0.0098	1.7551	0.7910	0.4272	0.3263	0.0199	0.0228
Renewable											
WAT	98.28%										
WND	1.72%										
WA											
Biomass		19.2%	1689.4	0.6277	0.0836	7.9959	22.7886	3.3902	2.4010	0.1529	5.3956
Boiler	100.00%	19.2%	1689.4	0.6277	0.0836	7.9959	22.7886	3.3902	2.4010	0.1529	5.3956
Coal		31.5%	1069.7	0.0123	0.0179	1.2452	0.2177	0.0070	0.0495	0.0157	0.1305
Boiler	100.00%	31.5%	1069.7	0.0123	0.0179	1.2452	0.2177	0.0070	0.0495	0.0157	0.1305
NG		51.2%	390.3	0.0077	0.0008	0.1438	0.0047	0.0075	0.0075	0.0170	0.0821
CC	97.44%	51.7%	394.6	0.0077	0.0008	0.0368	0.0044	0.0008	0.0008	0.0017	0.0279
CT	0.49%	28.8%	712.2	0.0152	0.0017	1.6350	0.0773	0.0393	0.0393	0.0125	0.4885
ICE	2.07%	40.4%	112.0	0.0022	0.0002	4.8257	0.0033	0.3137	0.3137	0.7382	2.5393
Nuclear											
Oil		32.3%	836.3	0.0358	0.0072	12.5050	1.1062	0.0132	0.0116	0.0129	0.0342
ICE	100.00%	32.3%	836.3	0.0358	0.0072	12.5050	1.1062	0.0132	0.0116	0.0129	0.0342
Renewable											
WAT	97.00%										
WND	3.00%										

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
WI											
Biomass		24.3%	810.2	0.3371	0.0520	3.8158	3.3778	0.4995	0.4690	0.1211	4.2748
Boiler	100.00%	24.3%	810.2	0.3371	0.0520	3.8158	3.3778	0.4995	0.4690	0.1211	4.2748
Coal		32.0%	1061.4	0.0121	0.0180	1.1344	3.0659	0.0475	0.0338	0.0152	0.1264
Boiler	100.00%	32.0%	1061.4	0.0121	0.0180	1.1344	3.0659	0.0475	0.0338	0.0152	0.1264
NG		41.8%	437.5	0.0087	0.0009	0.5328	0.0068	0.0374	0.0374	0.0650	0.3978
Boiler	0.97%	25.1%	813.6	0.0163	0.0017	2.3407	0.0370	0.0038	0.0038	0.0346	0.5287
CC	73.89%	51.1%	399.6	0.0078	0.0008	0.0473	0.0021	0.0008	0.0008	0.0017	0.0283
CT	20.33%	27.1%	660.1	0.0138	0.0015	0.8157	0.0238	0.0578	0.0578	0.0229	0.8341
ICE	4.80%	30.4%	1.5	0.0000	0.0000	6.4408	0.0003	0.5204	0.5204	1.2245	4.2120
Nuclear											
Oil		24.4%	1104.8	0.0473	0.0095	10.4601	0.4848	0.2423	0.0638	0.0093	0.0364
CT	38.05%	22.1%	1220.1	0.0522	0.0105	2.3198	0.5348	0.4507	0.1082	0.0030	0.0242
ICE	61.95%	26.1%	1033.9	0.0443	0.0089	15.4600	0.4541	0.1144	0.0366	0.0132	0.0439
Renewable											
WAT	92.53%										
WND	7.47%										
WV											
Coal		36.6%	909.7	0.0103	0.0155	1.5153	3.7784	0.2204	0.1737	0.0117	0.1227
Boiler	100.00%	36.6%	909.7	0.0103	0.0155	1.5153	3.7784	0.2204	0.1737	0.0117	0.1227
NG		32.5%	625.4	0.0127	0.0013	0.2911	0.0146	0.0349	0.0349	0.0111	0.4338
CT	100.00%	32.5%	625.4	0.0127	0.0013	0.2911	0.0146	0.0349	0.0349	0.0111	0.4338
Renewable											
WAT	88.21%										
WND	11.79%										

TABLE 15 (Cont.)

	Technology Share	Efficiency	CO_2	CH_4	N_2O	NO_x	SO_x	PM_{10}	$PM_{2.5}$	VOC	CO
WY											
Coal		32.0%	1066.5	0.0121	0.0181	1.7013	1.7864	1.2442	0.3645	0.0154	0.1283
Boiler	100.00%	32.0%	1066.5	0.0121	0.0181	1.7013	1.7864	1.2442	0.3645	0.0154	0.1283
NG		30.3%	665.4	0.0132	0.0013	1.3653	0.0176	0.0375	0.0375	0.0119	0.4654
CT	100.00%	30.3%	665.4	0.0132	0.0013	1.3653	0.0176	0.0375	0.0375	0.0119	0.4654
Oil		35.7%	755.7	0.0324	0.0065	11.2995	0.9494	0.1609	0.0420	0.0062	0.0221
ICE	100.00%	35.7%	755.7	0.0324	0.0065	11.2995	0.9494	0.1609	0.0420	0.0062	0.0221
Renewable											
WAT	49.14%										
WND	50.86%										

3.5 ELECTRICITY GENERATION MIXES

Electricity generation mixes are calculated as a national average, by NERC region, and by state, on the basis of the net electricity generation for each fuel type, as shown in Tables 16-18.

TABLE 16 Nationally averaged electricity generation mix (%)

							Of the other EGUs				
	Coal	NG	Oil	Biomass	Nuclear	Other EGUs	Hydro-electric	Geo-thermal	Wind	Solar PV	Waste heat
eGRID	50.04	21.89	1.65	1.47	17.96	6.99	82.39	5.03	11.85	0.0051	0.73
AEO	46.4	22.9	1.0	0.2	20.3	9.2	65.9	4.6	25	0.4	4.1

There are some discrepancies between the eGRID-based electricity generation mix and the one reported in EIA's Annual Energy Outlook (AEO), particularly for the coal and nuclear power shares. As we realize that there has been a decreasing trend in the coal-fired power plant share of the electricity generation mix, mostly due to the increasing share of NG-fired power plants and renewable power plants over the past decade, we decided to use the electricity generation mixes in AEO 2011 for year 2010 in GREET, to be consistent with the historical and future electricity generation mixes in GREET, which are also based on the AEO.

TABLE 17 Electricity generation mixes (%) by NERC region based on eGRID

NERC region (Share)	Biomass	Coal	NG	Nuclear	Oil	Other EGUs	Of the Other EGUs				
							SUN	GEO	WAT	WH	WND
ASCC (0.2%)	0.0%	9.5%	56.7%	0.0%	15.2%	18.5%	0.0%	0.0%	100.0%	0.0%	0.0%
FRCC (5.3%)	2.4%	33.4%	54.0%	5.2%	4.4%	0.6%	0.0%	0.0%	0.5%	99.5%	0.0%
HICC (0.3%)	4.3%	13.4%	0.6%	0.0%	77.0%	4.8%	0.0%	41.5%	15.4%	0.0%	43.0%
MRO (5.2%)	1.5%	71.5%	5.1%	15.5%	0.1%	6.3%	0.0%	0.0%	52.6%	0.0%	47.4%
NPCC (6.8%)	4.1%	15.0%	37.3%	28.1%	4.4%	11.0%	0.0%	0.0%	97.0%	0.0%	3.0%
RFC (24.2%)	0.6%	65.2%	7.0%	22.9%	3.6%	0.7%	0.0%	0.0%	75.4%	5.1%	19.5%
SERC (27.2%)	2.1%	59.2%	13.0%	23.9%	0.0%	1.7%	0.0%	0.0%	99.6%	0.1%	0.3%
SPP (5.1%)	1.4%	65.6%	23.0%	4.9%	0.0%	5.2%	0.0%	0.0%	57.8%	0.1%	42.1%
TRE (8.2%)	0.0%	35.1%	50.2%	12.0%	0.0%	2.7%	0.0%	0.0%	9.8%	2.5%	87.7%
WECC (17.7%)	1.0%	30.7%	31.8%	9.6%	0.0%	26.8%	0.01%	7.3%	86.1%	0.1%	6.4%

TABLE 18 Electricity generation mixes (%) by state based on eGRID

							Of the Other EGUs				
State (Share)	Biomass	Coal	NG	Nuclear	Oil	Other EGUs	SUN	GEO	WAT	WH	WND
AK (0.16%)	0.00%	9.54%	56.70%	0.00%	15.22%	18.54%	0.00%	0.00%	100.00%	0.00%	0.00%
AL (3.45%)	3.08%	57.23%	12.94%	23.87%	0.00%	2.88%	0.00%	0.00%	100.00%	0.00%	0.00%
AR (1.31%)	3.51%	47.01%	15.12%	28.36%	0.00%	5.98%	0.00%	0.00%	100.00%	0.00%	0.00%
AZ (2.72%)	0.00%	36.85%	33.58%	23.63%	0.00%	5.94%	0.10%	0.00%	99.90%	0.00%	0.00%
CA (5.07%)	1.93%	2.08%	57.05%	16.95%	0.03%	21.97%	0.01%	28.00%	59.55%	0.40%	12.04%
CO (1.3%)	0.00%	67.65%	26.96%	0.00%	0.01%	5.37%	0.08%	0.00%	53.91%	1.42%	44.59%
CT (0.8%)	3.83%	11.89%	29.49%	49.41%	4.35%	1.03%	0.00%	0.00%	100.00%	0.00%	0.00%
DC (0.0018%)	0.00%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
DE (0.2%)	0.00%	68.72%	31.04%	0.00%	0.24%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
FL (5.54%)	2.52%	36.53%	51.26%	4.93%	4.15%	0.62%	0.00%	0.00%	10.85%	89.15%	0.00%
GA (3.49%)	2.84%	62.73%	10.65%	22.44%	0.02%	1.32%	0.00%	0.00%	100.00%	0.00%	0.00%
HI (0.28%)	4.28%	13.36%	0.61%	0.00%	76.95%	4.80%	0.00%	41.54%	15.43%	0.00%	43.04%
IA (1.19%)	0.00%	77.12%	6.09%	9.08%	0.24%	7.47%	0.00%	0.00%	25.87%	0.00%	74.13%
ID (0.28%)	4.44%	0.81%	14.69%	0.00%	0.00%	80.06%	0.00%	0.00%	98.13%	0.00%	1.87%
IL (4.8%)	0.00%	47.65%	4.14%	47.80%	0.02%	0.38%	0.00%	0.00%	12.19%	0.00%	87.81%
IN (3.13%)	0.03%	94.35%	5.00%	0.00%	0.00%	0.62%	0.00%	0.00%	55.33%	44.67%	0.00%
KS (1.2%)	0.00%	73.07%	3.91%	20.69%	0.01%	2.32%	0.00%	0.00%	0.90%	0.00%	99.10%
KY (2.33%)	0.39%	96.95%	0.94%	0.00%	0.00%	1.72%	0.00%	0.00%	100.00%	0.00%	0.00%
LA (2.22%)	4.21%	28.72%	47.70%	18.45%	0.00%	0.91%	0.00%	0.00%	97.68%	2.32%	0.00%
MA (1.15%)	3.89%	26.17%	53.94%	10.88%	5.22%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%
MD (1.2%)	1.32%	62.98%	3.57%	28.59%	0.25%	3.29%	0.00%	0.00%	100.00%	0.00%	0.00%
ME (0.39%)	29.91%	0.00%	44.19%	0.00%	3.79%	22.12%	0.00%	0.00%	97.22%	0.00%	2.78%
MI (2.86%)	1.96%	61.03%	10.18%	19.68%	7.05%	0.11%	0.00%	0.00%	97.83%	0.00%	2.17%
MN (1.31%)	2.89%	60.83%	6.17%	24.03%	0.16%	5.92%	0.00%	0.00%	18.35%	0.00%	81.65%
MO (2.19%)	0.00%	83.10%	4.86%	10.28%	0.01%	1.74%	0.00%	0.00%	100.00%	0.00%	0.00%
MS (1.2%)	2.92%	41.68%	36.64%	18.77%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

TABLE 18 (Cont.)

State (Share)	Biomass	Coal	NG	Nuclear	Oil	Other EGUs	Of the Other EGUs				
MT (0.69%)	0.42%	65.17%	0.33%	0.00%	0.00%	34.08%	0.00%	0.00%	94.97%	0.00%	5.03%
NC (3.12%)	1.36%	61.90%	3.56%	30.77%	0.06%	2.34%	0.00%	0.00%	100.00%	0.00%	0.00%
ND (0.75%)	0.04%	93.54%	0.23%	0.00%	0.01%	6.17%	0.00%	0.00%	67.77%	0.00%	32.23%
NE (0.79%)	0.00%	59.84%	3.43%	33.54%	0.03%	3.16%	0.00%	0.00%	79.13%	0.00%	20.87%
NH (0.56%)	3.38%	18.29%	25.15%	46.29%	1.45%	5.44%	0.00%	0.00%	100.00%	0.00%	0.00%
NJ (1.51%)	1.77%	16.95%	30.48%	21.03%	30.13%	0.00%	0.00%	0.00%	108.97%	0.00%	-8.97%
NM (0.86%)	0.00%	76.91%	18.47%	0.00%	0.00%	4.62%	0.00%	0.00%	16.13%	0.00%	83.87%
NV (0.79%)	0.00%	21.61%	68.46%	0.00%	0.00%	9.93%	0.08%	38.44%	61.47%	0.00%	0.00%
NY (3.49%)	1.66%	15.18%	31.14%	29.37%	5.18%	17.48%	0.00%	0.00%	96.70%	0.00%	3.30%
OH (3.71%)	0.09%	86.68%	2.76%	10.19%	0.00%	0.27%	0.00%	0.00%	96.53%	0.00%	3.47%
OK (1.8%)	0.55%	52.96%	40.15%	0.00%	0.00%	6.35%	0.00%	0.00%	61.06%	0.00%	38.94%
OR (1.32%)	2.85%	7.91%	26.00%	0.00%	0.00%	63.25%	0.00%	0.00%	96.42%	0.00%	3.58%
PA (5.43%)	0.89%	55.20%	8.68%	34.26%	0.10%	0.88%	0.00%	0.00%	76.30%	0.00%	23.70%
RI (0.17%)	0.00%	0.00%	99.79%	0.00%	0.15%	0.06%	0.00%	0.00%	100.00%	0.00%	0.00%
SC (2.51%)	2.41%	46.61%	4.93%	45.90%	0.01%	0.14%	0.00%	0.00%	100.00%	0.00%	0.00%
SD (0.14%)	0.00%	47.08%	6.97%	0.00%	0.16%	45.79%	0.00%	0.00%	94.21%	0.00%	5.79%
TN (2.3%)	1.21%	63.58%	0.52%	30.17%	0.00%	4.51%	0.00%	0.00%	98.83%	0.00%	1.17%
TX (9.73%)	0.28%	36.92%	50.02%	10.10%	0.00%	2.69%	0.00%	0.00%	15.10%	2.22%	82.69%
UT (1.09%)	0.02%	82.00%	16.42%	0.00%	0.00%	1.55%	0.00%	23.33%	76.67%	0.00%	0.00%
VA (1.91%)	4.63%	47.84%	13.08%	34.80%	0.12%	0.00%	0.00%	0.00%	100.00%	0.00%	0.00%
VT (0.14%)	7.81%	0.00%	0.00%	80.77%	0.95%	10.47%	0.00%	0.00%	98.28%	0.00%	1.72%
WA (2.57%)	1.31%	8.30%	6.81%	7.58%	0.00%	76.00%	0.00%	0.00%	97.00%	0.00%	3.00%
WI (1.52%)	1.50%	65.32%	10.37%	7.30%	13.21%	2.31%	0.00%	0.00%	92.53%	0.00%	7.47%
WV (2.25%)	0.00%	98.11%	0.35%	0.00%	0.03%	1.51%	0.00%	0.00%	88.21%	0.00%	11.79%
WY (1.09%)	0.00%	94.80%	1.94%	0.00%	0.00%	3.25%	0.00%	0.00%	49.14%	0.00%	50.86%

3.6 ELECTRICITY TRANSMISSION AND DISTRIBUTION LOSS

The electricity transmission and distribution (T&D) loss factors (%) on a national and state average basis were calculated by dividing the estimated losses by the result of total disposed electricity minus directly used electricity, i.e., net generated electricity, which are obtained from EIA's State Electricity Profiles 2010 (EIA, 2011). The results are shown in Table 19.

TABLE 19 Electricity T&D gross grid loss factors (%) on a state and national average basis

	2000	2004	2005	2006	2007	2008	2009	2010
AL	5.03	4.39	4.31	4.57	5.69	4.86	4.16	4.64
AK	7.43	6.63	7.73	7.89	7.79	8.10	6.80	7.56
AZ[1]	4.91	4.38	5.31	5.19	5.94	5.37	5.35	NA[2]
AR	7.13	7.45	8.93	6.88	8.96	7.75	7.32	7.82
CA	8.73	10.64	9.56	10.19	11.12	11.33	11.03	8.87
CO	7.00	8.12	8.87	8.60	5.77	8.56	8.51	8.01
CT[3]	6.74	4.48	4.56	5.57	6.73	8.94	5.13	NA
DE[4]	NA	NA	NA	NA	NA	NA	NA	NA
FL	7.53	7.16	7.54	7.92	8.70	8.27	7.82	8.36
GA	7.17	16.88	8.58	6.98	8.70	10.01	9.08	8.61
HI	6.83	4.79	5.78	6.08	6.84	6.53	6.12	6.01
ID[5]	NA	NA	NA	NA	NA	NA	NA	NA
IL[6]	5.53	5.09	5.84	5.91	5.43	4.81	4.15	NA
IN	5.65	5.77	9.01	5.24	6.40	5.70	6.08	5.95
IA[7]	6.92	6.38	5.69	6.61	6.35	4.93	4.87	NA
KS	5.71	7.40	9.33	7.60	8.32	8.61	8.17	8.29
KY	6.02	7.17	6.87	6.62	8.51	6.71	5.56	6.52
LA	8.27	6.82	7.66	8.10	9.11	8.14	7.99	7.14
ME[8]	6.28	NA	NA	NA	NA	NA	NA	NA
MD[9]	8.69	9.22	10.30	9.94	NA	NA	11.34	11.28
MA	9.29	4.85	4.75	8.81	8.87	7.65	5.92	5.44
MI	7.26	6.69	6.58	7.47	7.91	7.58	7.74	7.31
MN	7.47	9.67	8.18	7.91	7.18	7.28	9.72	7.57
MS	9.15	8.41	8.44	8.42	9.23	8.91	7.86	7.71
MO	6.78	6.87	7.50	7.35	7.81	7.50	6.47	7.11
MT[10]	3.96	11.50	NA	NA	NA	NA	NA	NA
NE	5.97	6.63	7.40	7.71	8.58	8.67	7.91	7.53
NV	5.03	4.39	4.31	4.57	5.69	4.86	4.16	4.64
NH[11]	4.37	NA	NA	NA	NA	NA	NA	NA
NJ	8.94	10.70	11.24	10.39	10.75	8.61	7.21	10.94
NM	4.00	4.00	5.03	4.98	4.83	4.99	4.97	5.97

TABLE 19 (Cont.)

	2000	2004	2005	2006	2007	2008	2009	2010
NY	7.00	10.57	7.81	4.38	5.67	5.57	6.27	5.85
NC	7.19	7.29	10.25	10.90	8.49	8.37	8.14	7.64
ND[12]	NA	6.82	4.67	4.79	4.88	4.63	4.91	4.76
OH	7.97	8.66	6.76	7.15	7.99	7.91	7.83	5.66
OK	6.50	5.76	6.24	6.77	7.77	7.21	6.97	7.23
OR	7.00	5.42	6.64	6.82	6.87	6.44	5.91	5.76
PA	4.83	5.24	5.43	5.22	5.42	5.00	4.55	5.05
RI[13]	6.62	8.03	7.17	8.34	8.23	NA	4.75	5.22
SC	6.00	5.10	5.61	5.60	6.23	6.05	5.64	5.59
SD[14]	6.08	NA	NA	NA	NA	NA	NA	8.60
TN	7.36	5.18	6.32	5.92	7.29	6.46	6.29	8.64
TX	6.76	5.78	4.13	4.73	5.66	7.22	6.08	6.39
UT	4.55	4.91	5.70	5.76	5.91	5.64	5.47	6.37
VT[15]	NA	4.92	5.12	4.22	5.28	4.66	NA	4.91
VA[16]	9.26	8.15	9.31	NA	10.76	8.79	8.72	11.15
WA	6.18	4.38	5.79	4.81	5.58	5.20	4.78	4.83
WV[17]	NA	NA	NA	NA	NA	NA	NA	NA
WI	8.15	7.70	7.11	6.10	7.78	7.48	6.28	6.01
WY[18]	NA	NA	NA	NA	NA	NA	NA	NA
United States[19]	**6.62**	**6.93**	**6.82**	**6.72**	**7.29**	**7.10**	**6.72**	**6.49**

[1]Original EIA-calculated number is 3.70 in 2010.

[2]Not available.

[3]Original EIA-calculated number is 3.27 in 2010.

[4]Original EIA-calculated numbers are 14.60, 14.63, 16.52, 14.74, 17.10, 12.99, 18.56, and 16.89 in 2000 and 2004-2010, respectively.

[5]Original EIA-calculated numbers are 14.32, 16.17, 19.33, 18.50, 21.11, 20.74, 16.11, and 17.18 in 2000 and 2004-2010, respectively.

[6]Original EIA-calculated number is 3.86 in 2010.

[7]Original EIA-calculated number is 53.39 in 2010.

[8]Original EIA-calculated numbers are 2.40, 2.61, 2.31, 2.28, 3.03, 2.14, and 1.79 in 2004-2010, respectively.

[9]Original EIA-calculated numbers are 12.19 and 12.31in 2007 and 2008, respectively.

[10]Original EIA-calculated numbers are 13.31, 12.67, 12.28, 15.55, and 22.73 in 2005-2009, respectively.

[11]Original EIA-calculated numbers are 2.59, 2.69, 3.09, 3.33, 3.19, 2.24, 2.94 in 2004-2010, respectively.

[12]Original EIA-calculated number is 2.06 in 2000.

[13]Original EIA-calculated number is 1.92 in 2008.

[14]Original EIA-calculated numbers are 14.57, 13.92, 12.23, 16.59, 14.83, and 12.42 in 2004-2009, respectively.

[15]Original EIA-calculated numbers are 3.81 and 3.04 in 2000 and 2009, respectively.

[16]Original EIA-calculated number is 12.81 in 2006.

[17]Original EIA-calculated numbers are 2.16, 2.04, 2.80, 3.25, 3.51, 3.66, 3.60, and 3.45 in 2000 and 2004-2010, respectively.

[18]Original EIA-calculated number are 1.96, 2.28, 2.45, 2.77, 3.03, 3.27, 2.94 and 2.90 in 2000 and 2004-2010, respectively.

[19]EIA-calculated numbers on an end-use weighted-average basis (EIA, 2011).

On the basis of Table 19, the U.S. average T&D loss factor will be updated from 8% to 6.5% for 2010 in GREET 1_2012.

3.7 PROBABILITY DISTRIBUTION FUNCTIONS OF GHG AND CAP EMISSION FACTORS AND ENERGY EFFICIENCIES BY FUEL TYPE AND COMBUSTION TECHNOLOGY OF EGUS

Table 20 summarizes the PDFs of energy efficiency and GHG and CAP emission factors by fuel type and combustion technology for EGUs on a national-average basis. Both the best-fit PDFs based on the eleven default PDFs in GREET’s Add-on Stochastic Tool and the best-fit PDFs from a comprehensive pool of PDFs in EasyFit were developed to give dual options for users, based on their access to the stochastic simulation tools, to perform uncertainty analysis of life-cycle GHG and CAP emissions of various vehicle/fuel systems.

TABLE 20 Probability distribution functions of energy efficiency, GHG and CAP emission factors by fuel type and combustion technology of EGUs

Fuel type	Generation Technology	Efficiency, GHG, CAP	Best of best					Best of eleven			
			PDF Type	PDF Parameters				PDF Type	PDF Parameters		
Coal	BLR	Efficiency	Logistic (sigma, mu)	0.01662	0.34827			Logistic	0.01662	0.34827	
		CO_2	Burr (k, alpha, beta, gamma)	0.71435	20.839	943.31	0	Gamma (alpha, beta, gamma)	13.235	26.647	622.46
		CH_4	Burr	0.61648	23.506	0.01063	0	Gamma	7.5929	3.84E-04	0.00819
		N_2O	Dagum (k, alpha, beta, gamma)	0.87227	19.317	0.01654	0	Logistic	9.06E-04	0.01642	
		NO_x	Dagum	0.29521	5.799	1.7364	0.13662	Gamma	8.1772	0.22238	-0.44698
		SO_x	Dagum	0.40774	2.9293	5.216	0	Gamma	1.5808	2.4629	0
		PM_{10}	Johnson SB (gamma, delta, lambda, xi)	0.15061	0.4292	0.32148	-0.00315	Uniform (min, max)	0	0.32782	
		$PM_{2.5}$	Gen. Gamma (k, alpha, beta, gamma)	2.5624	0.23192	0.31314	3.4597E-5	Gamma	0.75895	0.15778	3.50E-05
		VOC	Burr	0.71244	9.8929	0.01214	9.70E-05	Lognormal (sigma, mu)	0.22452	-4.3457	
		CO	Burr	1.9823	8.2229	0.11858	0	Logistic	0.01071	0.10689	
Natural gas	BLR	Efficiency	Cauchy (sigma, mu)	0.01537	0.33108			Logistic	0.02183	0.33049	
		CO_2	Cauchy	27.469	622.21			Lognormal	0.12105	6.4417	
		CH_4	Cauchy	6.23E-04	0.01199			Lognormal	0.17885	-4.3759	
		N_2O	Cauchy	7.03E-05	0.00121			Lognormal	0.13508	-6.7084	
		NO_x	Johnson SB	1.1552	0.97946	3.8044	-0.19597	Gamma	1.5767	0.53551	
		SO_x	Dagum	0.5521	1.4298	0.014	0	Weibull	0.64099	0.01402	

TABLE 20 (Cont.)

Fuel type	Generation Technology	Efficiency, GHG, CAP	Best of best					Best of eleven			
			PDF Type	PDF Parameters				PDF Type	PDF Parameters		
		PM_{10}	Frechet (alpha, beta, gamma)	4.0662	0.00955	0.02595		Logistic	0.00265	0.03687	
		$PM_{2.5}$	Frechet (alpha, beta, gamma)	4.0662	0.00955	0.02595		Logistic	0.00265	0.03687	
		VOC	Cauchy	0.00121	0.02612			Lognormal	0.12575	-3.6324	
		CO	Cauchy	0.02005	0.39927			Logistic	0.0393	0.40057	
	CT	Efficiency	Erlang (m, beta, gamma)	247	0.00345	-0.51541		Gamma	271.64	0.0033	-0.55931
		CO_2	Gumbel Max (sigma, mu)	82.211	575.25			Gamma	3.0396	60.669	438.29
		CH_4	Burr	0.38607	16.419	0.01069	0	Gamma	1.7565	0.0019	0.00902
		N_2O	Burr	0.38838	16.824	0.00107	0	Gamma	1.7048	1.90E-04	9.04E-04
		NO_x	Lognormal	0.85145	-1.4381			Lognormal	0.85145	-1.4381	
		SO_x	Log-Pearson3(alpha, gamma, beta)	2553.3	-0.03081	75.311		Lognormal	1.5566	-3.3441	
		PM_{10}	Pearson 5	44.797	1.4961	0		Lognormal	0.1521	-3.3881	
		$PM_{2.5}$	Pearson 5	44.797	1.4961	0		Lognormal	0.1521	-3.3881	
		VOC	Pearson 6 (alpha1, alpha2, beta, gamma)	227.49	53.581	0.00251	0	Lognormal	0.15211	-4.5332	
		CO	Pearson 5	44.796	18.587	0		Lognormal	0.1521	-0.86845	
	CC	Efficiency	Dagum	0.35393	10915	112.94	-112.42	Weibull (alpha, beta, gamma)	19.851	0.57763	-0.05989
		CO_2	Burr	0.68446	5.2657	57.907	336.9	Gamma	5.3917	12.917	339.04
		CH_4	Burr	0.40398	50.882	0.00761	0	Gamma	9.284	1.57E-04	0.00647

TABLE 20 (Cont.)

Fuel type	Gener-ation Tech-nology	Efficiency, GHG, CAP	Best of best					Best of eleven			
			PDF Type	PDF Parameters				PDF Type	PDF Parameters		
		N_2O	Burr	0.35932	50.619	7.59E-04	0	Gamma	7.0675	1.97E-05	6.56E-04
		NO_x	Pert (m, a, b)	0.01672	0.01672	0.31399		Weibull	1.7341	0.07173	0
		SO_x	Gen. Gamma	0.62	2.0995	0.00135	7.1094E-4	Lognormal	0.87044	-5.476	
		PM_{10}	Frechet	21.279	8.0049E-04	0		Gamma	8.8646	1.7166E-5	6.7324E-4
		$PM_{2.5}$	Frechet	21.279	8.0049E-04	0		Gamma	8.8646	1.7166E-5	6.7324E-4
		VOC	Burr	0.37778	50.825	0.00162	0	Gamma	8.8646	3.53E-05	0.00138
		CO	Cauchy	0.000928	0.02815			Logistic	0.00283	0.02797	
	ICE	Efficiency	Weibull	5.2046	0.3501	0		Weibull	5.2046	0.3501	0
		CO_2	Cauchy	32.607	484.98			Triangular (m, a, b)	472	-33.855	1179.6
		CH_4	Cauchy	6.95E-04	0.00964			Logistic	0.00253	0.01006	
		N_2O	Burr	0.39265	10.221	0.00229	-0.00151	Uniform	0	0.00346	
		NO_x	Frechet	1.4637	1.6988			Weibull	1.5134	3.5087	0
		SO_x	Inv.Gaussian (lambda, mu, gamma)	0.02136	0.04038	0		Weibull	0.83778	0.03374	0.00141
		PM_{10}	Error (k, sigma, mu)	1.7065	0.22548	0.46614		Logistic	0.12431	0.46614	
		$PM_{2.5}$	Error	1.7065	0.22548	0.46614		Logistic	0.12431	0.46614	
		VOC	Error	1.7065	0.53054	1.0968		Logistic	0.2925	1.0968	
		CO	Error	1.7065	1.8249	3.7726		Logistic	1.0061	3.7726	
Oil	BLR	Efficiency	Beta (alpha1, alpha2, a, b)	4.1764	0.63941	0.15373	0.35697	Weibull	17.242	0.34167	
		CO_2	Gamma	65.864	12.024			Gamma	65.864	12.024	
		CH_4	Uniform	0.01823	0.04302			Uniform	0.01823	0.04302	
		N_2O	Johnson SB	0.28694	0.74013	0.0066	0.00308	Uniform	0.00304	0.00878	
		NO_x	Dagum	0.122	15.757	2.0294	0	Uniform	0.41012	2.2977	

TABLE 20 (Cont.)

Fuel type	Generation Technology	Efficiency, GHG, CAP	Best of best					Best of eleven			
			PDF Type	PDF Parameters				PDF Type	PDF Parameters		
		SO_x	Burr	0.2158	8.1622	1.6563	0	Lognormal	0.54375	1.0341	
		PM_{10}	Burr	1.2487E+13	0.74828	9.9915E+11	0	Logistic	2.3552E-6	2.9309E-6	Logistic
		$PM_{2.5}$	Burr	1.6154	0.52344	0.03067	0.04765	Weibull	0.43755	0.06256	0.04764
		VOC	Gen. Gamma	1.1575	0.25775	5.8236E-4	2.9E-5	Lognormal	1.0617	-9.3916	
		CO	Pearson 5 (alpha, beta, gamma)	2.0333	3.0057E-4	0		Lognormal	0.88006	-8.5539	
	CT	Efficiency	Johnson SB	-0.89523	0.60427	0.28076	0.13344	Weibull	1.60E+08	7.03E+06	-7.03E+06
		CO_2	Frechet	1.6757	133.6	565.66		Exponential (lambda, gamma)	0.00523	626	
		CH_4	Gen. Pareto (k, sigma, mu)	0.35239	0.00514	0.02744		Weibull	0.76873	0.00894	0.02744
		N_2O	Gen. Pareto (k, sigma, mu)	0.3446	0.00103	0.0055		Weibull	0.65721	0.00171	0.0055
		NO_x	Johnson SB	0.13815	0.40494	2.967	0.89903	Lognormal	0.57976	0.68013	
		SO_x	Inv.Gaussian	1.2694	0.83826	0		Weibull	1.2214	0.89486	
		PM_{10}	Fatigue Life (alpha, beta, gamma)	1.5315	0.02977	0.23914		Gamma	0.55914	0.10226	0.24174
		$PM_{2.5}$	Beta	0.63293	4.8745	0.04545	0.23507	Gamma	8.388	0.00794	0
		VOC	Power Function (alpha, a, b)	0.18673	9.80E-05	0.00856		Uniform	0	0.00365	
		CO	Log-Logistic	1.597	0.00333	0.01261		Exponential	212.61	0.01297	
	ICE	Efficiency	Dagum	0.69165	28.606	0.36016	0	Logistic	0.01592	0.35351	
		CO_2	Fatigue Life	0.20375	297.52	464.38		Gamma	13.771	16.815	536.52
		CH_4	Laplace	488.17	0.03288			Lognormal	0.08116	-3.4185	

TABLE 20 (Cont.)

Fuel type	Gener-ation Tech-nology	Efficiency, GHG, CAP	Best of best					Best of eleven			
			PDF Type	PDF Parameters				PDF Type	PDF Parameters		
			(gamma, mu)								
		N_2O	Burr	0.79531	33.683	0.0079	-0.00142	Gamma	23.837	1.10E-04	0.00398
		NO_x	Frechet	3.63E+06	6.84E+06	-6.84E+06		Uniform	6.0291	13.238	
		SO_x	Lognormal	0.23374	0.18686	-0.41726		Gamma	11.602	0.08769	-0.19363
		PM_{10}	Cauchy	0.0038	0.07654			Gamma	1.2247	0.07964	0
		$PM_{2.5}$	Dagum	0.37656	63.413	0.34821	-0.28986	Weibull	4.1231	0.07614	-0.02211
		VOC	Log-Logistic	8.43E+08	3.77E+06	-3.77E+06		Uniform	0.0044	0.03471	
		CO	Uniform	0.00775	0.04128			Uniform	0.00775	0.04128	
Biomass	BLR	Efficiency	Burr	2.2266	7.0379	0.25274	0	Logistic	0.02502	0.2197	
		CH_4	Normal (sigma, mu)	0.10442	0.54313			Normal (sigma, mu)	0.10442	0.54313	
		N_2O	Logistic	0.00769	0.07378			Logistic	0.00769	0.07378	
		NO_x	Johnson SB	-0.14898	0.36949	7.6054	0.76866	Uniform	0.30096	9.5998	
		SO_x	Uniform	0	28.673			Uniform	0	28.673	
		PM_{10}	Gumbel Min (sigma, mu)	0.49519	3.1532			Weibull	4.9717	3.1168	
		$PM_{2.5}$	Log-Logistic	12.185	2.1766	0		Gamma	10.842	0.10278	1.091
		VOC	Hypersecant (sigma, mu)	0.02764	0.13454			Logistic	0.01524	0.13454	
		CO	Logistic	0.49399	4.8079			Logistic	0.49399	4.8079	

3.8 PROJECTION OF GENERATION MIX, EFFICIENCY, COMBUSTION TECHNOLOGY SHARE, AND EMISSION FACTORS

We use the GHG and CAP emission factors, the efficiencies, and the generation technology share of the EGUs by fuel type that are developed in this work, and the AEO 2011 electricity generation mix, as the baseline update for year 2010 in GREET. For 2015 and 2020, we use AEO 2012's projection of the electricity generation mix to update the generation mix, and we assume incremental improvements in the combustion technology mix based on the relative change rate of our baseline update compared to previous GREET numbers. As a result, an NGCC share of 84.2% and 87.8%, an NG CT share of 6.1% and 6.2%, and an IGCC share of 1.0% and 3.0% for both coal-fired and biomass-fired EGUs are estimated for 2015 and 2020, respectively, in GREET. An incremental improvement, assumed on the basis of the same rationale, is applied to the efficiencies for years 2015 and 2020, while an incremental decrease in CAP emission factors is assumed for EGUs of various fuel types and generation technologies, except for NGCCs, which are assumed to have constantly low-level CAP emission factors. In addition, for CAP emission factors in the future, the low side of the present PDFs could serve as a much better predictor of future emission performance than the high side or even the average, because the worst performers will be preferentially retired or turned down, mainly as a result of the NSPS mandates and low NG prices.

3.9 LIFE-CYCLE ENERGY USE, GHG AND CAP EMISSIONS OF SELECTED VEHICLE/FUEL SYSTEMS

The relative changes in energy use, GHG and CAP emissions per kWh electricity generated for both electricity generation only and the full fuel cycle of the power plant, which are calculated on the basis of the updated GHG and CAP emission factors and energy conversion efficiencies from the present study, are depicted in Figure 2 in comparison with those based on the default parameters of GREET 1_2011.

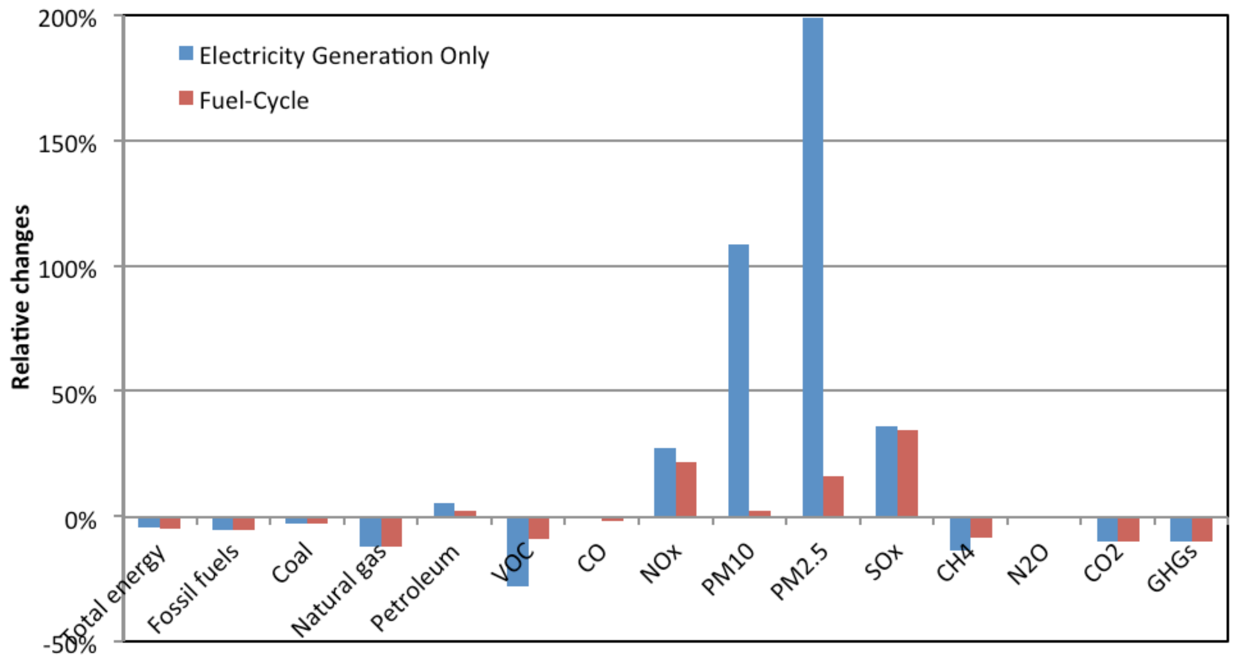
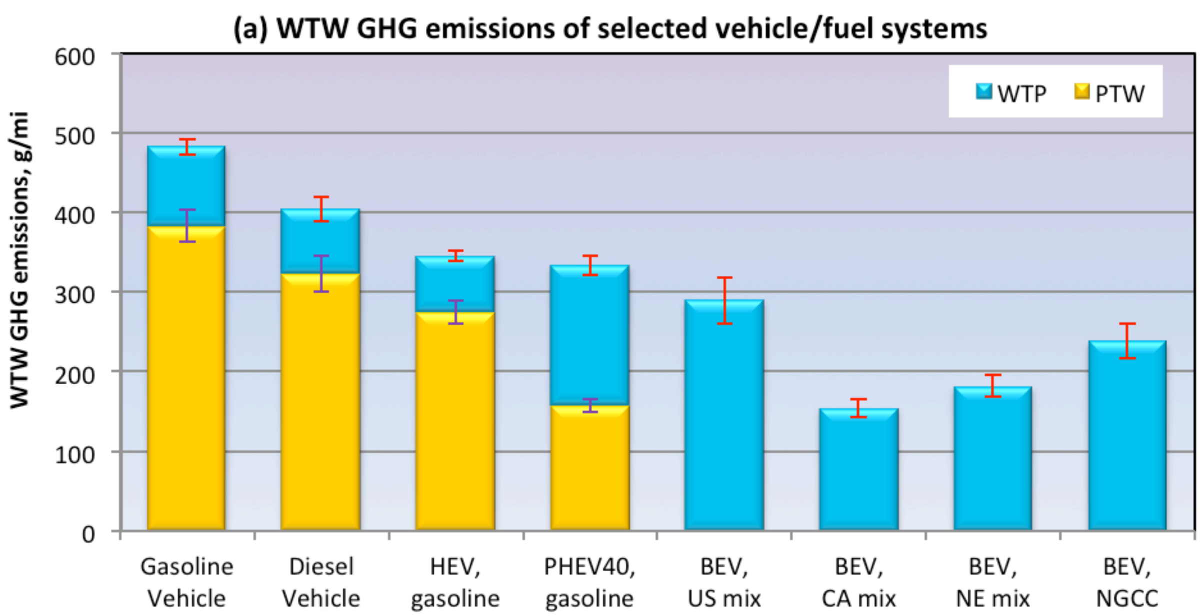
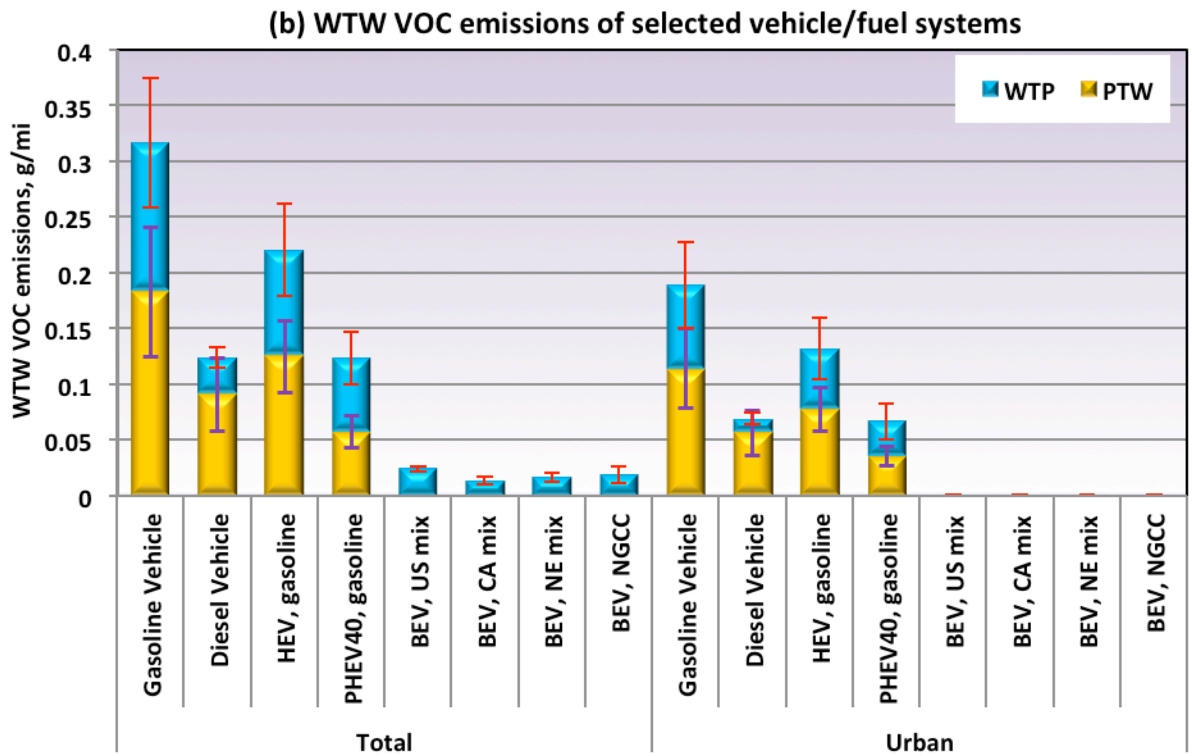


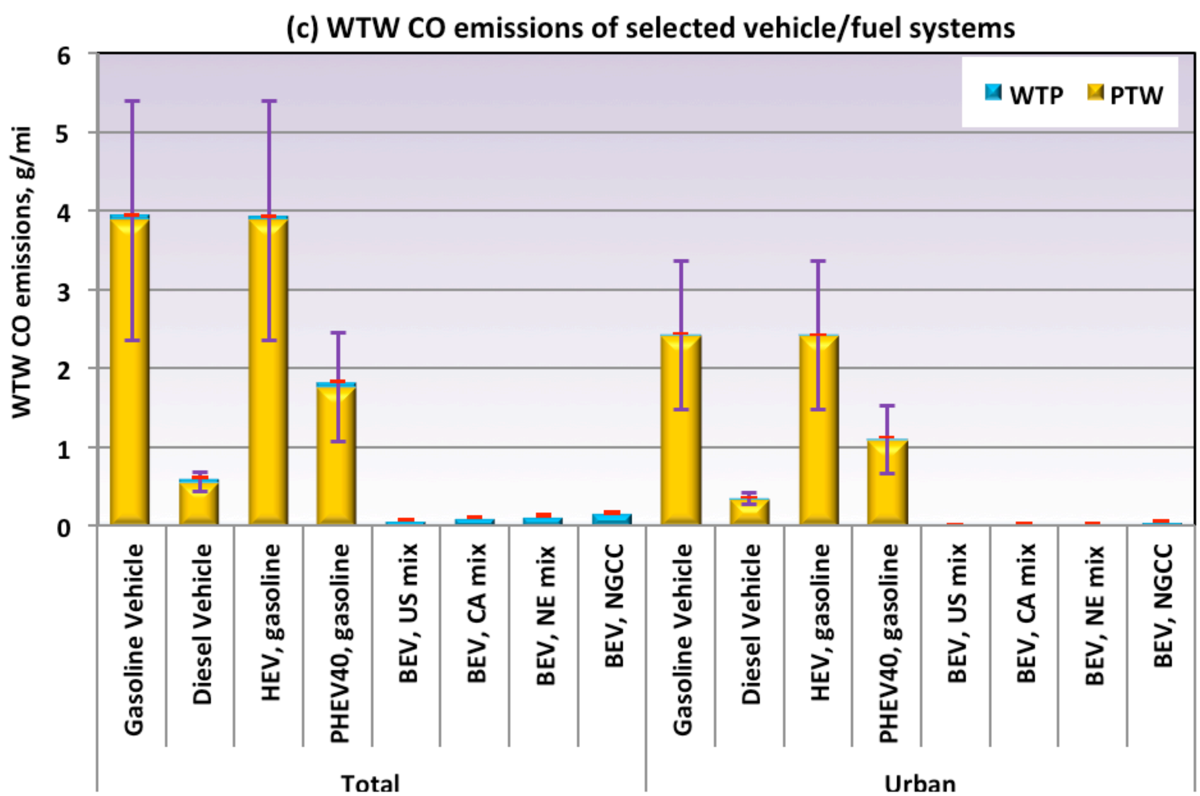
FIGURE 2 Differences in energy use, GHG emissions, and CAP emissions per kWh electricity generated found in the present study, relative to those in GREET 1_2011, for electricity generation only and the full fuel cycle of the power plant.

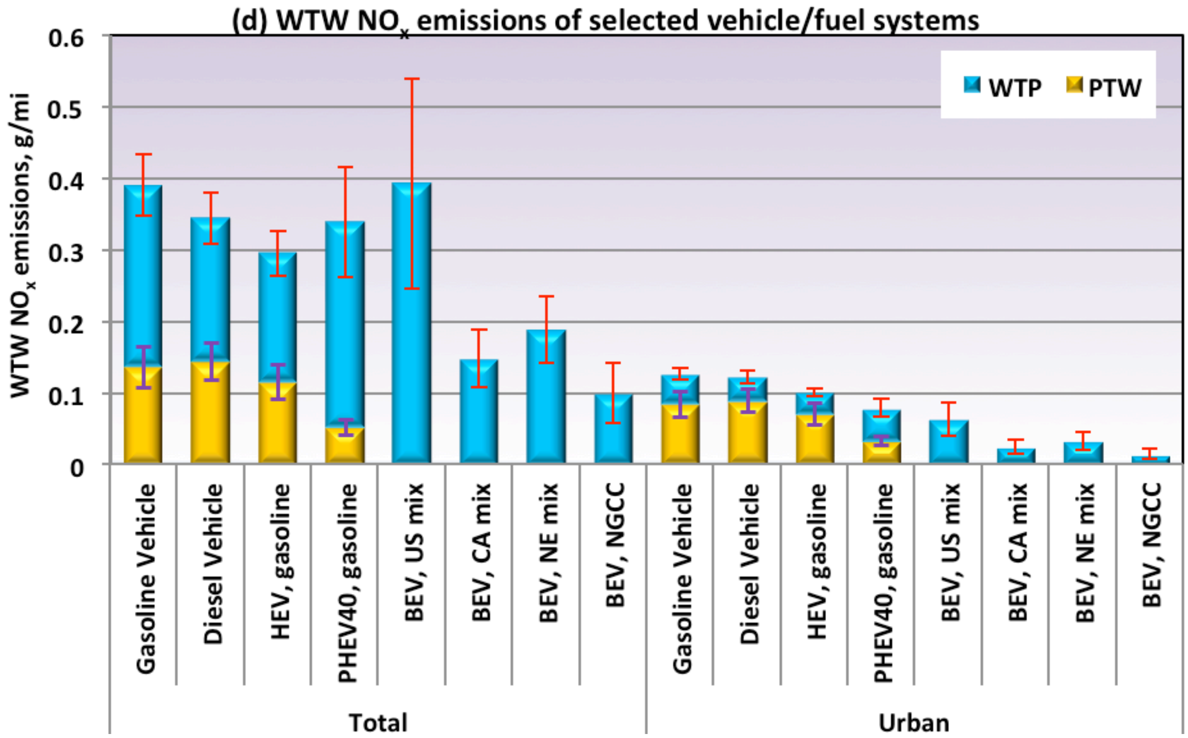
With the updated characterization of electricity generation in the present study, the total energy use per kWh electricity generated decreases by about 4.6% and 4.8%, respectively, for electricity generation only and for the total fuel cycle, mostly owing to the significant decrease in NG consumption by about 12%, which is due to the significant increase (from 44.0% to 79.9%) in the share of NGCC, a highly efficient combustion technology. The increase in the use of RFO by about 5.5% and 2.0%, respectively, for electricity generation only and for the total fuel cycle is mainly due to the decreased efficiency of oil-fired boilers, from 34.8% in GREET1_2011 to 32.7% in this study. For nationally averaged total GHG emissions, a significant decrease by about 10.2% is estimated, primarily owing to the decrease in CO_2 emissions by the same magnitude and to the decrease in electricity T&D losses. CAP emissions have increased by 27.1%, 108.3%, 199.0% and 36.1% for PM_{10}, $PM_{2.5}$, SO_x and NO_x, respectively, and decreased by 28.0% and 1.0%, respectively, for VOC and CO for electricity generation only, and the CAP emissions have increased by 21.7%, 2.2%, 16.1%, and 34.4%, respectively, for PM_{10}, $PM_{2.5}$, SO_x and NO_x, and decreased by 9.3% and 2.0%, respectively, for VOC and CO for the total fuel cycle of electricity generation, which results from the variation in CAP emission factors and efficiencies of various types of power plants. The increased PM_{10}, $PM_{2.5}$, SO_x and NO_x emissions will necessitate a reevaluation of the environmental impacts of electricity generation and the application of electrified vehicle technologies. Also, the decreased VOC emissions and increased NO_x emissions from the power sector could lead to critical reevaluation of the impacts of power plants on the occurrence of ozone pollution episodes and the formulation of ozone pollution control strategies, particularly in the so-called NO_x-limited regions for ozone formation.

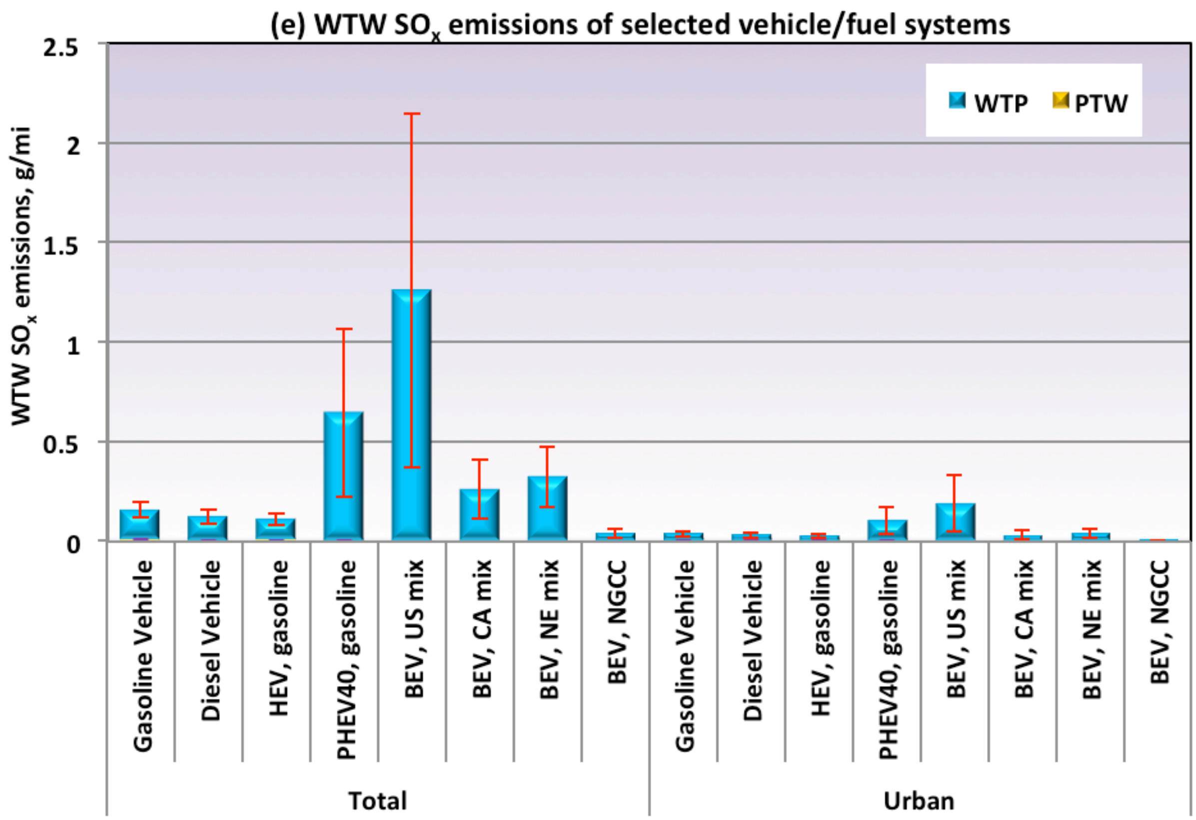
Using the updated GHG and CAP emission factors, energy conversion efficiencies, and combustion technology shares, life-cycle GHG and CAP emissions of selected vehicle/fuel systems were examined. Furthermore, the uncertainties of both well-to-pump (WTP) and pump-to-wheels (PTW) GHG and CAP emissions were quantified using the updated PDFs, as summarized in Table 20. Figure 3 illustrates the well-to-wheels (WTW) GHG and CAP emissions of selected vehicle/fuel systems, including hybrid electric vehicles (HEVs) and gasoline plug-in HEVs with 40 miles of rated all-electric range (PHEV40), as well as the associated uncertainties. For battery-powered electric vehicles (BEVs), the WTW GHG and CAP emissions produced by recharging with the U.S. grid mix, northeast (NE) grid mix, California (CA) grid mix, and 100% NGCC electricity are illustrated and compared.

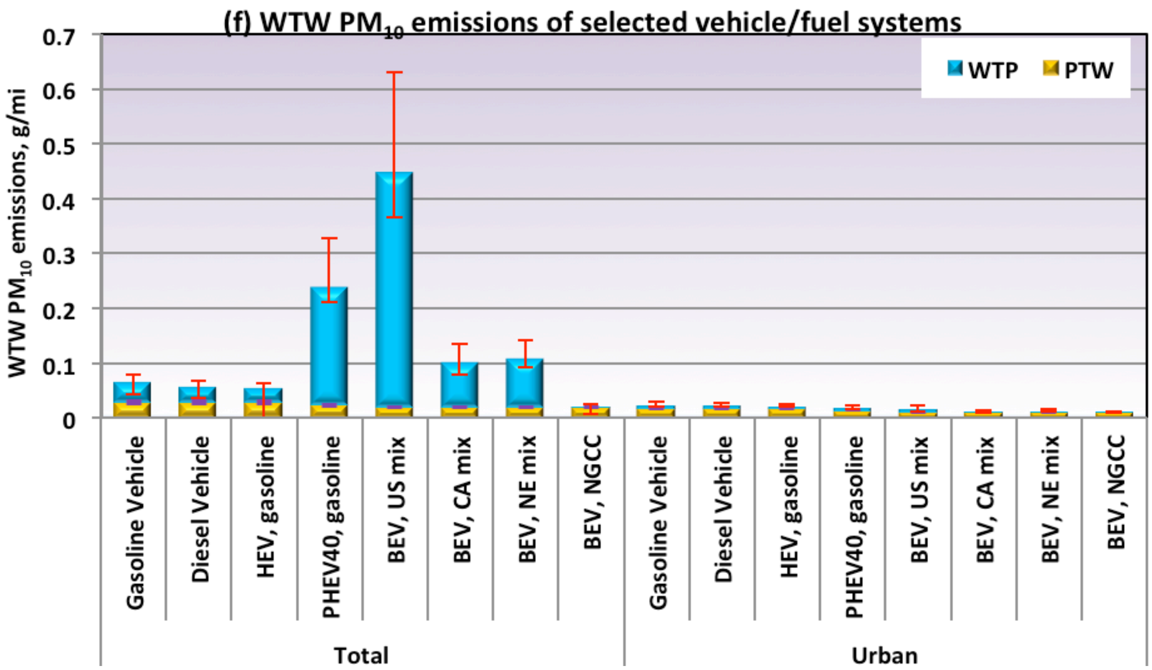



(b) WTW VOC emissions of selected vehicle/fuel systems
WTW VOC emissions, g/mi
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
WTP
PTW
Gasoline Vehicle
Diesel Vehicle
HEV, gasoline
PHEV40, gasoline
BEV, US mix
BEV, CA mix
BEV, NE mix
BEV, NGCC
Total
Urban


(c) WTW CO emissions of selected vehicle/fuel systems
WTW CO emissions, g/mi
6
5
4
3
2
1
0
WTP
PTW
Gasoline Vehicle
Diesel Vehicle
HEV, gasoline
PHEV40, gasoline
BEV, US mix
BEV, CA mix
BEV, NE mix
BEV, NGCC
Total
Urban


(d) WTW NOx emissions of selected vehicle/fuel systems
WTW NOx emissions, g/mi
0.6
0.5
0.4
0.3
0.2
0.1
0
WTP
PTW
Gasoline Vehicle
Diesel Vehicle
HEV, gasoline
PHEV40, gasoline
BEV, US mix
BEV, CA mix
BEV, NE mix
BEV, NGCC
Gasoline Vehicle
Diesel Vehicle
HEV, gasoline
PHEV40, gasoline
BEV, US mix
BEV, CA mix
BEV, NE mix
BEV, NGCC
Total
Urban


(e) WTW SOx emissions of selected vehicle/fuel systems
WTW SOx emissions, g/mi
2.5
2
1.5
1
0.5
0
WTP
PTW
Gasoline Vehicle
Diesel Vehicle
HEV, gasoline
PHEV40, gasoline
BEV, US mix
BEV, CA mix
BEV, NE mix
BEV, NGCC
Gasoline Vehicle
Diesel Vehicle
HEV, gasoline
PHEV40, gasoline
BEV, US mix
BEV, CA mix
BEV, NE mix
BEV, NGCC
Total
Urban



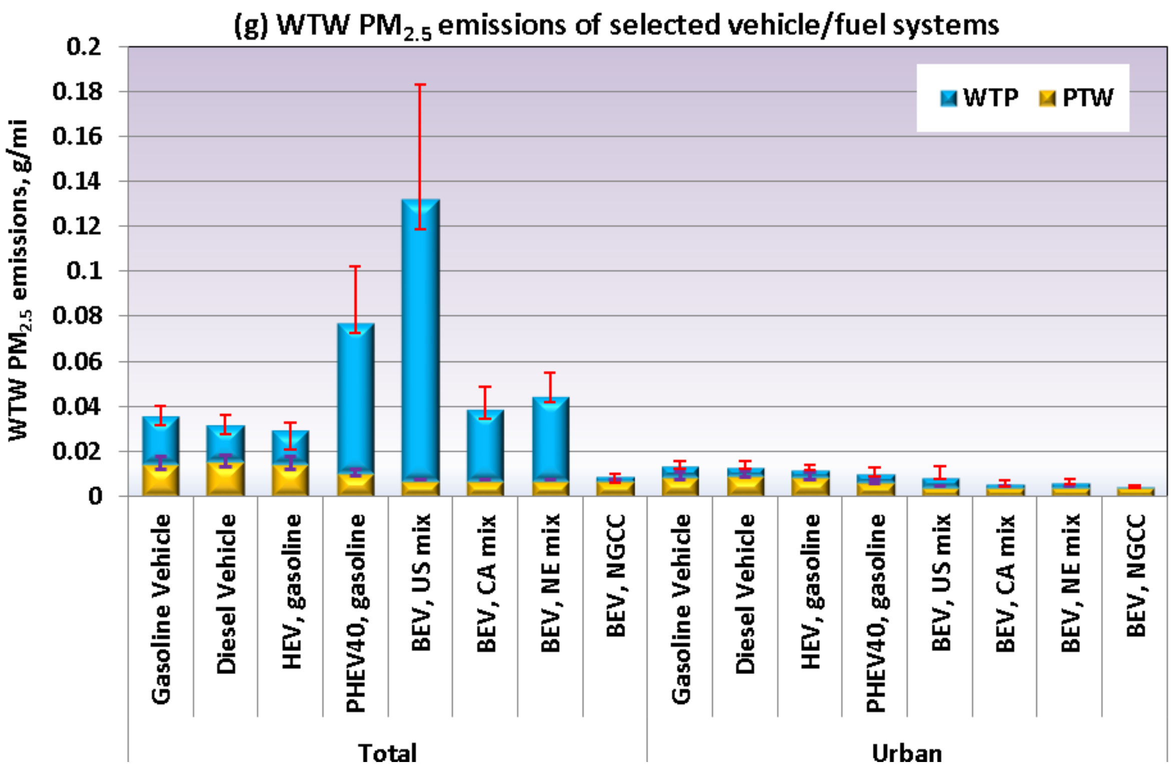


FIGURE 3 **Life-cycle (a) GHG; (b) VOC; (c) CO; (d) NO_x; (e) SO_x; (f) PM_{10}; and (g) $PM_{2.5}$ emissions of selected vehicle/fuel systems with updated characterization of electricity generation module in GREET 1_2011. The red and purple error bars denote the standard deviations of the WTP and PTW emissions based on multiple stochastic simulations.**

Figure 3(a) shows that vehicle/fuel systems like diesel vehicles, gasoline and diesel HEVs, PHEV40S, and BEVs with various grid mixes could achieve different extents of GHG reduction benefits, with the highest reduction potentials of about 68%, 62%, 51% and 34%, respectively, for BEVs with CA grid mix, NE grid mix, NGCC, and the U.S. average grid mix, compared to conventional gasoline vehicles.

Figure 3(b) shows that BEVs with various grid mixes could achieve significant reductions in total VOC emissions, mainly because of the low VOC emissions associated with the WTP stage and avoidance of PTW VOC emissions. Low-sulfur conventional diesel vehicles, gasoline HEVs and gasoline PHEV40 could also achieve considerable reductions in VOC emissions, mainly because of lower WTP and PTW emissions as a result of higher fuel economy and lower tailpipe VOC emission factors, compared to conventional gasoline vehicles. These vehicle/fuel systems could also contribute to reductions in urban VOC emissions, which are precursors of major urban air pollution concerns like ozone formation and fine PM. In addition, moderate to large uncertainties are associated with WTP VOC emissions for most vehicle/fuel systems, particularly for BEVs, indicating that the primary uncertainties are associated with upstream electricity generation.

Figure 3(c) shows that the WTW CO emissions of all the vehicle/fuel systems except for BEVs are dominated by PTW emissions, despite notable uncertainties associated with tailpipe CO emission factors. Meanwhile, diesel vehicles and PHEV40 show remarkable reductions in both total and urban WTW CO emissions, mostly owing to lower tailpipe CO emission factors and higher fuel economy compared to conventional gasoline vehicles.

Figure 3(d) shows that the WTW NO_x emissions for PHEV40 and BEVs are dominated by WTP emissions, while the WTP NO_x emissions are comparable to the PTW emissions for conventional gasoline and diesel vehicles. In addition, it is possible that gasoline PHEV40s and BEVs will generate more total NO_x emissions than conventional gasoline and diesel vehicles, mainly because of their high WTP NO_x emissions from electricity generation. On the other hand, BEVs charged by cleaner generation mixes like the CA and NE mixes, or by electricity from more efficient combustion technologies like NGCC, will doubtless achieve both total and urban WTW NO_x emission reductions compared to conventional gasoline vehicles. Moreover, BEVs will produces less urban NO_x emissions, even with the U.S. average electricity generation mix.

As shown in Figure 3(e), WTW SO_x emissions are dominated by WTP emissions for all vehicle/fuel systems, mainly because of consumption of process fuels like coal, biomass, and residual oil in the fuel production and electricity generation processes. Consequently, BEVs using the current U.S. average electricity generation mix, the CA generation mix, or the NE generation mix are likely to produce more total SO_x emissions than conventional gasoline and diesel vehicles, while BEVs charged by the U.S. average mix and the NE mix are likely to have slightly higher urban SO_x emissions, with those charged by the CA mix likely to have slightly lower urban SO_x emissions, in comparison to conventional gasoline and diesel vehicles.

Figures 3(f) and 3(g) show that WTP PM_{10} and $PM_{2.5}$ emissions are comparable to PTW emissions for conventional gasoline and diesel vehicles and HEVs, while the WTW PM_{10} and $PM_{2.5}$ emissions for gasoline PHEV40s and BEVs are dominated by WTP emissions. WTP emissions are also comparable to PTW emissions for conventional gasoline, diesel vehicles, and HEVs, although ─ particularly for BEVs and PHEV40s ─, large uncertainties are associated with the WTP PM_{10} emissions, which are mainly due to the wide range of PM_{10} and $PM_{2.5}$ emission factors for EGUs burning coals with diverse ash and sulfur contents and with different deployment rates of PM and sulfur emission control devices. Consequently, gasoline PHEV40s and BEVs charged by the U.S. average electricity generation mix or regional mixes like the CA mix and NE mix are likely to generate more total PM_{10} emissions than conventional gasoline and diesel vehicles, while BEVs charged by electricity from highly efficient NGCC plants are very likely to produce less total and urban PM_{10} emissions than conventional gasoline and diesel vehicles.

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APPENDIX

Table and Figure list:

TABLE A1 NO$_x$ emission factors of EGUs by fuel type, combustion technology, firing type and emission control technology

	Uncon-trolled	LNB	LNB w/ OFA	OFA	Reburn	BOOS, BF	SNCR	SCR	LNB w/ SNCR	LNB w/ OFA and SCR	LEA	FGR	WI	Com. Opt.
Coal (unit: lb/ton)														
BIT, BLR, PC, dry bottom	12	(0.55)*12	(0.5)*12	(0.75)*12	(0.45)*12	(0.85)*12	(0.55)*12	(0.2)*12	(0.35)*12	(0.1)*12	(0.8[a])*12	(0.65[a])*12	(0.7[a])*12	
BIT, BLR, PC, wet bottom	31													
BIT, BLR, tangential	10	9.7											7	8
BIT, FBC	15.2													
BIT, Stoker	11													
BIT, Cyclone	33													
SUB, BLR, PC, dry bottom	7.4													
SUB, BLR, PC, wet bottom	24													
SUB, BLR, tangential	7.2													
SUB, FBC	15.2													
SUB, Stoker	8.8													
SUB, Cyclone	17													

TABLE A1 (Cont.)

	Uncon-trolled	LNB	LNB w/ OFA	OFA	Reburn	BOOS, BF	SNCR	SCR	LNB w/ SNCR	LNB w/ OFA and SCR	LEA	FGR	WI	Com. Opt.
Coal (unit: lb/ton)														
SUB, Cell	14													
LIG, BLR, PC, dry bottom	6.3	4.6		4.6										
LIG, BLR, tangential	7.1			6										
LIG, Cyclone	15													
LIG, FBC	3.6													
PetCoke, BLR	21													
NG (unit: lb/million scf)														
NG, BLR	190[b]; 100[c]	140[b]; 32[c]										100[b]; 32[c]		
NG, BLR (tangen-tial)	170											76		
NG, ICE	2840													
NG, CT	0.32												0.13	0.099
LFG, CT[d]	0.14													
BFG, BLR	23													
DG, CT[d]	0.16													
Oil (unit: lb/1000 gal)														
RFO, BLR	47[e]; 32[f]	40[e]; 26[f]												
DFO, BLR	24	10										10		

TABLE A1 (Cont.)

	Uncon-trolled	LNB	LNB w/ OFA	OFA	Reburn	BOOS, BF	SNCR	SCR	LNB w/ SNCR	LNB w/ OFA and SCR	LEA	FGR	WI	Com. Opt.
Oil (unit: lb/1000 gal)														
DFO, CT	0.88[d]												0.24[d]	
DFO, ICE	604													
JF, CT	0.88[d]													
KER, CT	0.88[d]													
WO, BLR	19													
Biomass (lb/mmBtu)														
Dry WDS, BLR, ≤20% moisture	0.49													
Wet WDS, BLR, ≥20% moisture	0.22													
BLQ, BLR												0.209[g]		

Notes: BOOS is burners-out-of-service.
BF is biased firing.
SCR is selective catalytic reduction.
SNCR is selective noncatalytic reduction.
LEA is low excess air.
Com.Opt. is combustion optimization.
The numbers in parentheses indicate the emission reduction ratio achieved by the corresponding emission control device in operation, obtained mainly from AP-42 on an average basis.

TABLE A1 (Cont.)

[a] Source: World Bank Group, 1998.
[b] For boilers >100 million Btu/hr.
[c] For boilers <100 million Btu/hr.
[d] Unit is lb/mmBtu.
[e] Normal firing boilers.
[f] Tangential firing boilers.
[g] Unit is lb/ton.

TABLE A2 SO_x emission factors of EGUs by fuel type, combustion technology, firing type and emission control technology

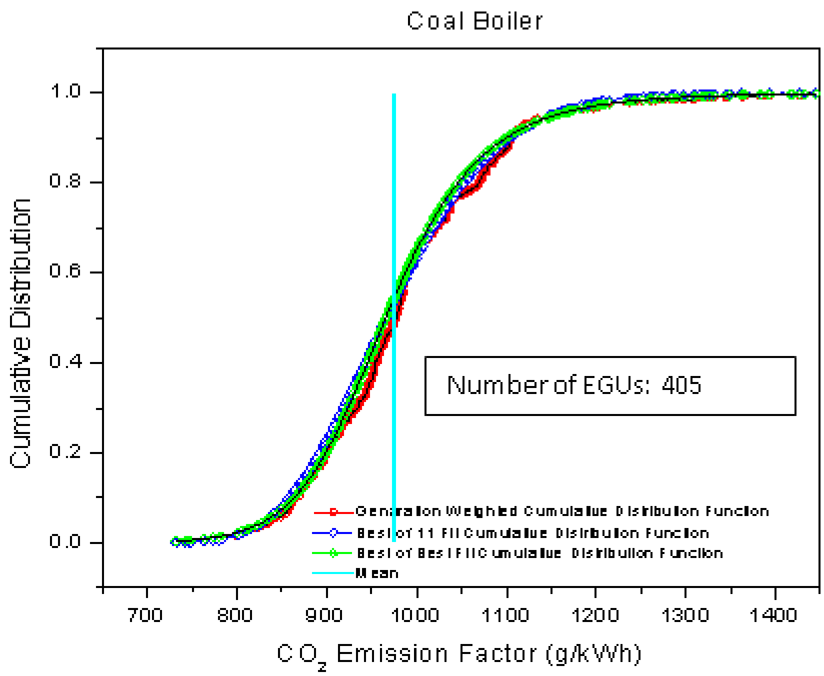
	Uncontrolled	Wet scrubber	Spray drying	Furnace injection	Duct injection
Coal (unit: lb/ton)					
BIT, BLR, PC, dry bottom	38*S	0.1*38*S	0.2*38*S	0.625*38*S	0.625*38*S
BIT, BLR, PC, wet bottom	38*S				
BIT, BLR, tangential	38*S				
BIT, FBC	38*S				
BIT, Stoker	38*S				
BIT, Cyclone	38*S				
SUB, BLR, PC, dry bottom	35*S				
SUB, BLR, PC, wet bottom	35*S				
SUB, BLR, tangential	35*S				
SUB, FBC	35*S				
SUB, Stoker	35*S				
SUB, Cyclone furnace	35*S				
SUB, Cell	35*S				
LIG, BLR, PC, dry bottom	38*S				
LIG, BLR, tangential	38*S				
LIG, BLR, Cyclone	38*S				
LIG, FBC	38*S				
PetCoke, BLR	39*S				
NG (unit: lb/million scf)					
NG, BLR	0.6				
NG, BLR (tangential)	0.6				
NG, ICE	0.6				
NG, CT	0.94*S				

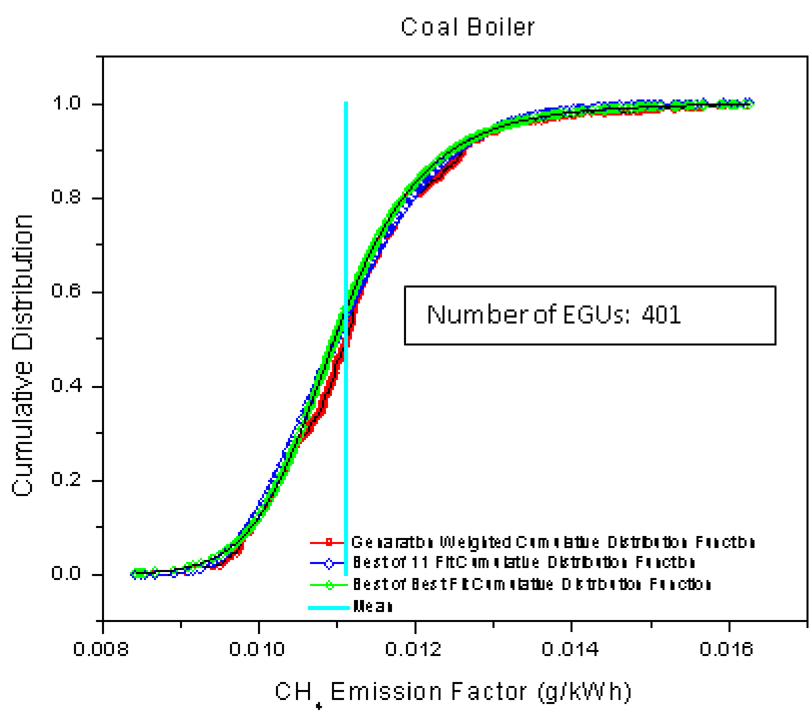
TABLE A2 (Cont.)

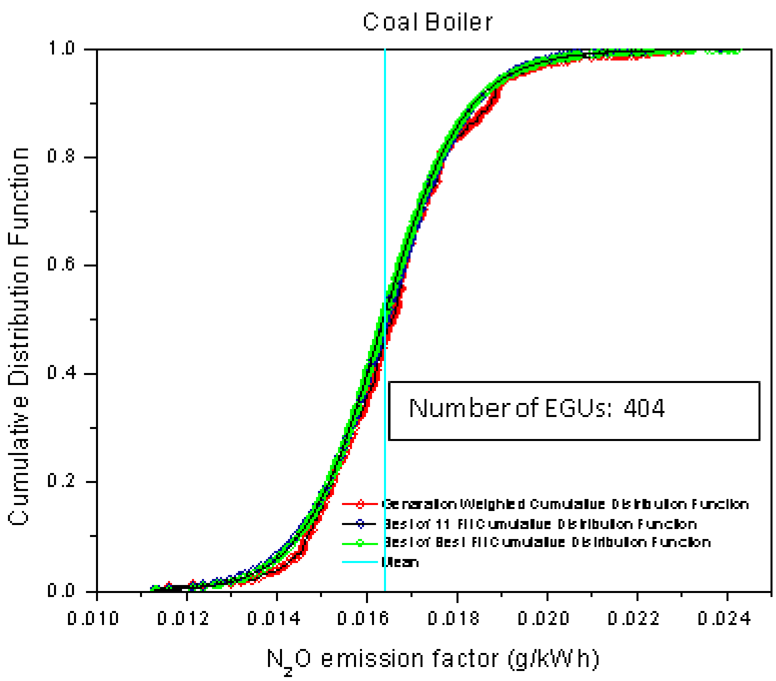
	Uncontrolled	Wet scrubber	Spray drying	Furnace injection	Duct injection
NG (unit: lb/million scf)					
LFG, CT[a]	0.045				
BFG	950*S				
DG, BLR	4.5				
Oil (unit: lb/1000 gal)					
RFO, BLR	157*S				
DFO, BLR	142*S				
DFO, CT	140.39*S				
DFO, ICE	0.29				
JF, CT	1.01*S				
KER, CT[a]	1.01*S				
WO, BLR	147*S				
Biomass (unit: lb/mmBtu)					
Dry WDS, BLR, ≤20% moisture	0.025				
Wet WDS, BLR, ≥20% moisture	0.025				
BLQ, BLR		0.000804[b]			

[a] Unit is lb per mmBtu;
[b] Unit is lb per ton.

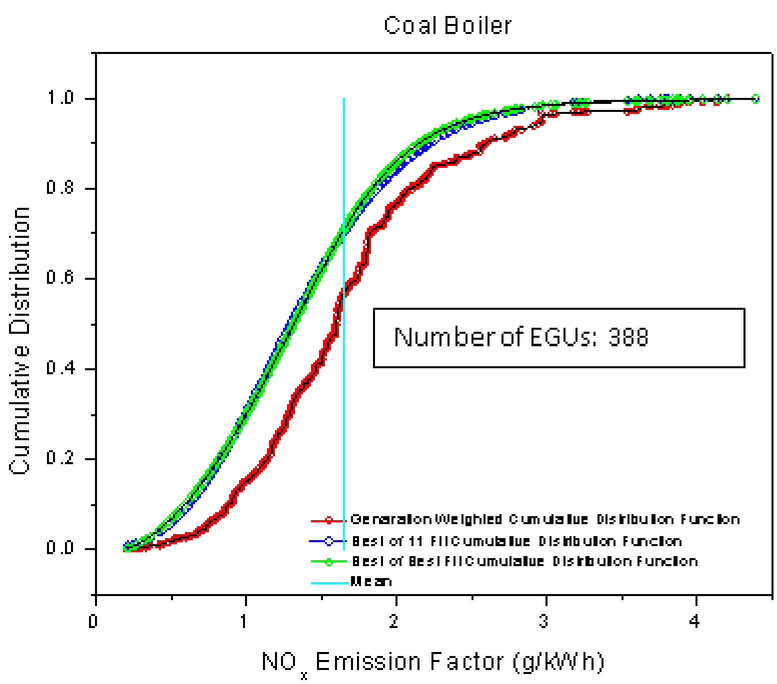
The following figures give cumulative probability distributions (CDFs) of PDFs developed for energy conversion efficiencies and GHG and CAP emission factors of coal-, natural gas-, oil- and biomass-fired boilers, combustion turbines, combined-cycle, and internal combustion engines for U.S. EGUs.



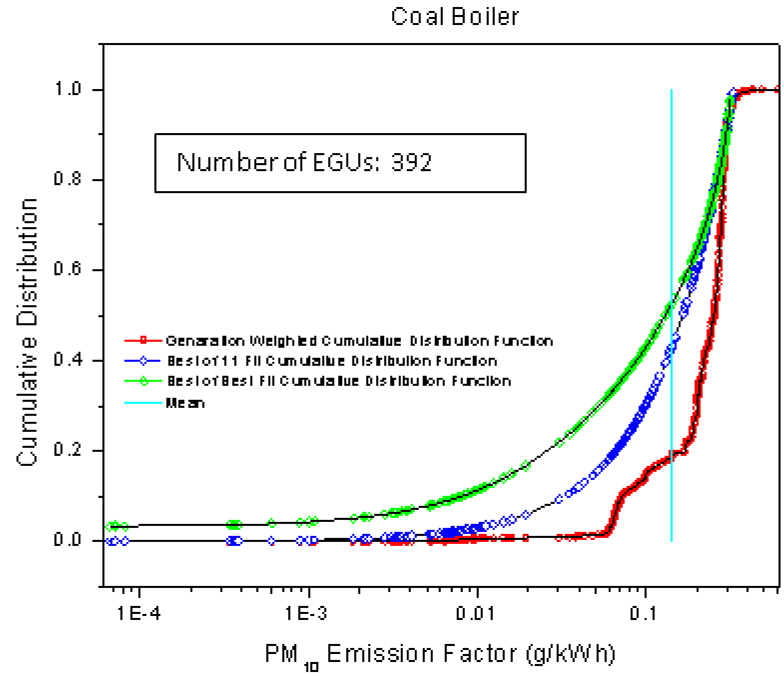


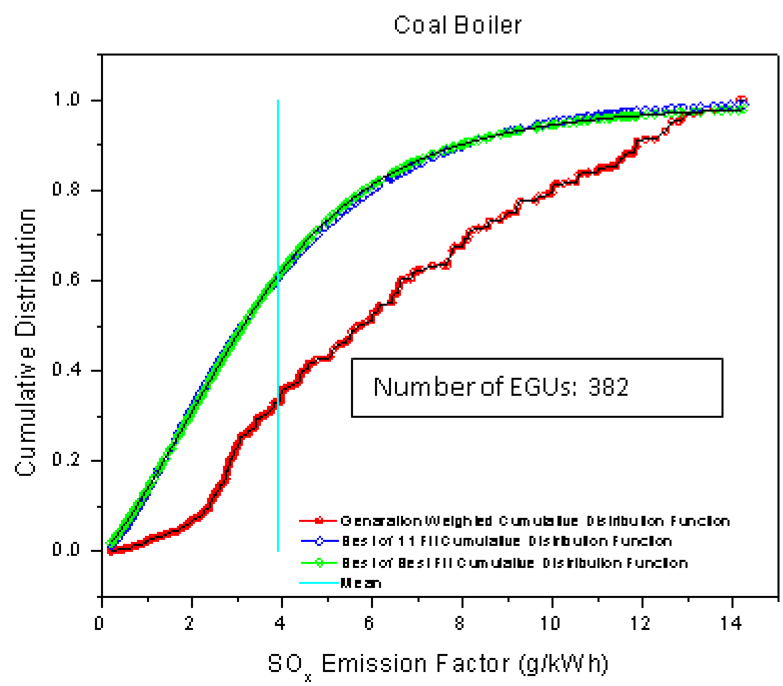


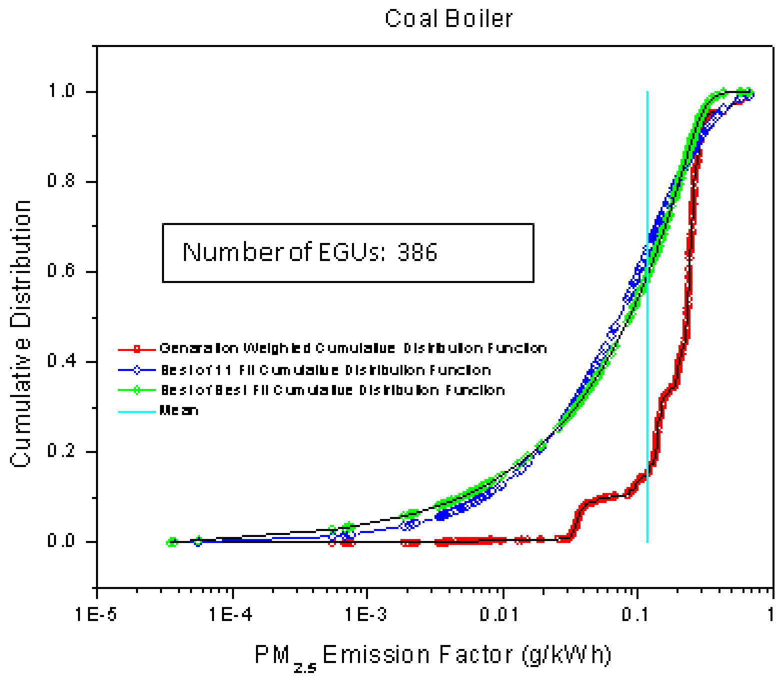
Coal Boiler
Cumulative Distribution Function
N2O emission factor (g/kWh)
Number of EGUs: 404
Mean

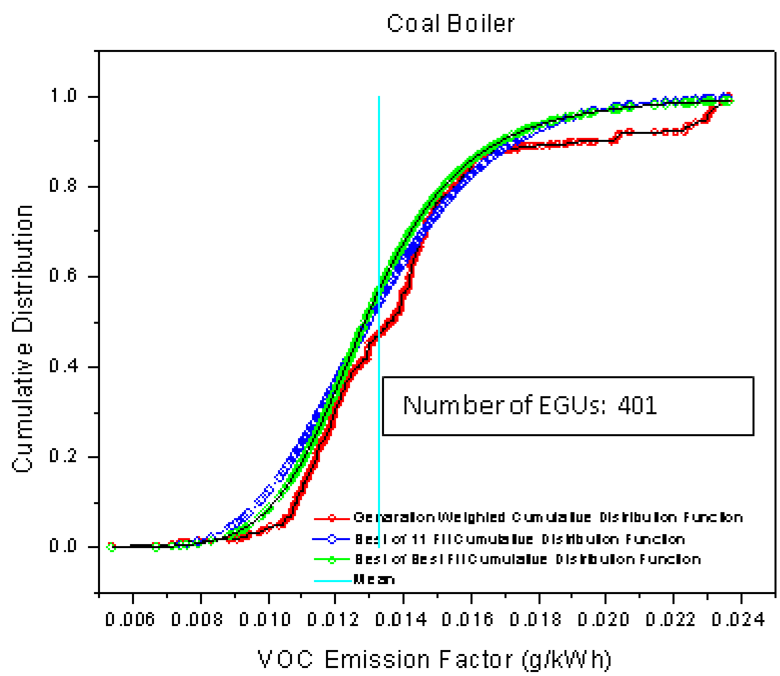


Coal Boiler
Cumulative Distribution
NOx Emission Factor (g/kWh)
Number of EGUs: 388
Mean


Coal Boiler
Number of EGUs: 392
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
Cumulative Distribution
PM10 Emission Factor (g/kWh)


Coal Boiler
Number of EGUs: 382
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
Cumulative Distribution
SOx Emission Factor (g/kWh)


Coal Boiler
Number of EGUs: 386
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
1E-5
1E-4
1E-3
0.01
0.1
1
PM2.5 Emission Factor (g/kWh)


Coal Boiler
Number of EGUs: 401
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
0.006
0.008
0.010
0.012
0.014
0.016
0.018
0.020
0.022
0.024
VOC Emission Factor (g/kWh)

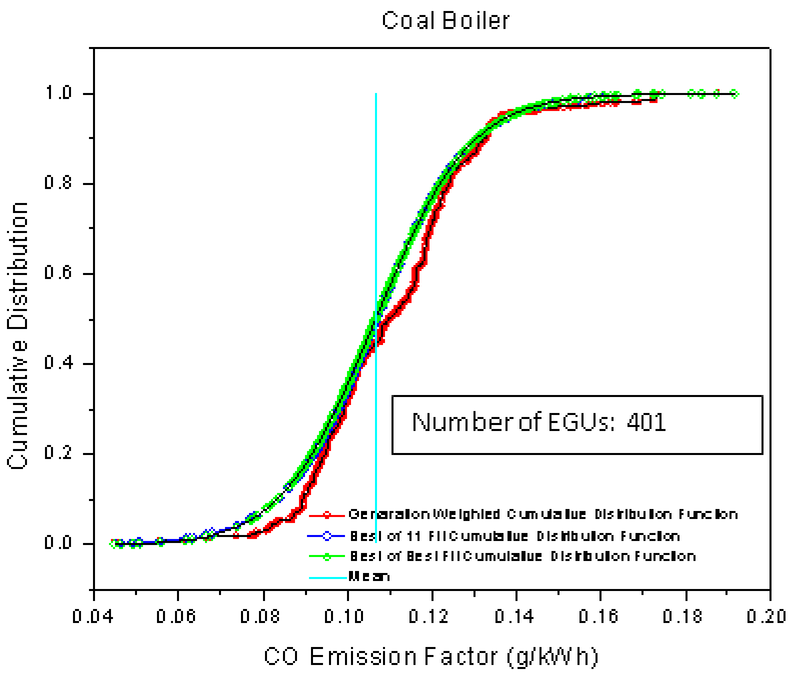
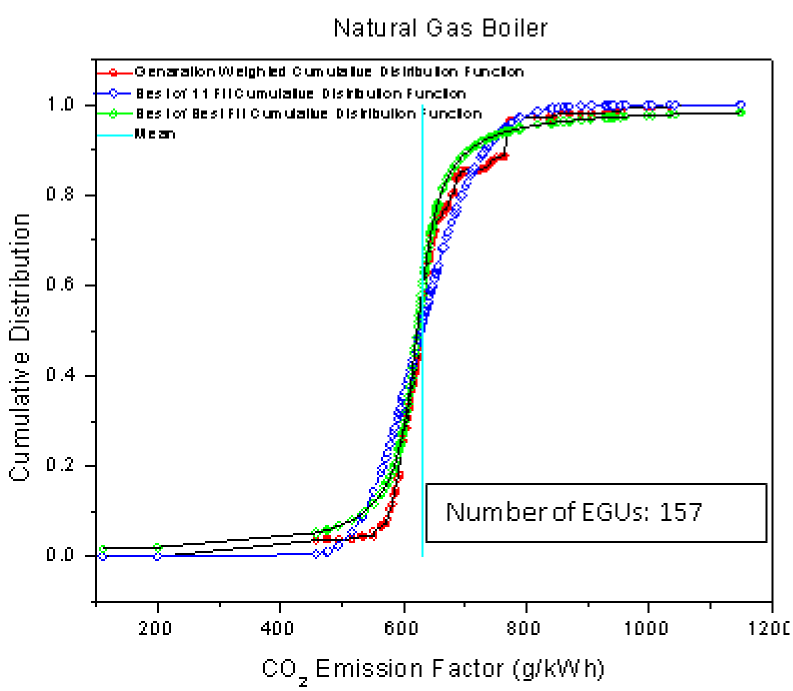
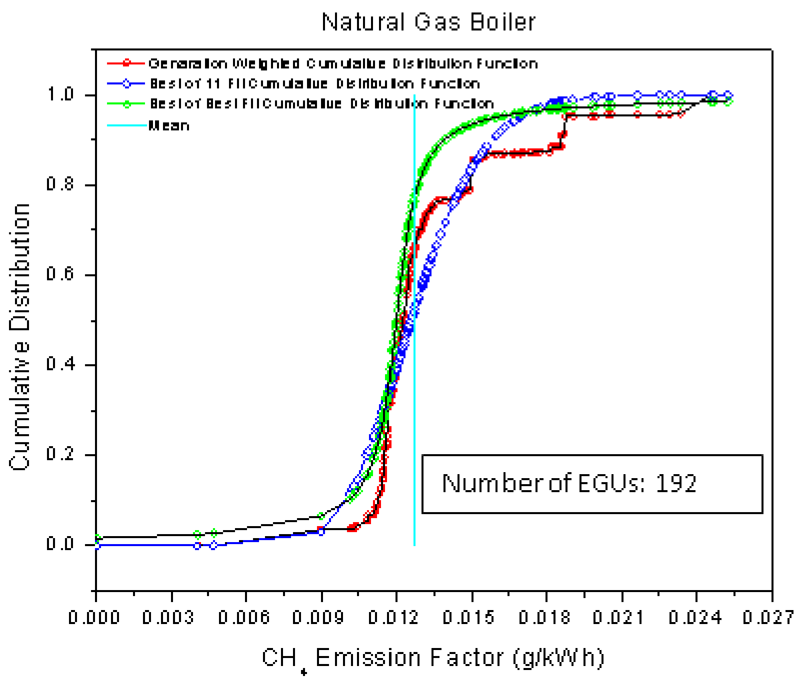
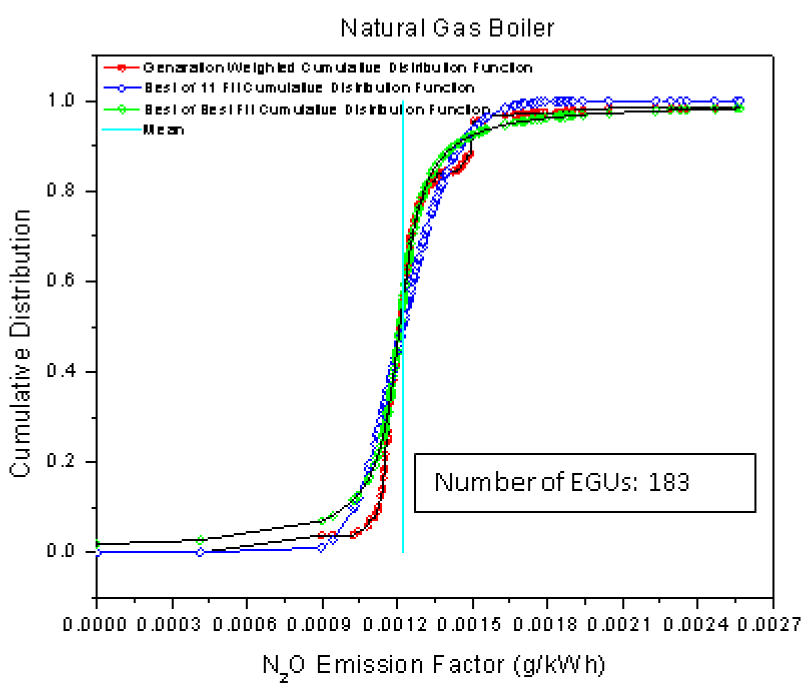
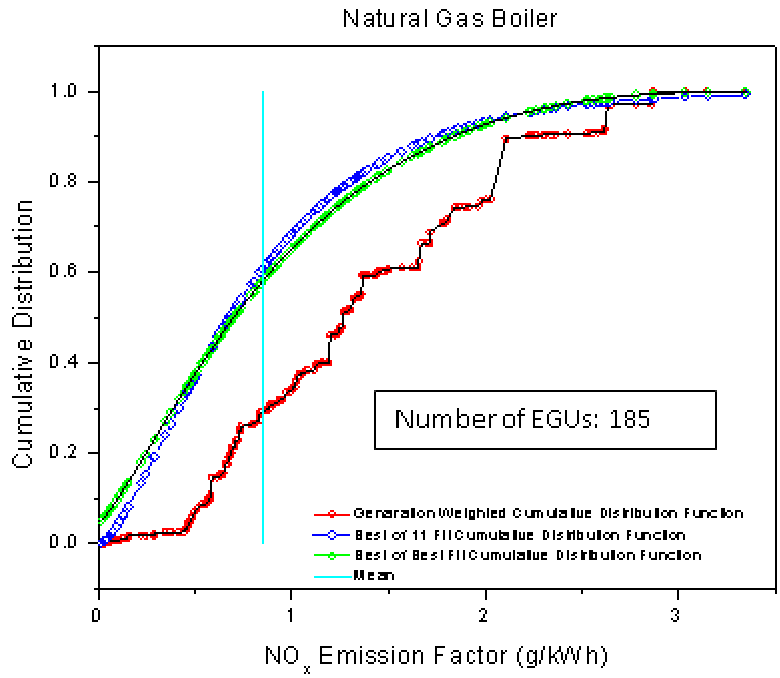


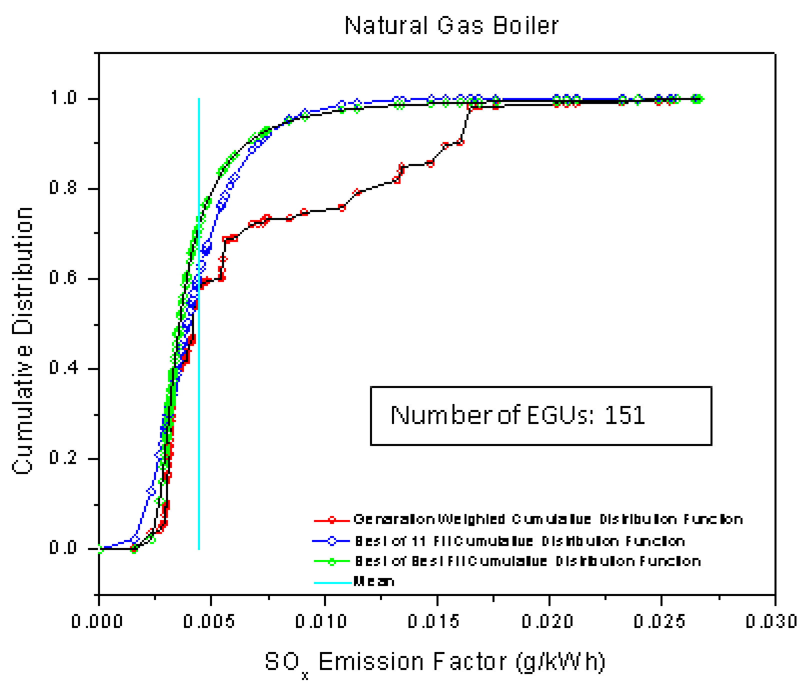
FIGURE A1 Best-fit CDFs of electricity-generation-weighted GHG and CAP emission factors for coal-fired boilers.

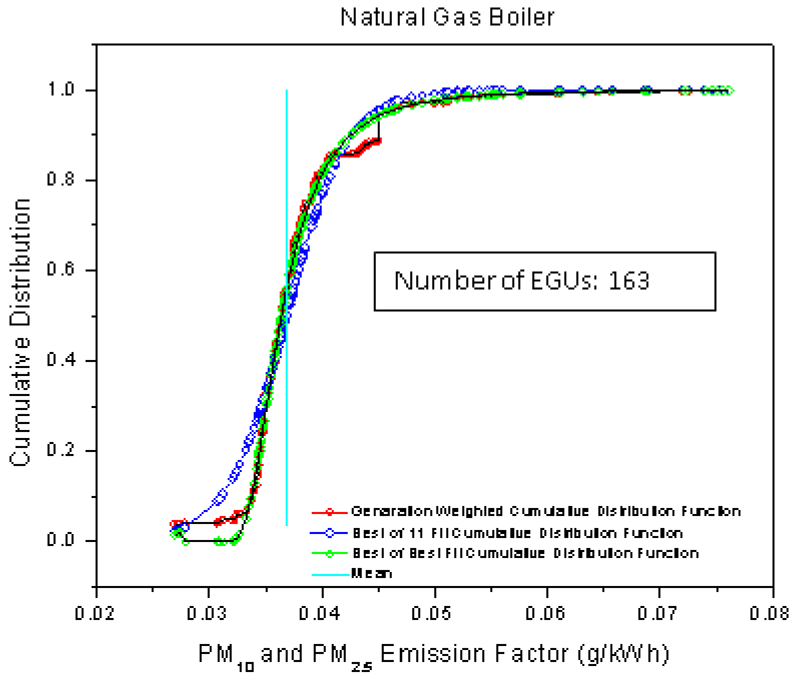


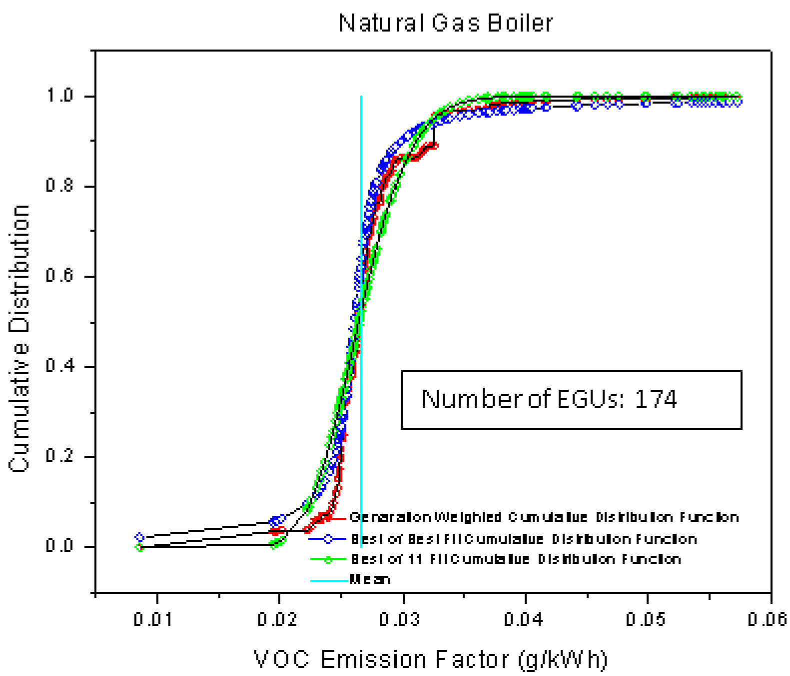

Natural Gas Boiler
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
Number of EGUs: 192
Cumulative Distribution
CH4 Emission Factor (g/kWh)
0.000 0.003 0.006 0.009 0.012 0.015 0.018 0.021 0.024 0.027
0.0 0.2 0.4 0.6 0.8 1.0


Natural Gas Boiler
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
Number of EGUs: 183
Cumulative Distribution
N2O Emission Factor (g/kWh)
0.0000 0.0003 0.0006 0.0009 0.0012 0.0015 0.0018 0.0021 0.0024 0.0027
0.0 0.2 0.4 0.6 0.8 1.0


Natural Gas Boiler
Cumulative Distribution
NO$_x$ Emission Factor (g/kWh)
Number of EGUs: 185
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean


Natural Gas Boiler
Cumulative Distribution
SO$_x$ Emission Factor (g/kWh)
Number of EGUs: 151
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean


Natural Gas Boiler
Cumulative Distribution
PM10 and PM2.5 Emission Factor (g/kWh)
Number of EGUs: 163
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
0.0
0.2
0.4
0.6
0.8
1.0
0.02
0.03
0.04
0.05
0.06
0.07
0.08


Natural Gas Boiler
Cumulative Distribution
VOC Emission Factor (g/kWh)
Number of EGUs: 174
Generation Weighted Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Mean
0.0
0.2
0.4
0.6
0.8
1.0
0.01
0.02
0.03
0.04
0.05
0.06

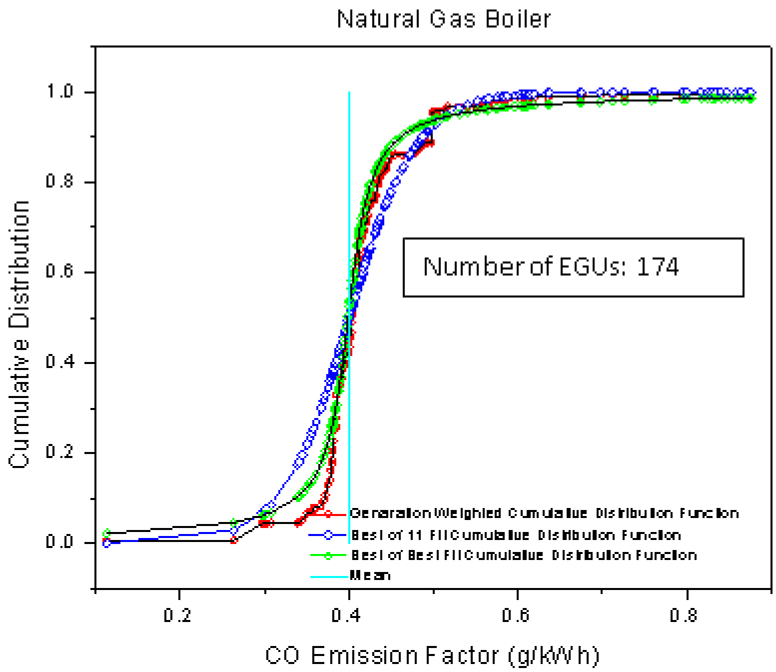
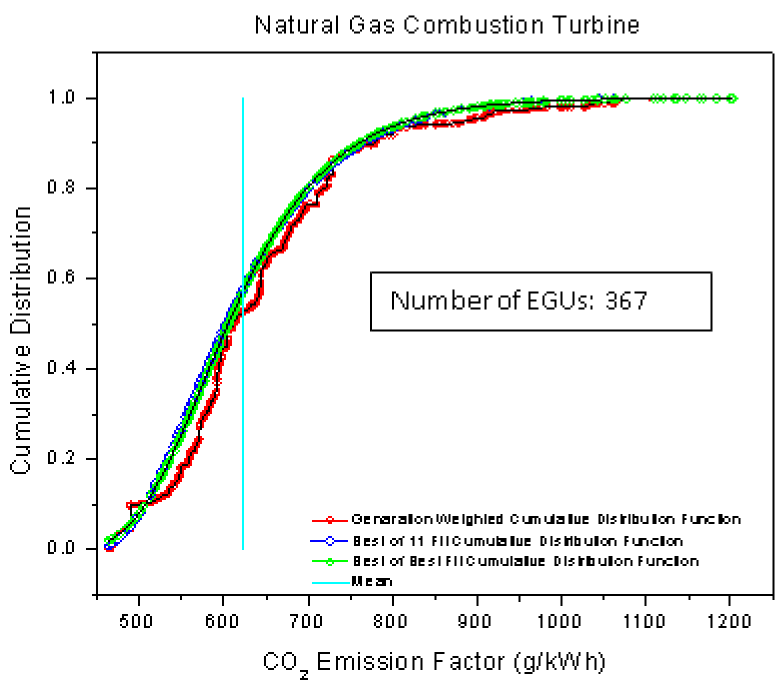
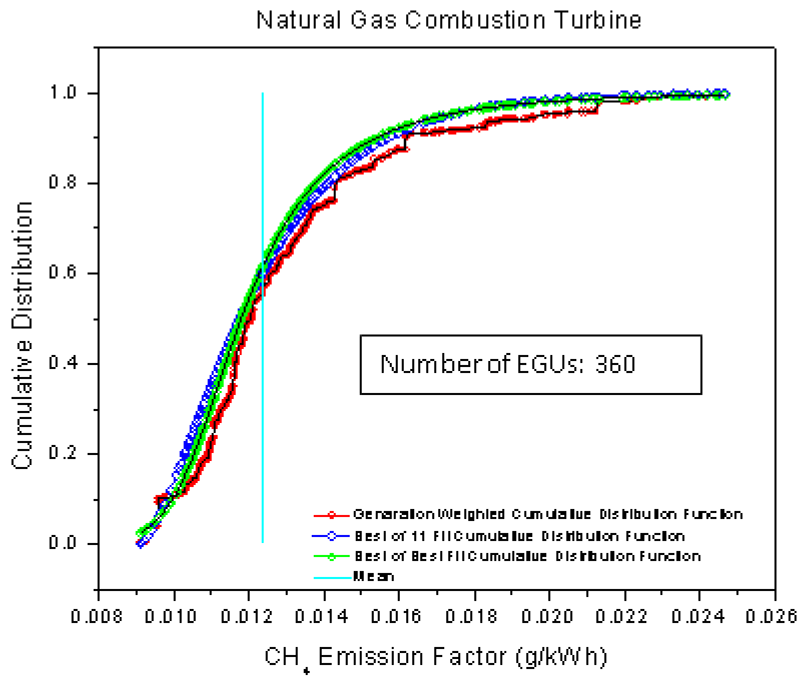
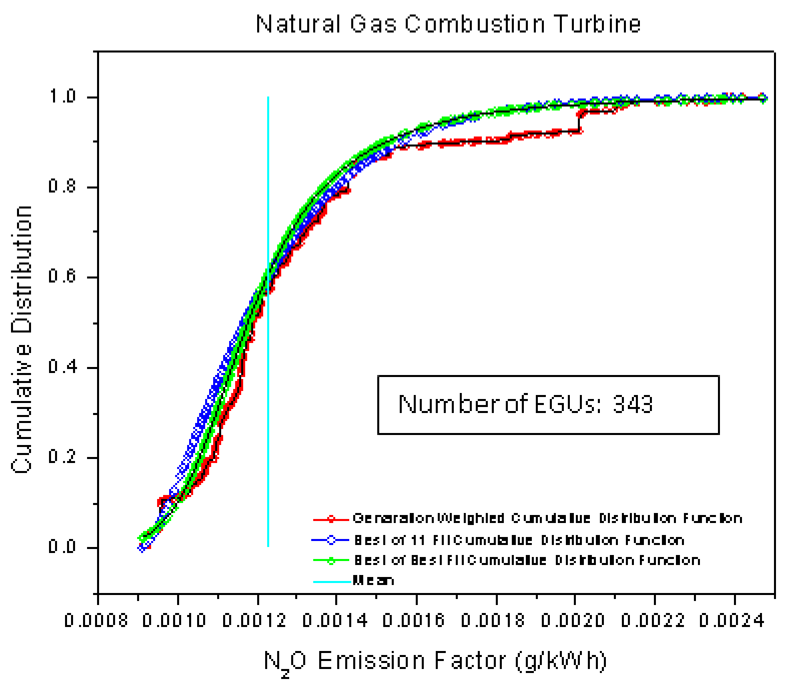
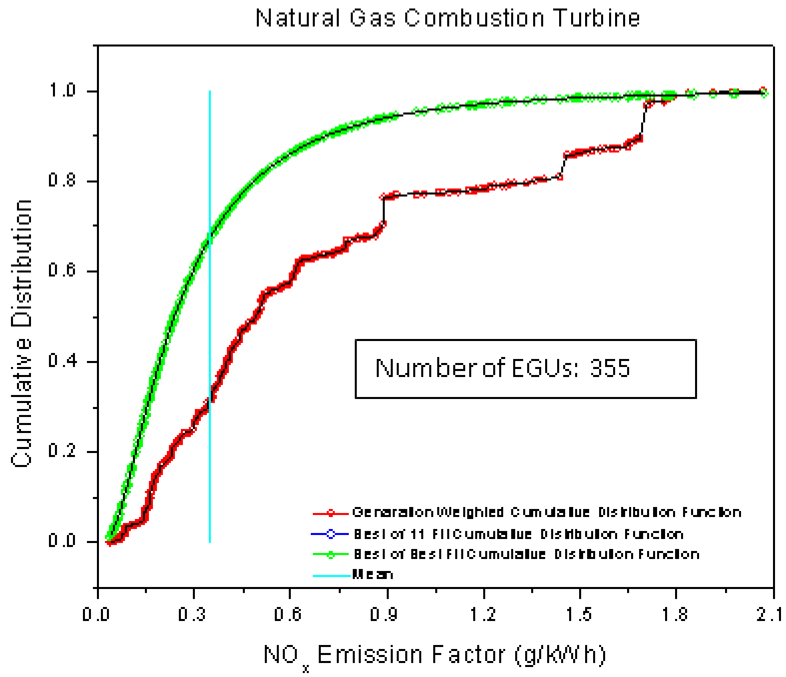


FIGURE A2 Best-fit CDFs of electricity-generation-weighted GHG and CAP emission factors for natural gas-fired boilers.

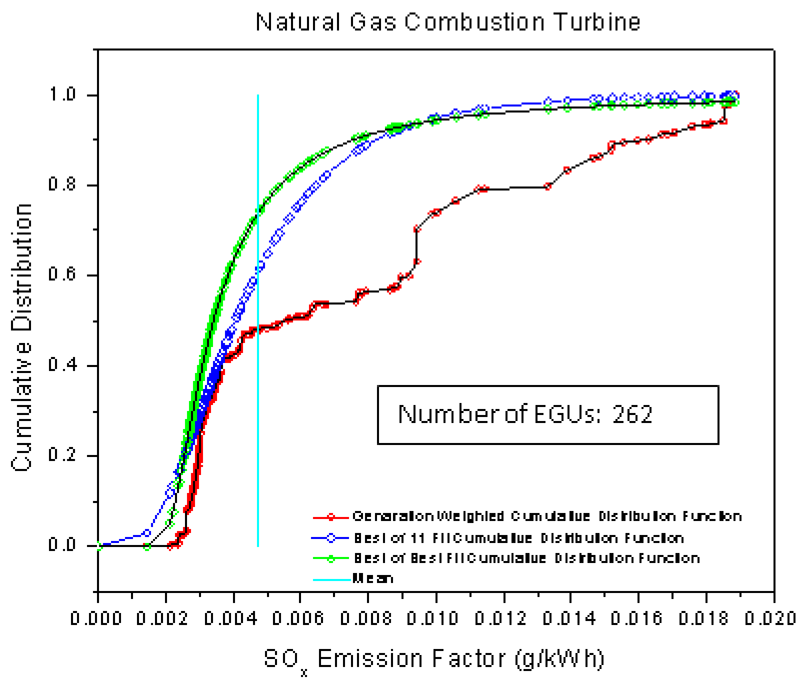



Natural Gas Combustion Turbine
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Number of EGUs: 360
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
0.008 0.010 0.012 0.014 0.016 0.018 0.020 0.022 0.024 0.026
CH_4 Emission Factor (g/kWh)

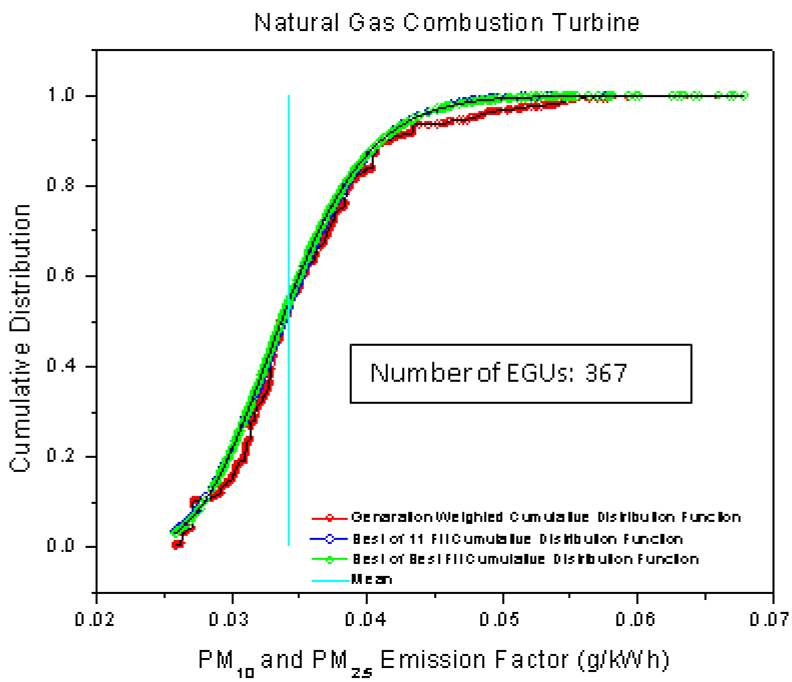

Natural Gas Combustion Turbine
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Number of EGUs: 343
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
0.0008 0.0010 0.0012 0.0014 0.0016 0.0018 0.0020 0.0022 0.0024
N_2O Emission Factor (g/kWh)

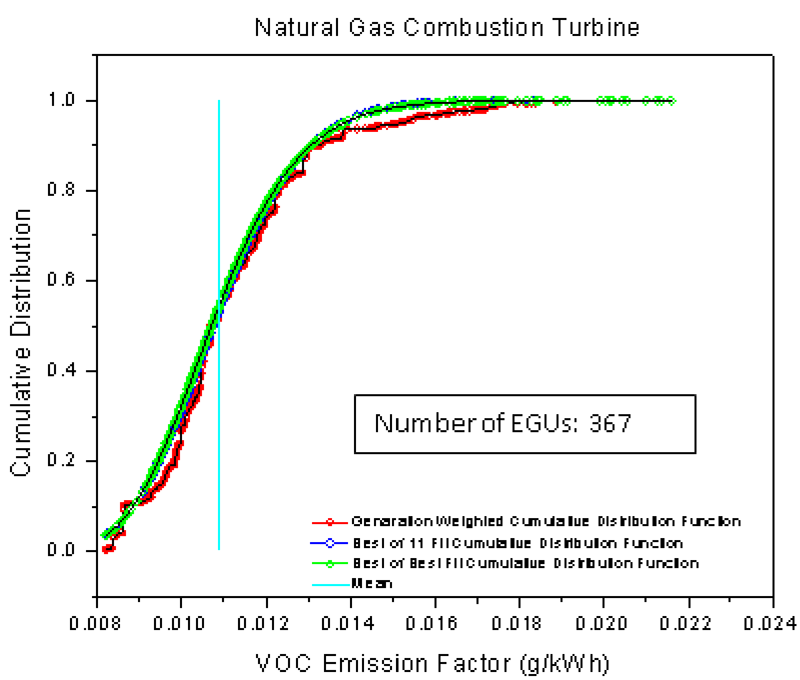


Natural Gas Combustion Turbine
Cumulative Distribution
Number of EGUs: 355
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
NO_x Emission Factor (g/kWh)



Natural Gas Combustion Turbine
Cumulative Distribution
Number of EGUs: 262
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
SO_x Emission Factor (g/kWh)


Natural Gas Combustion Turbine
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
0.02
0.03
0.04
0.05
0.06
0.07
PM10 and PM2.5 Emission Factor (g/kWh)
Number of EGUs: 367
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean


Natural Gas Combustion Turbine
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
0.008
0.010
0.012
0.014
0.016
0.018
0.020
0.022
0.024
VOC Emission Factor (g/kWh)
Number of EGUs: 367
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean

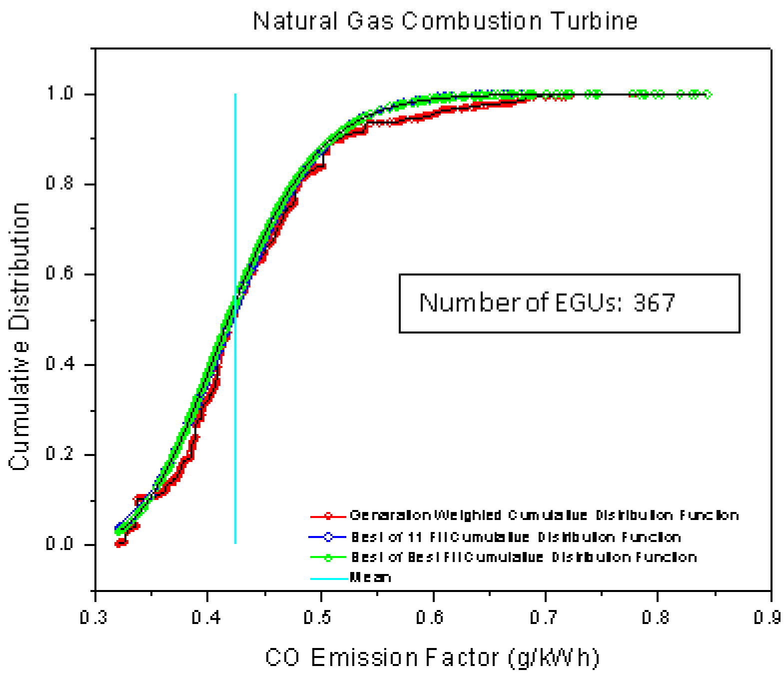
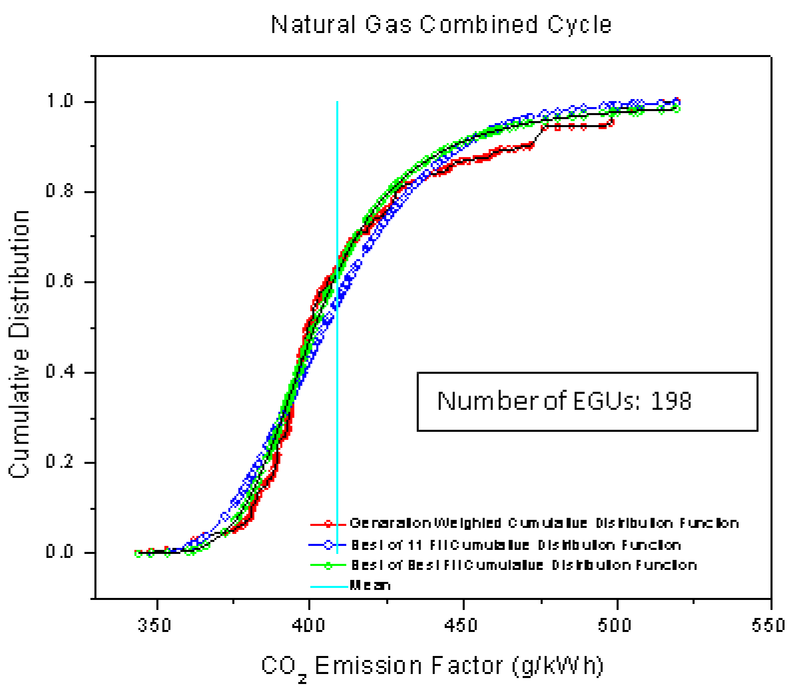
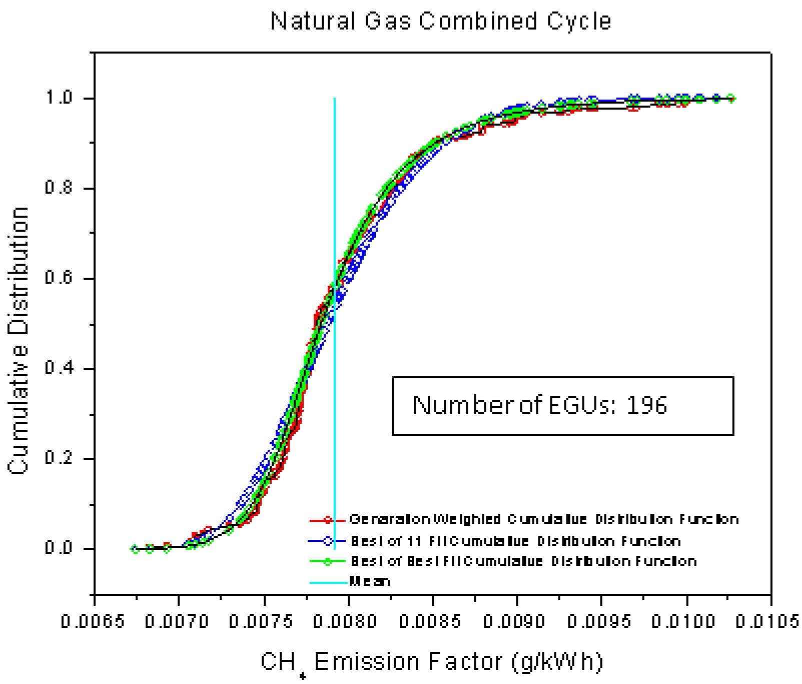
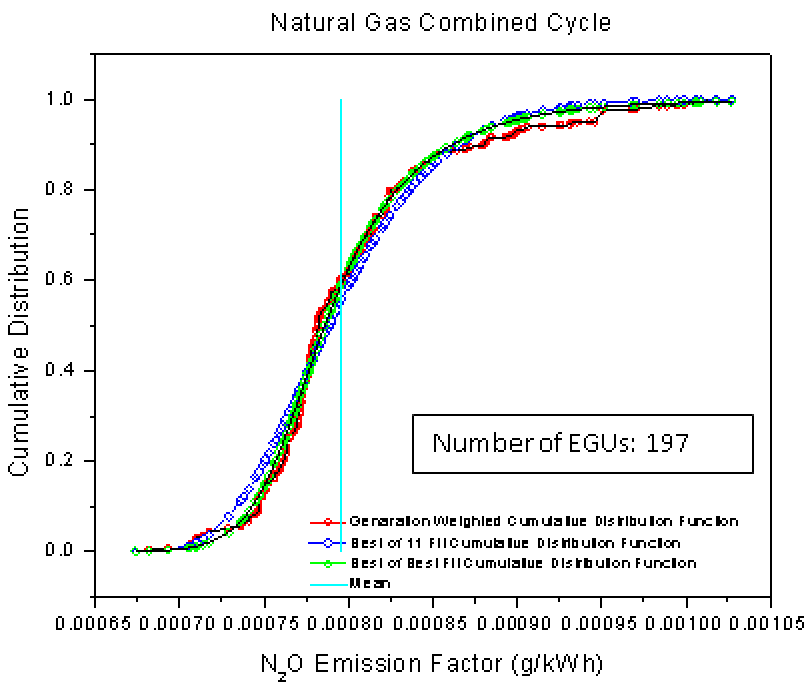


FIGURE A3 Best-fit CDFs of electricity-generation-weighted GHG and CAP emission factors for natural gas-fired combustion turbines.

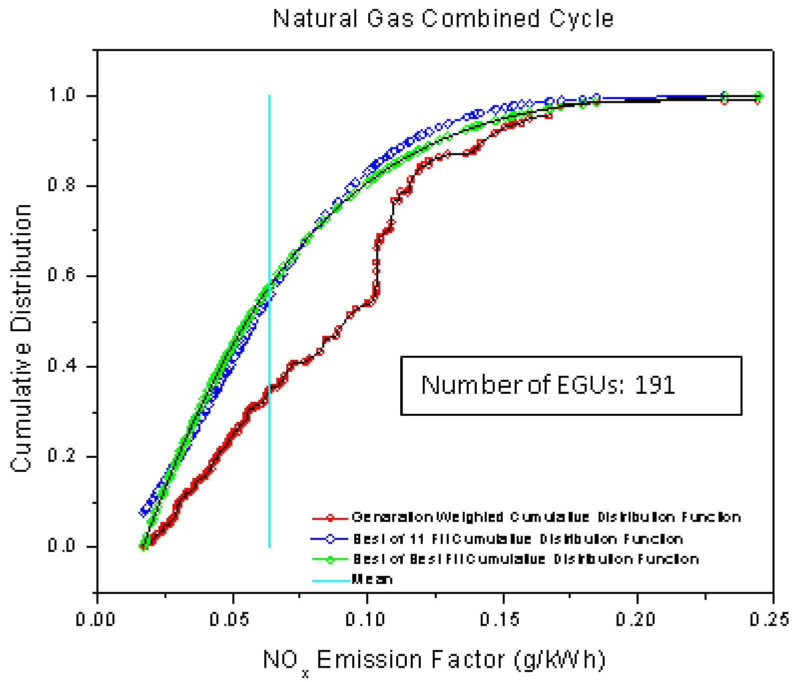


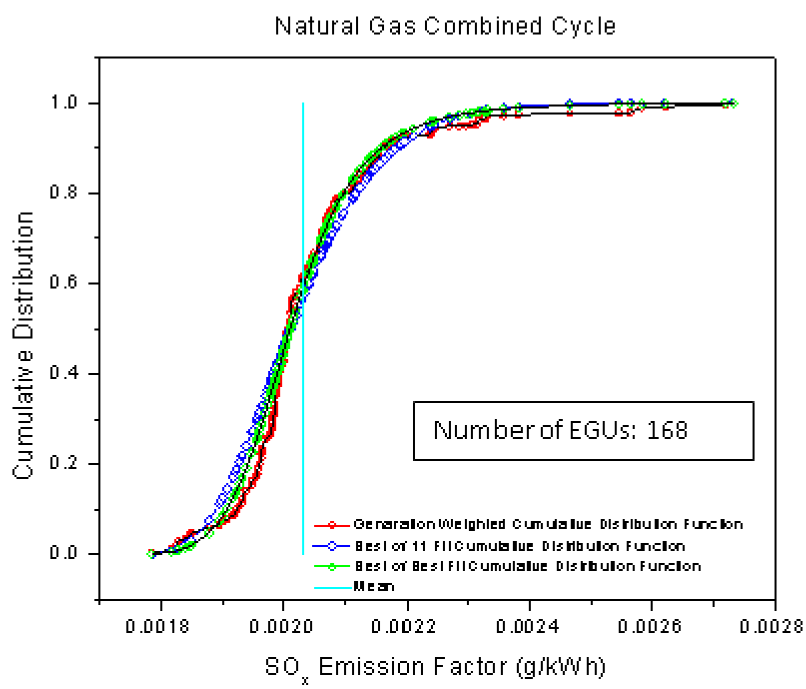


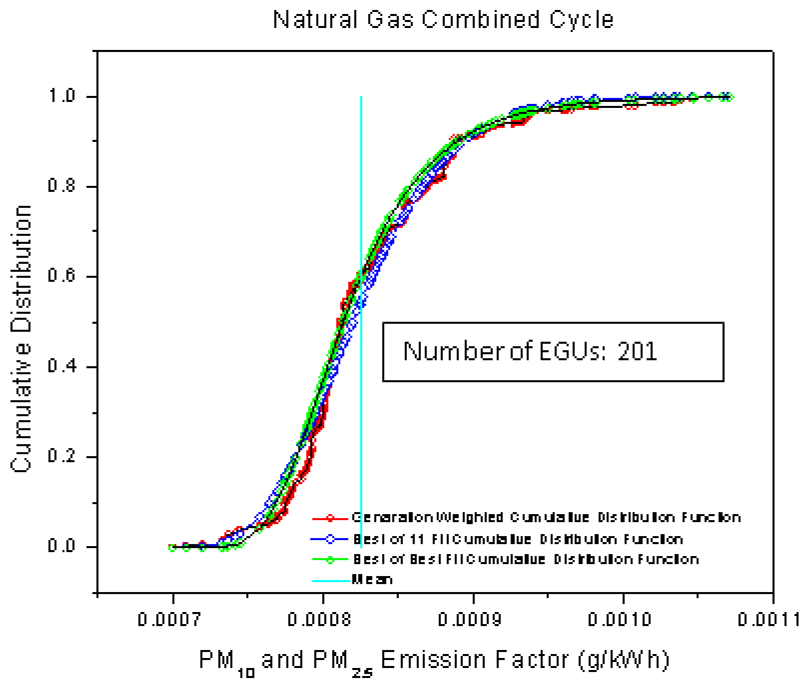
Natural Gas Combined Cycle
Cumulative Distribution
Number of EGUs: 196
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
1.0
0.8
0.6
0.4
0.2
0.0
0.0065 0.0070 0.0075 0.0080 0.0085 0.0090 0.0095 0.0100 0.0105
CH4 Emission Factor (g/kWh)

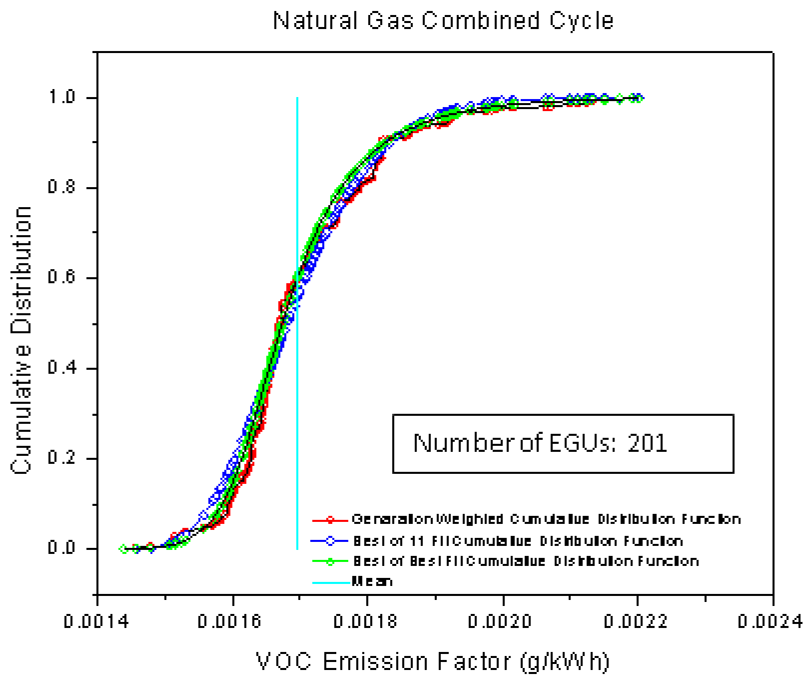


Natural Gas Combined Cycle
Cumulative Distribution
Number of EGUs: 197
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
1.0
0.8
0.6
0.4
0.2
0.0
0.00065 0.00070 0.00075 0.00080 0.00085 0.00090 0.00095 0.00100 0.00105
N2O Emission Factor (g/kWh)


Natural Gas Combined Cycle
Cumulative Distribution
NO_x Emission Factor (g/kWh)
Number of EGUs: 191
1.0
0.8
0.6
0.4
0.2
0.0
0.00
0.05
0.10
0.15
0.20
0.25


Natural Gas Combined Cycle
Cumulative Distribution
SO_x Emission Factor (g/kWh)
Number of EGUs: 168
1.0
0.8
0.6
0.4
0.2
0.0
0.0018
0.0020
0.0022
0.0024
0.0026
0.0028


Natural Gas Combined Cycle
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
0.0007
0.0008
0.0009
0.0010
0.0011
PM_{10} and $PM_{2.5}$ Emission Factor (g/kWh)
Number of EGUs: 201
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean


Natural Gas Combined Cycle
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
0.0014
0.0016
0.0018
0.0020
0.0022
0.0024
VOC Emission Factor (g/kWh)
Number of EGUs: 201
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean

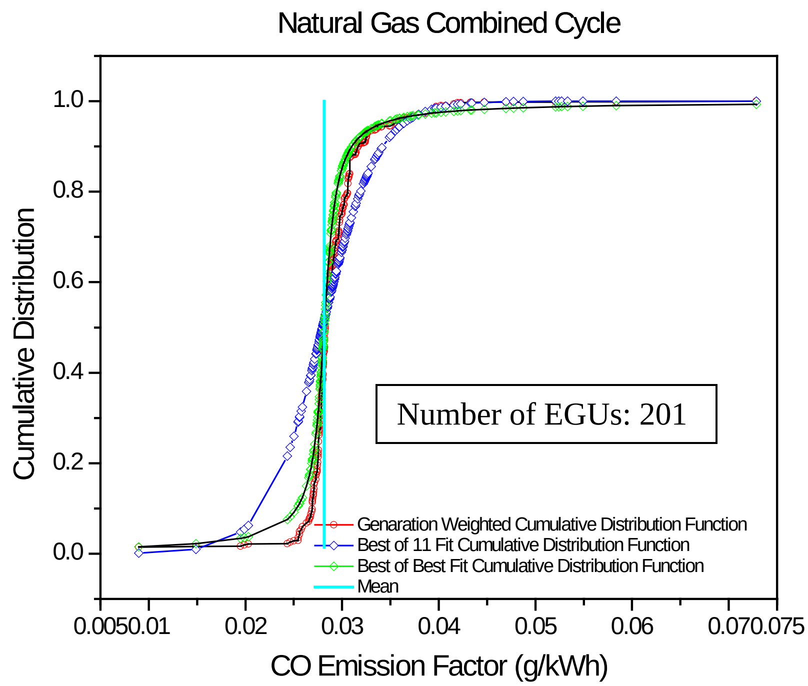
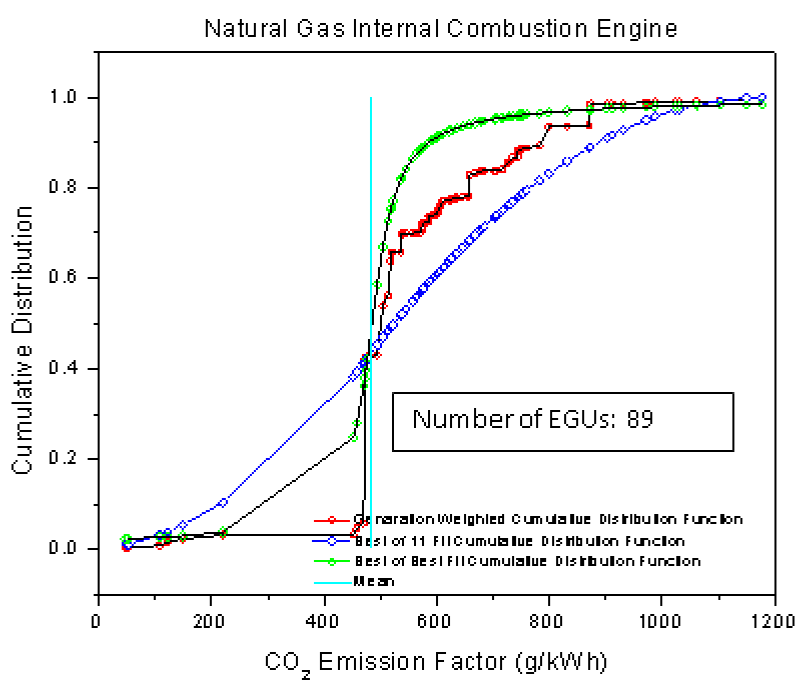
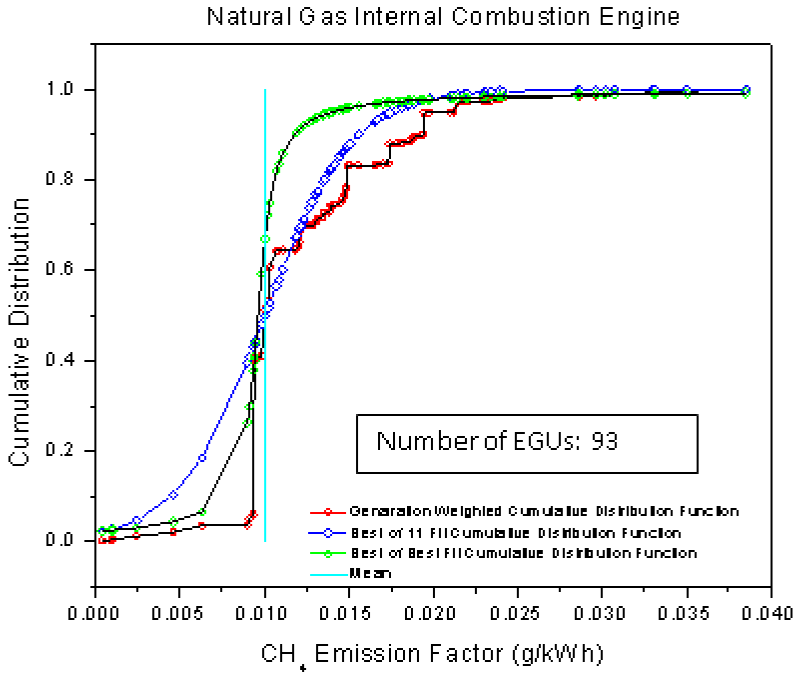
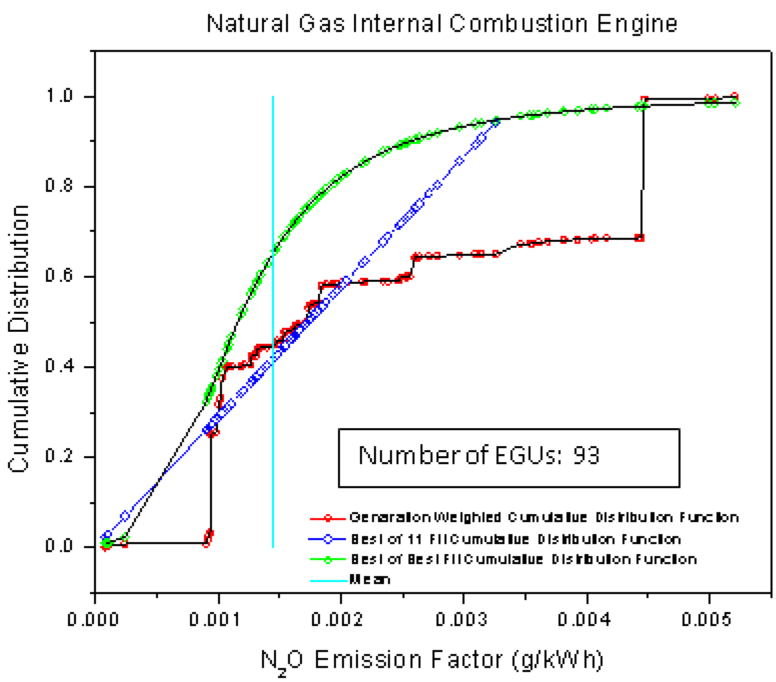


FIGURE A4 **Best-fit CDFs of electricity-generation-weighted GHG and CAP emission factors for natural gas-fired combined-cycle plants.**

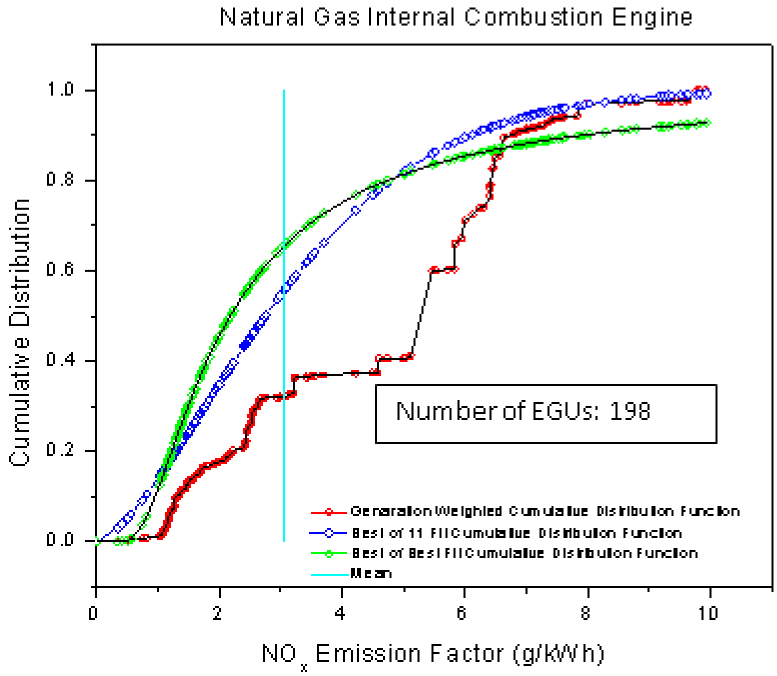


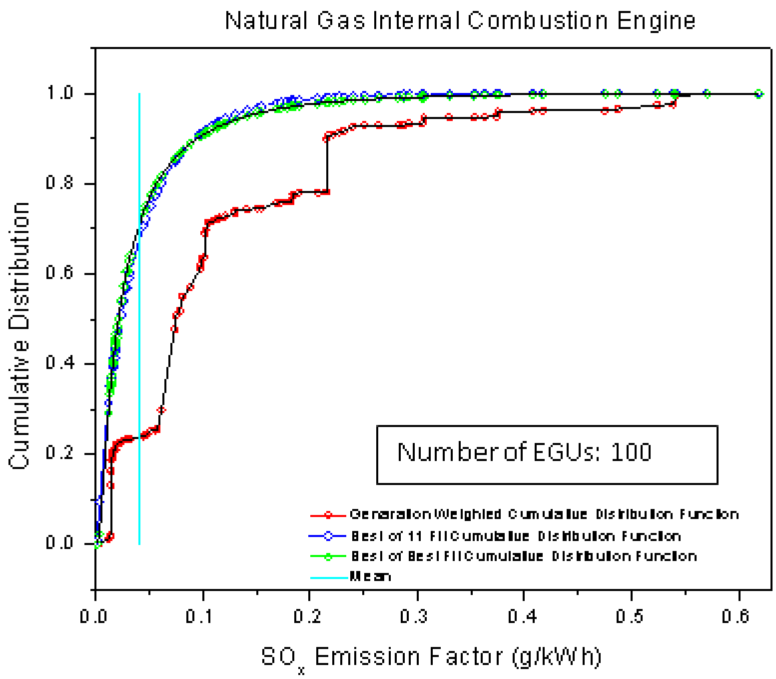


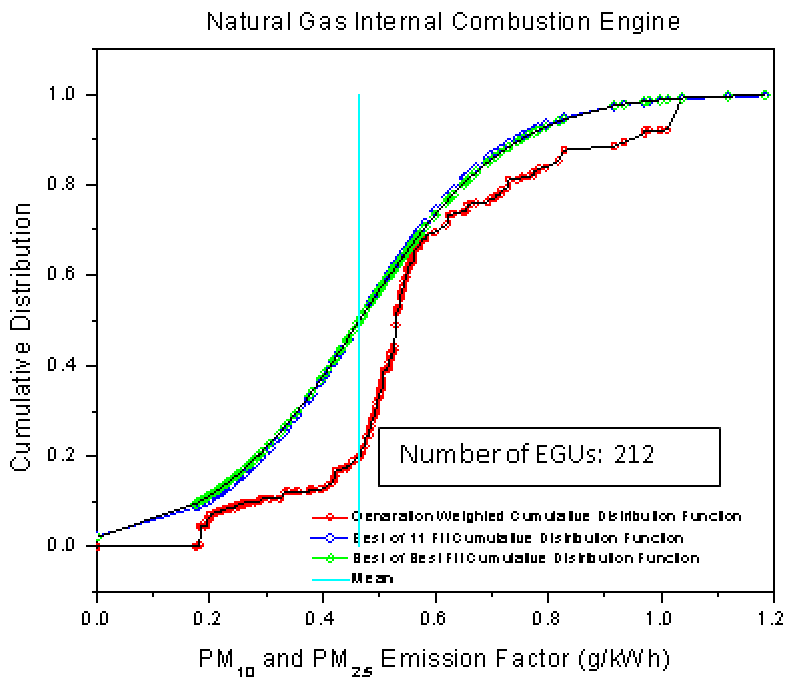
Natural Gas Internal Combustion Engine
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Number of EGUs: 93
Mean
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035
0.040
CH4 Emission Factor (g/kWh)



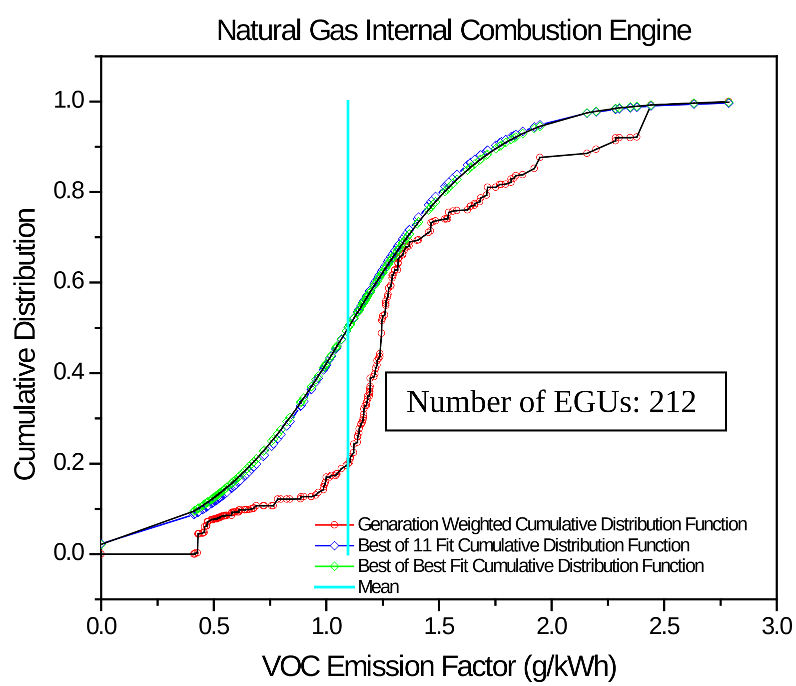
Natural Gas Internal Combustion Engine
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Number of EGUs: 93
Mean
0.000
0.001
0.002
0.003
0.004
0.005
N2O Emission Factor (g/kWh)


Natural Gas Internal Combustion Engine
Cumulative Distribution
NOx Emission Factor (g/kWh)
Number of EGUs: 198
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean


Natural Gas Internal Combustion Engine
Cumulative Distribution
SOx Emission Factor (g/kWh)
Number of EGUs: 100
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean



Natural Gas Internal Combustion Engine
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Number of EGUs: 212
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
0.0
0.2
0.4
0.6
0.8
1.0
1.2
PM_{10} and $PM_{2.5}$ Emission Factor (g/kWh)



Natural Gas Internal Combustion Engine
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Number of EGUs: 212
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
0.0
0.5
1.0
1.5
2.0
2.5
3.0
VOC Emission Factor (g/kWh)

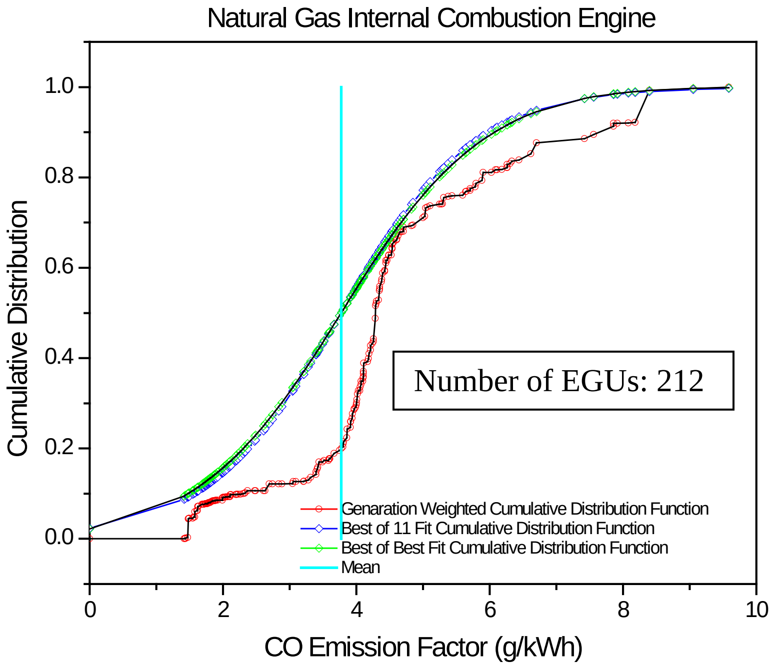
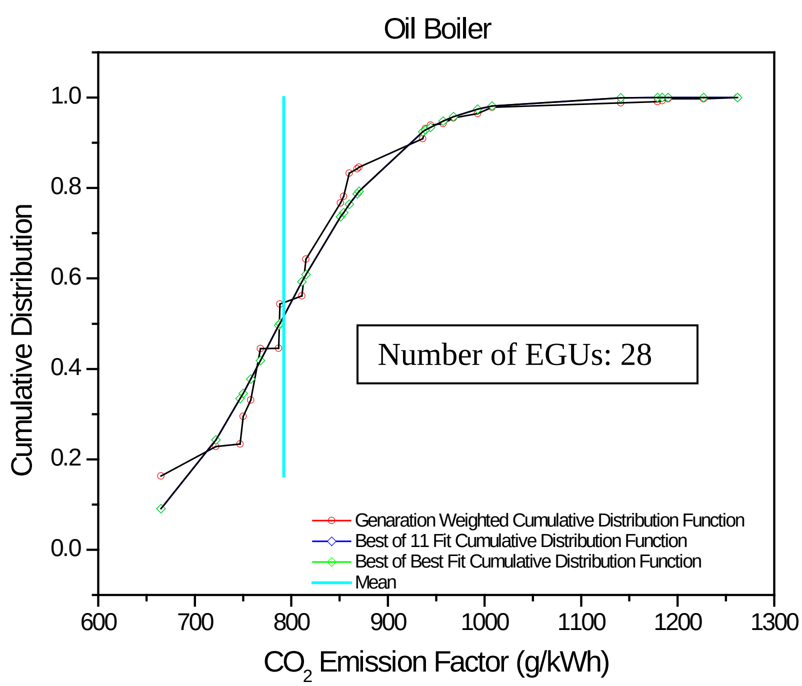
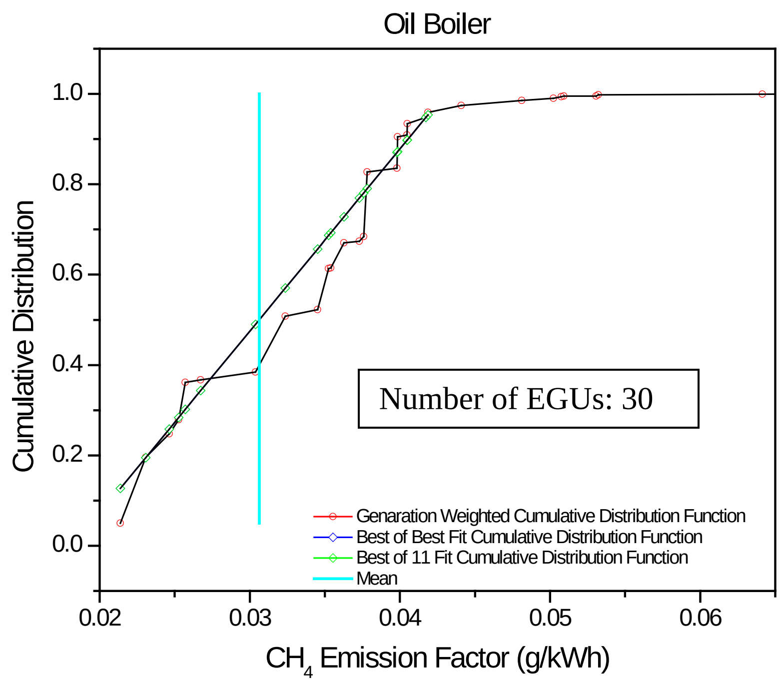
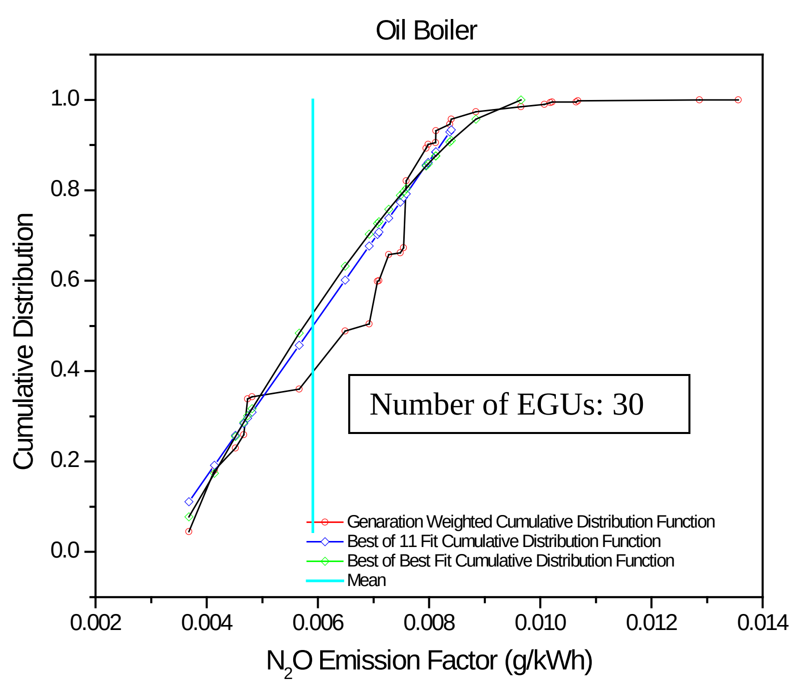
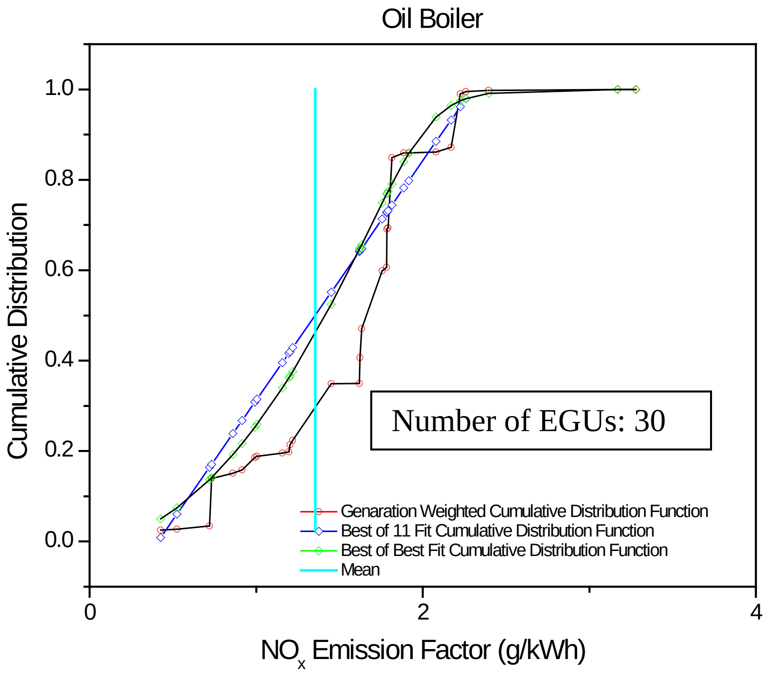


FIGURE A5 **Best-fit CDFs of electricity-generation-weighted GHG and CAP emission factors for natural gas-fired internal combustion engines.**

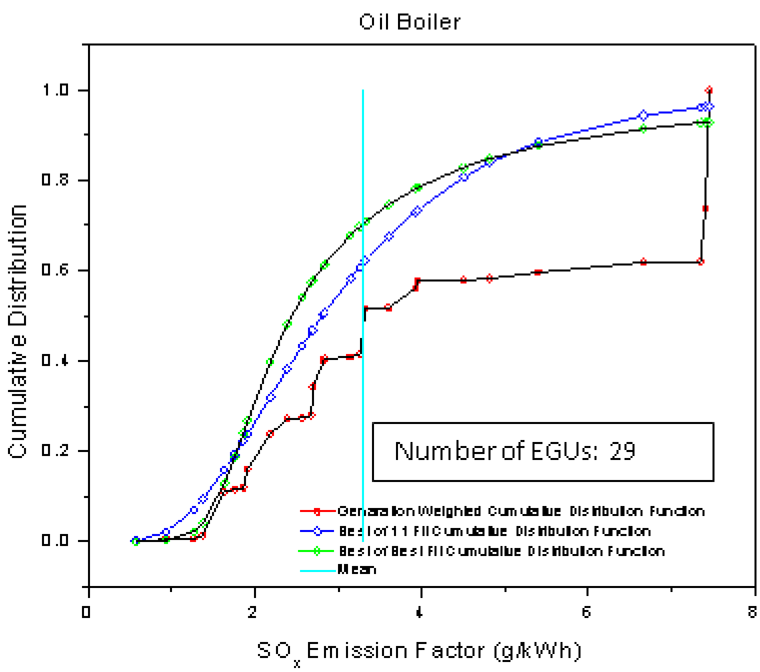



Oil Boiler
Cumulative Distribution
CH4 Emission Factor (g/kWh)
Number of EGUs: 30
Genaration Weighted Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Mean
0.0
0.2
0.4
0.6
0.8
1.0
0.02
0.03
0.04
0.05
0.06

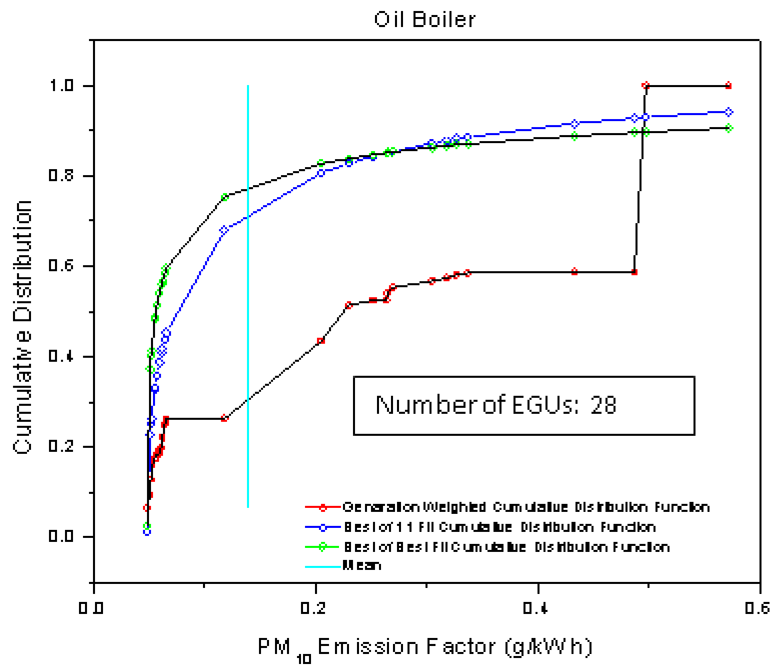

Oil Boiler
Cumulative Distribution
N2O Emission Factor (g/kWh)
Number of EGUs: 30
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
0.0
0.2
0.4
0.6
0.8
1.0
0.002
0.004
0.006
0.008
0.010
0.012
0.014

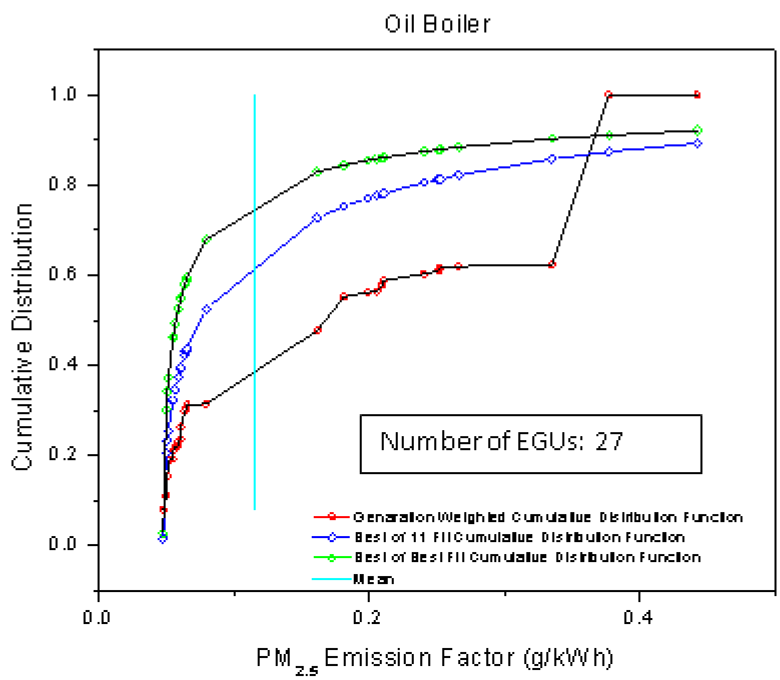


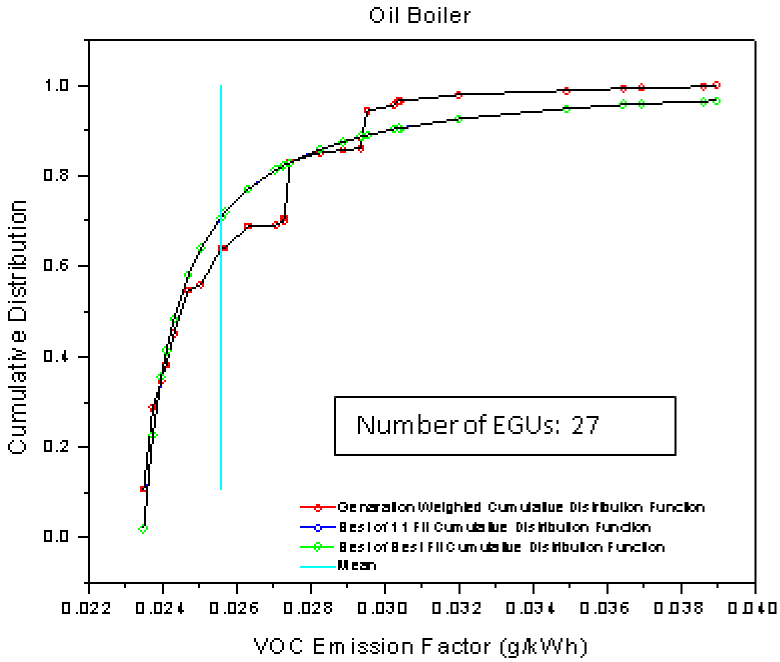
Oil Boiler
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
NOx Emission Factor (g/kWh)
Number of EGUs: 30
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean



Oil Boiler
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
0
2
4
6
8
SOx Emission Factor (g/kWh)
Number of EGUs: 29
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean


Oil Boiler
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Number of EGUs: 28
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
0.0
0.2
0.4
0.6
PM10 Emission Factor (g/kWh)


Oil Boiler
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Number of EGUs: 27
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
0.0
0.2
0.4
PM2.5 Emission Factor (g/kWh)



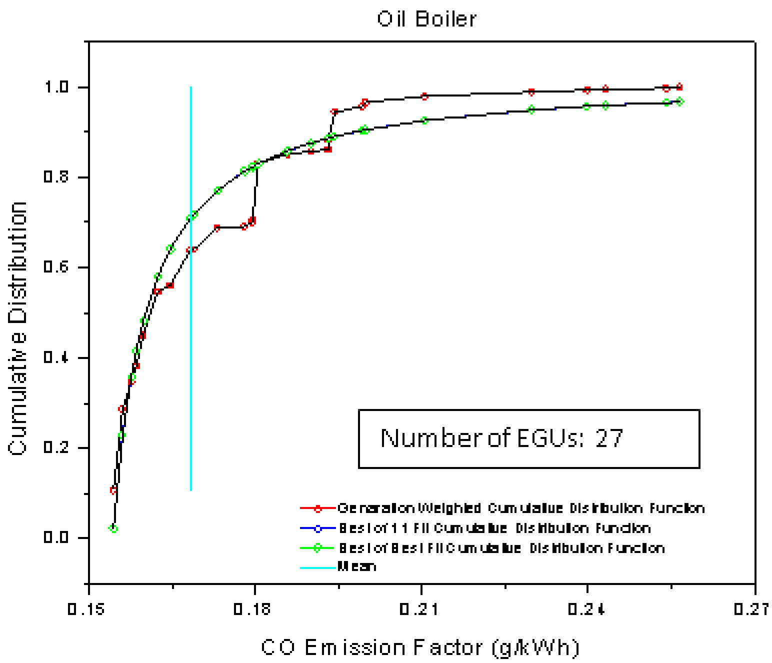
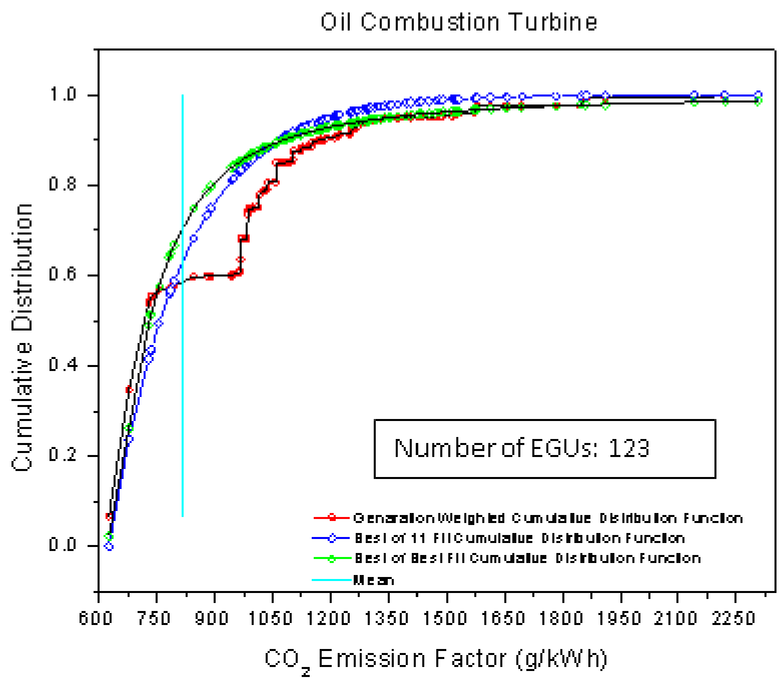
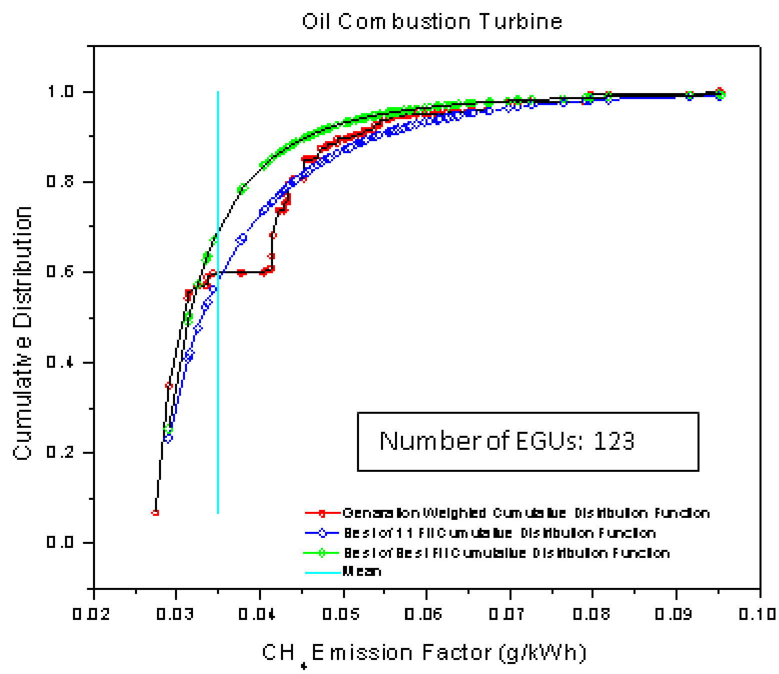


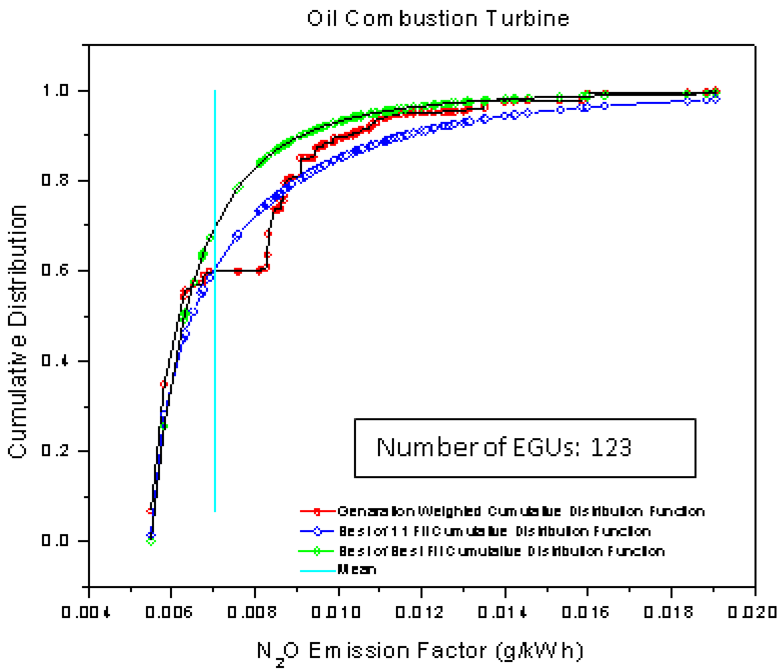
FIGURE A6 Best-fit CDFs of electricity-generation-weighted GHG and CAP emission factors for oil-fired boilers.

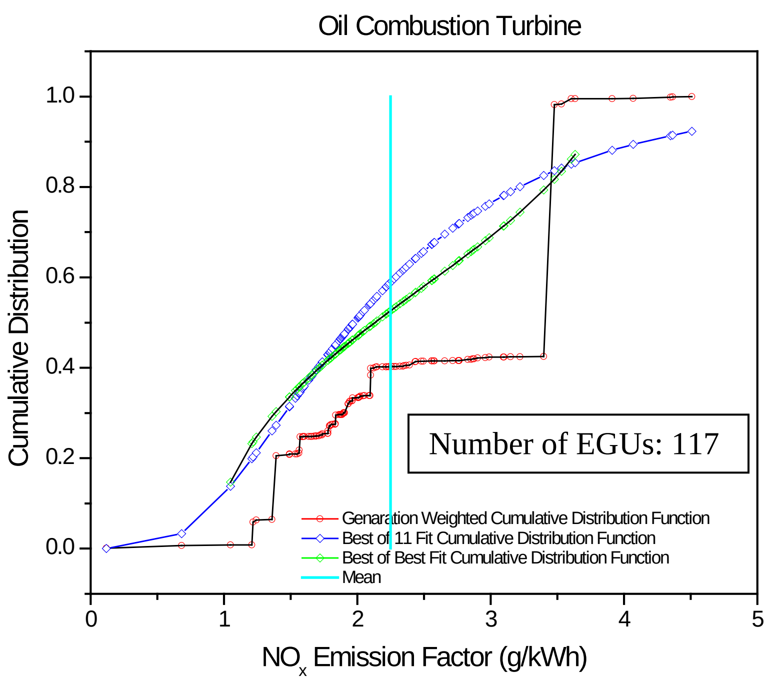


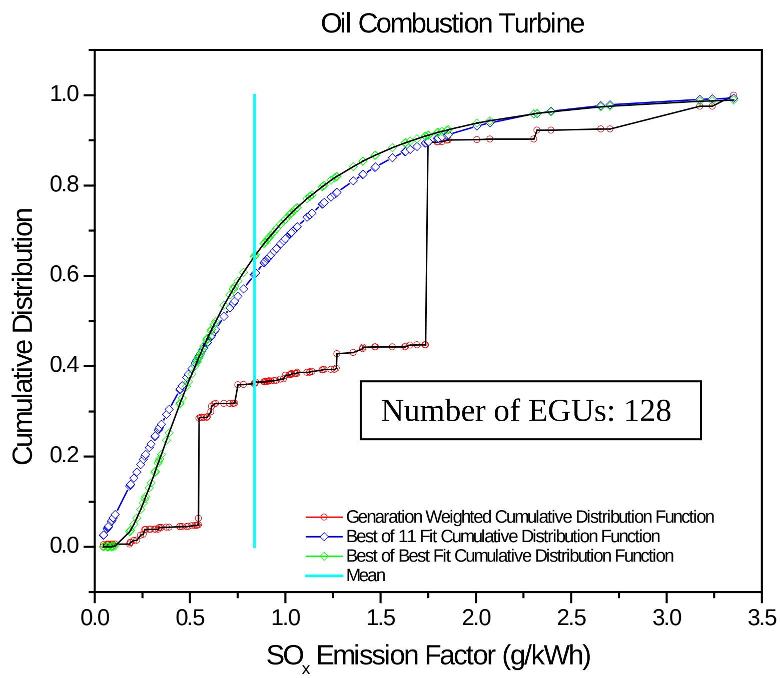
Oil Combustion Turbine
Cumulative Distribution
CO2 Emission Factor (g/kWh)
Number of EGUs: 123
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean

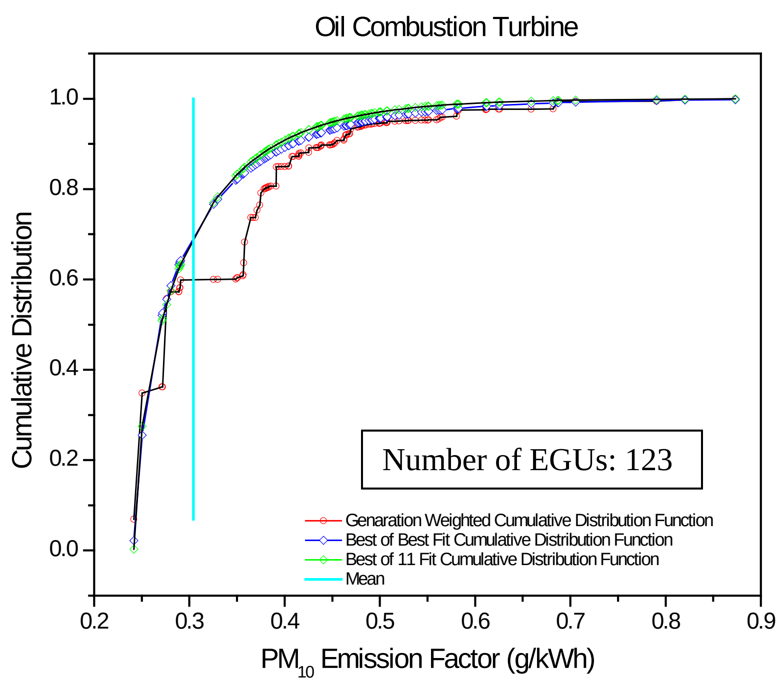


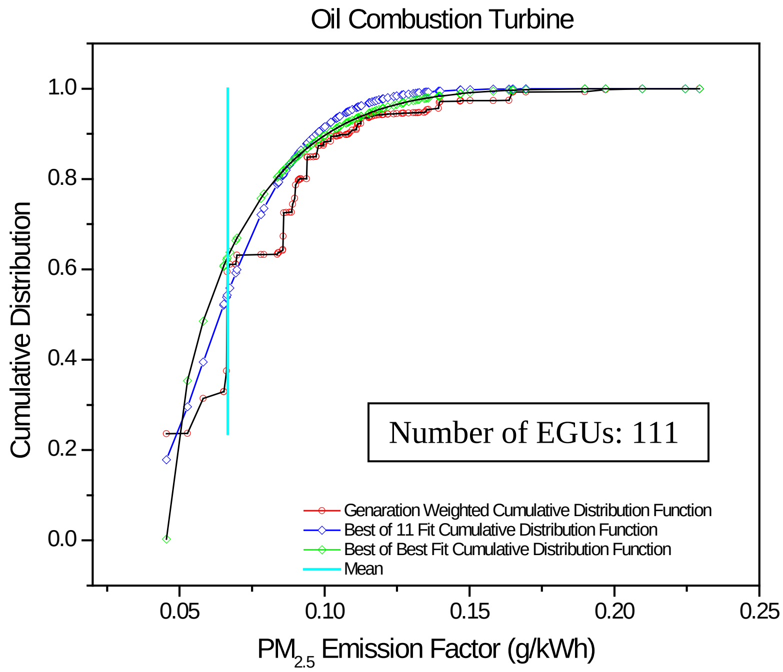
Oil Combustion Turbine
Cumulative Distribution
CH4 Emission Factor (g/kWh)
Number of EGUs: 123
Generation Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean


Oil Combustion Turbine
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
0.004
0.006
0.008
0.010
0.012
0.014
0.016
0.018
0.020
N2O Emission Factor (g/kWh)
Number of EGUs: 123
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean

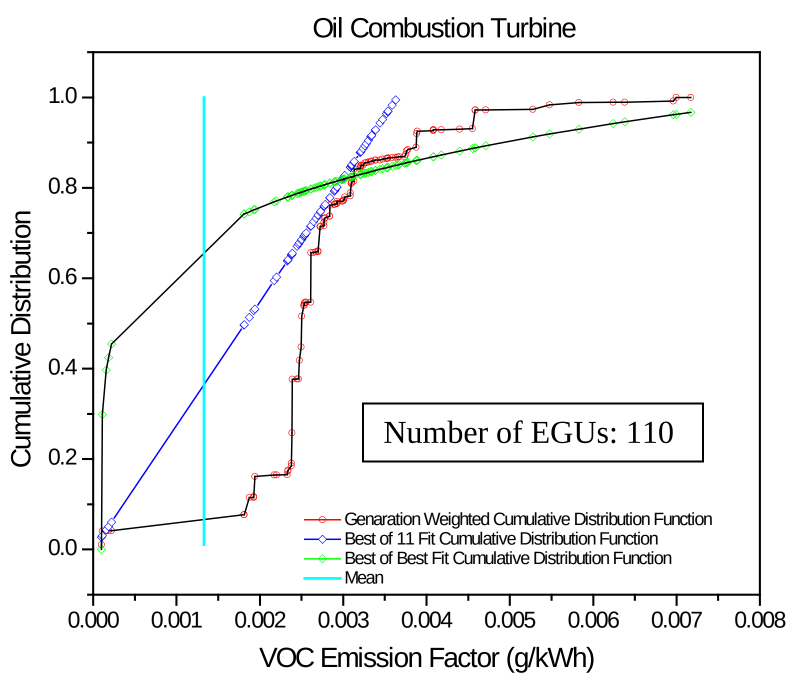

Oil Combustion Turbine
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
NOx Emission Factor (g/kWh)
Number of EGUs: 117
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean


Oil Combustion Turbine
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Number of EGUs: 128
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
SOx Emission Factor (g/kWh)


Oil Combustion Turbine
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Number of EGUs: 123
Genaration Weighted Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Mean
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
PM10 Emission Factor (g/kWh)



Oil Combustion Turbine
Cumulative Distribution
Number of EGUs: 111
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
$PM_{2.5}$ Emission Factor (g/kWh)



Oil Combustion Turbine
Cumulative Distribution
Number of EGUs: 110
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
VOC Emission Factor (g/kWh)

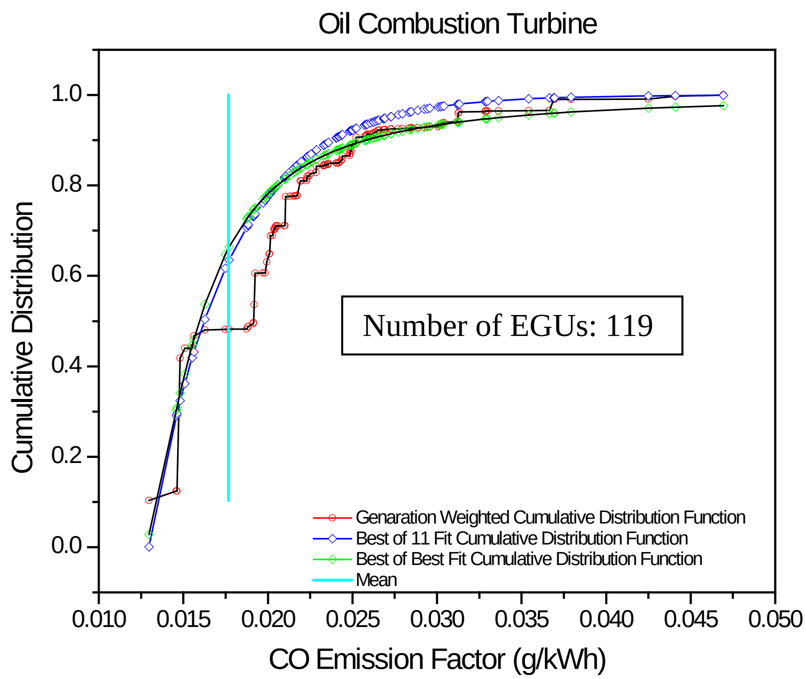
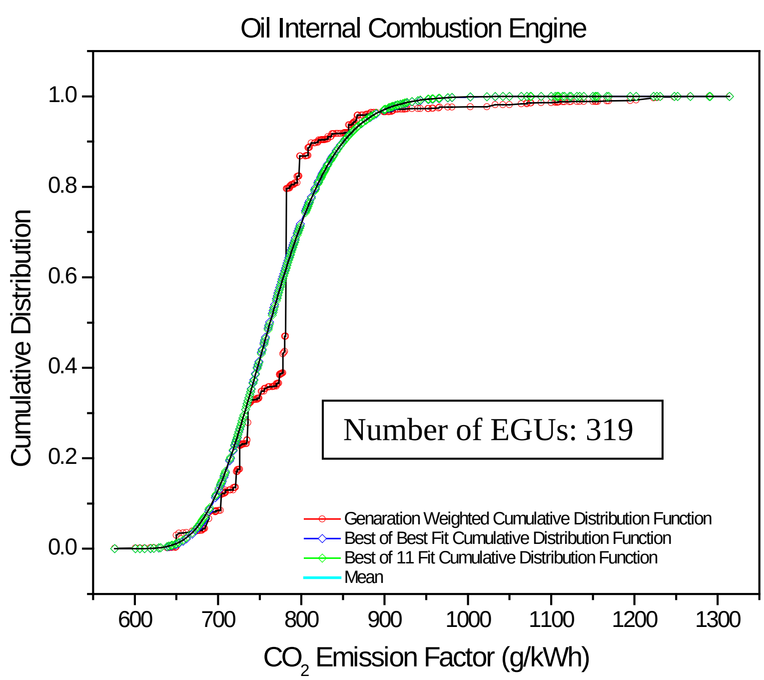
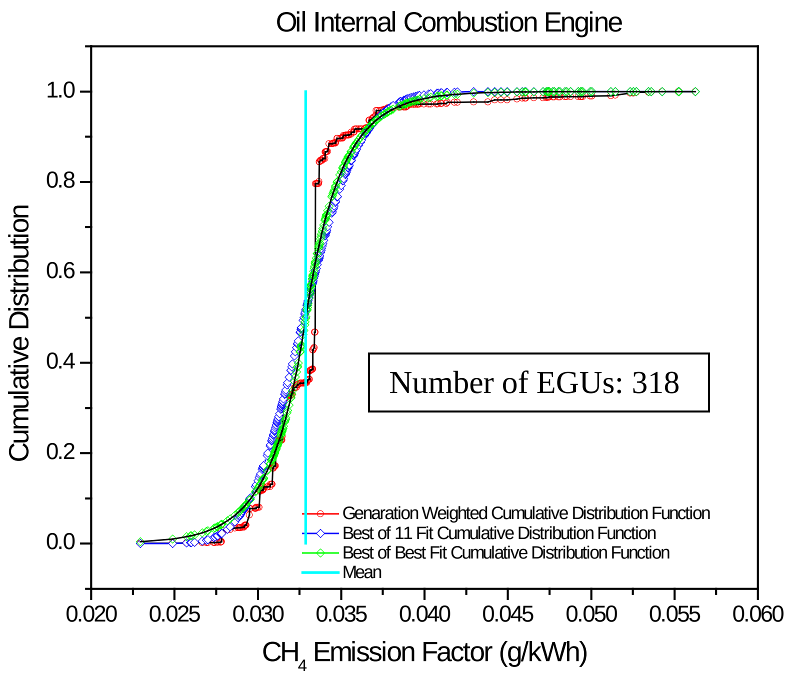
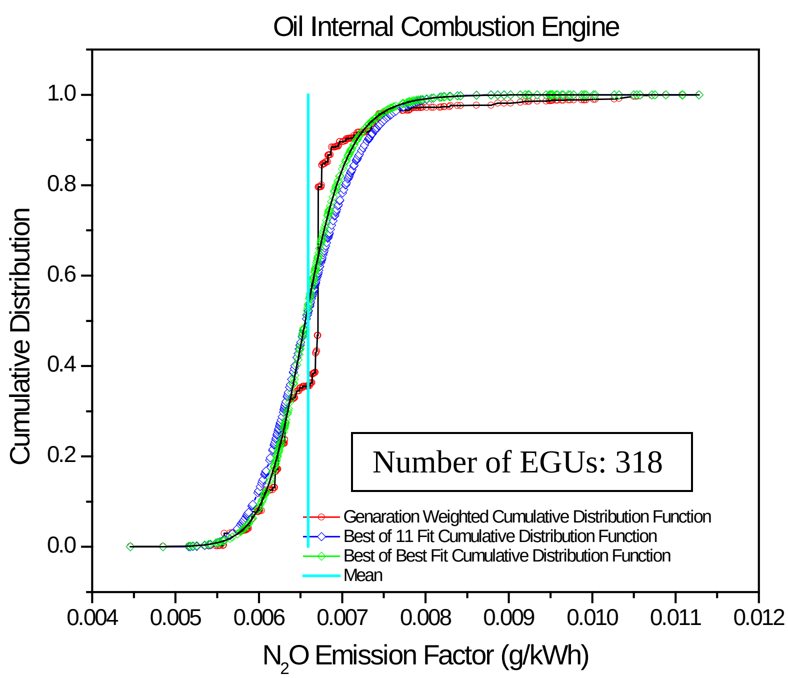


FIGURE A7 Best-fit CDFs of electricity-generation-weighted GHG and CAP emission factors for oil-fired combustion turbines.

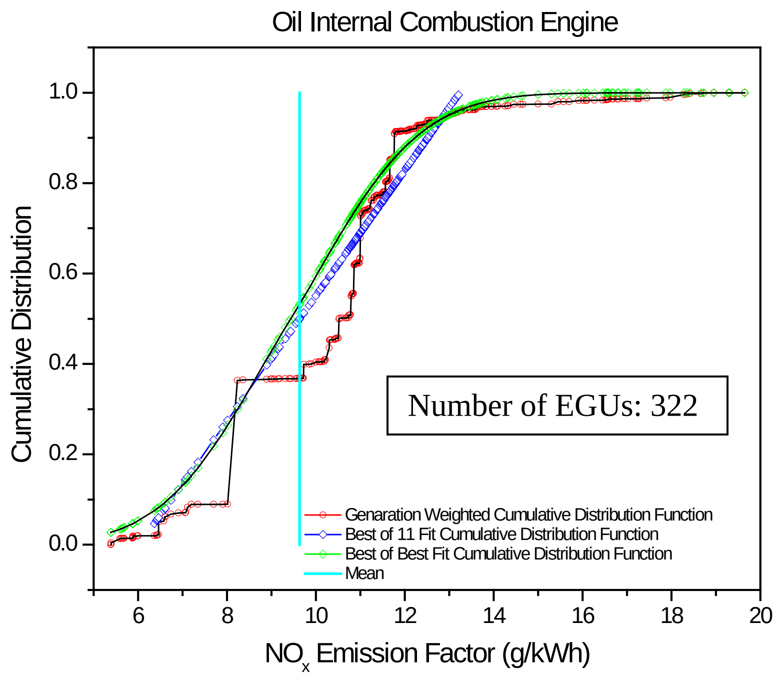


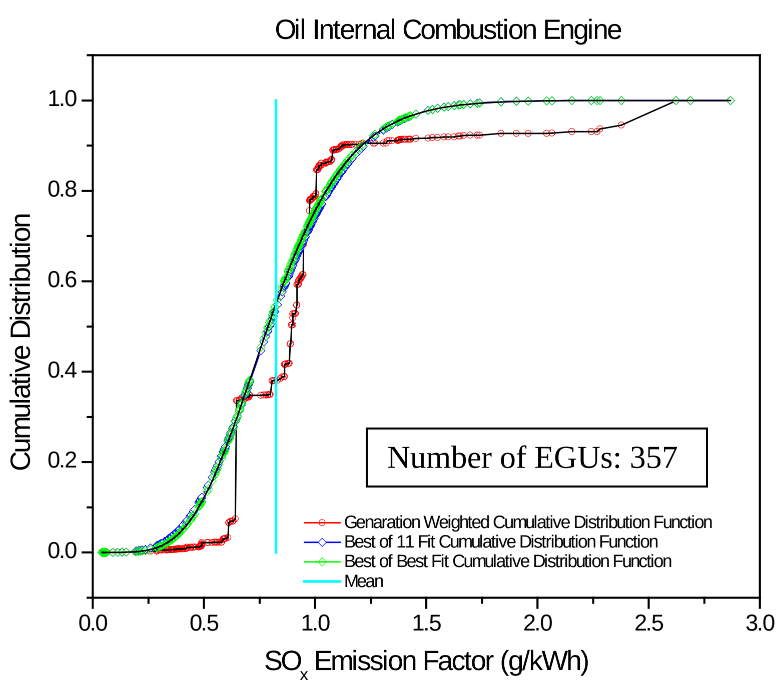


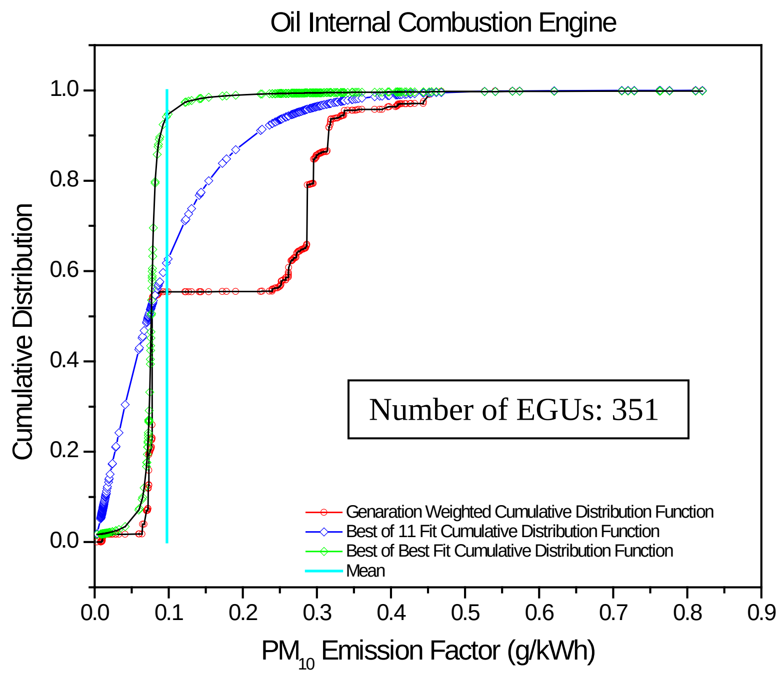
Oil Internal Combustion Engine
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Number of EGUs: 318
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
0.020
0.025
0.030
0.035
0.040
0.045
0.050
0.055
0.060
CH4 Emission Factor (g/kWh)

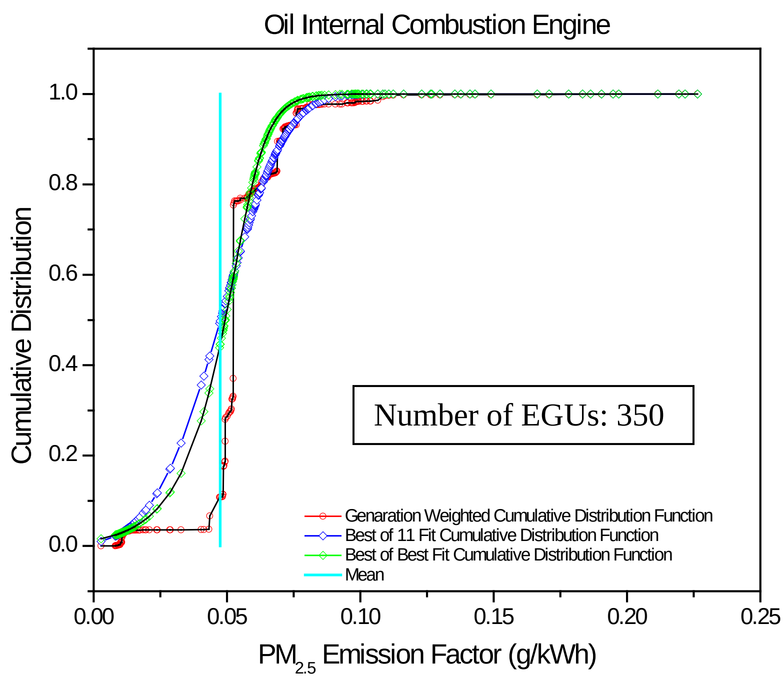


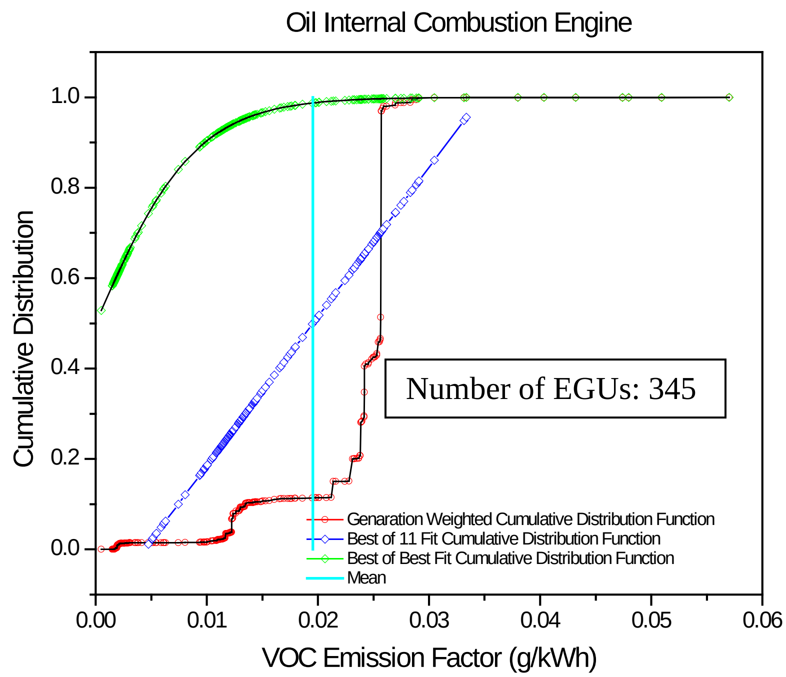
Oil Internal Combustion Engine
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Number of EGUs: 318
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
0.004
0.005
0.006
0.007
0.008
0.009
0.010
0.011
0.012
N2O Emission Factor (g/kWh)


Oil Internal Combustion Engine
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Number of EGUs: 322
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
6
8
10
12
14
16
18
20
NO$_x$ Emission Factor (g/kWh)


Oil Internal Combustion Engine
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Number of EGUs: 357
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
0.0
0.5
1.0
1.5
2.0
2.5
3.0
SO$_x$ Emission Factor (g/kWh)


Oil Internal Combustion Engine
Cumulative Distribution
Number of EGUs: 351
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
PM10 Emission Factor (g/kWh)


Oil Internal Combustion Engine
Cumulative Distribution
Number of EGUs: 350
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
PM2.5 Emission Factor (g/kWh)



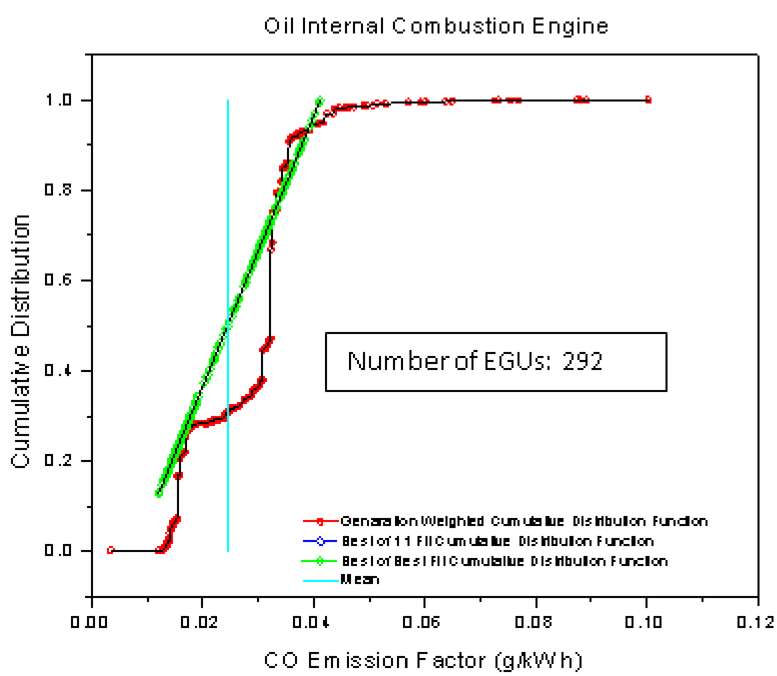
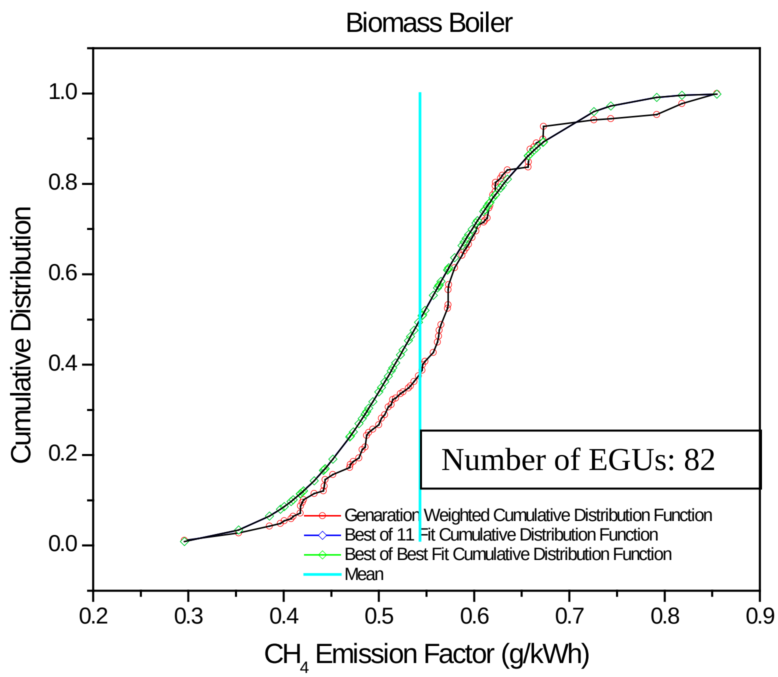
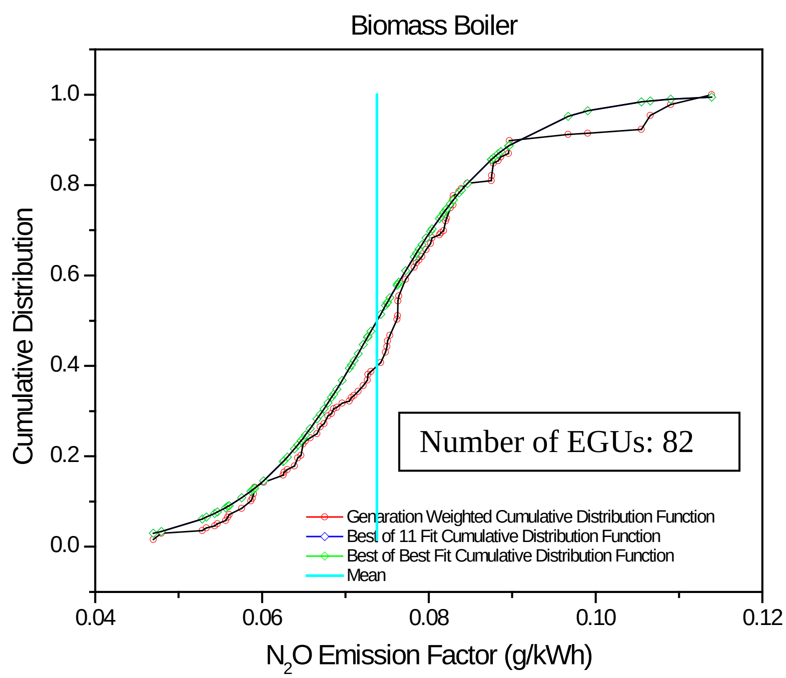
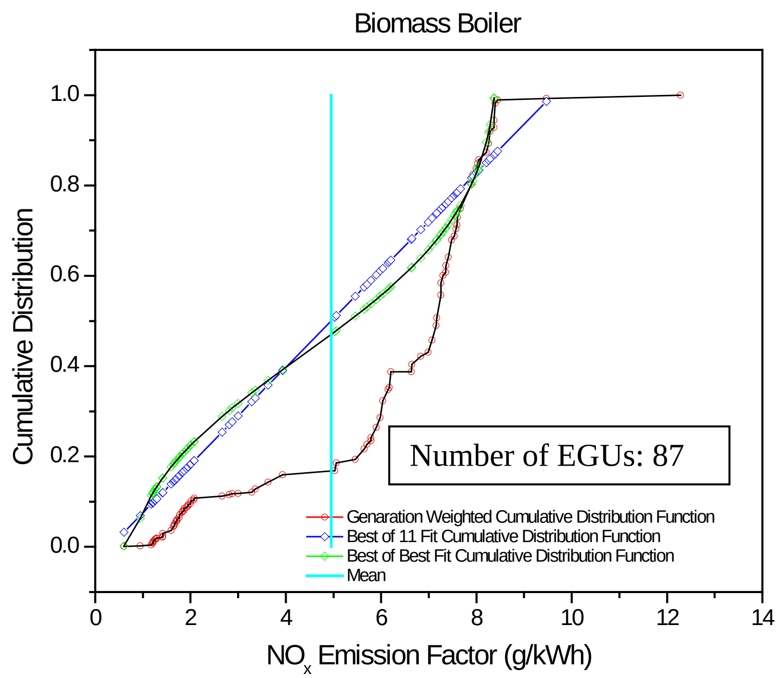
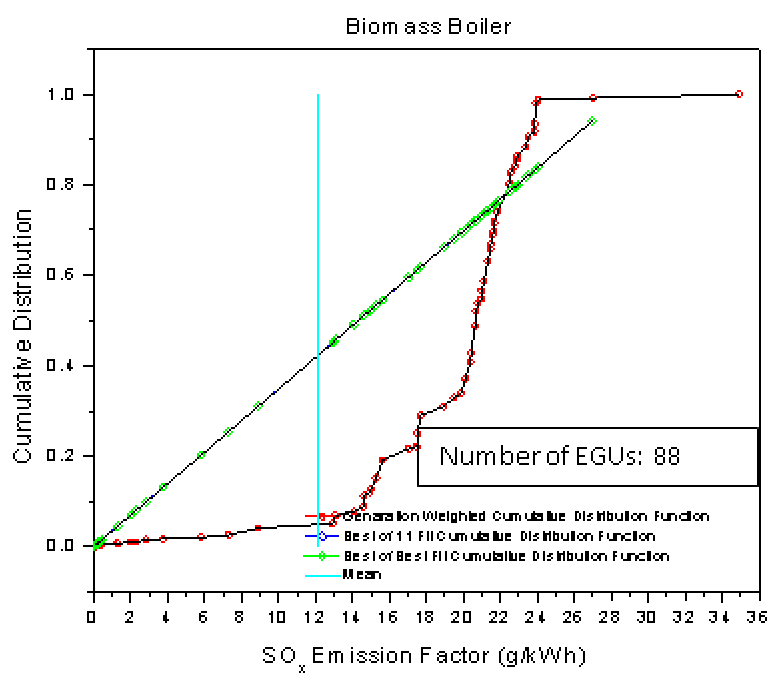


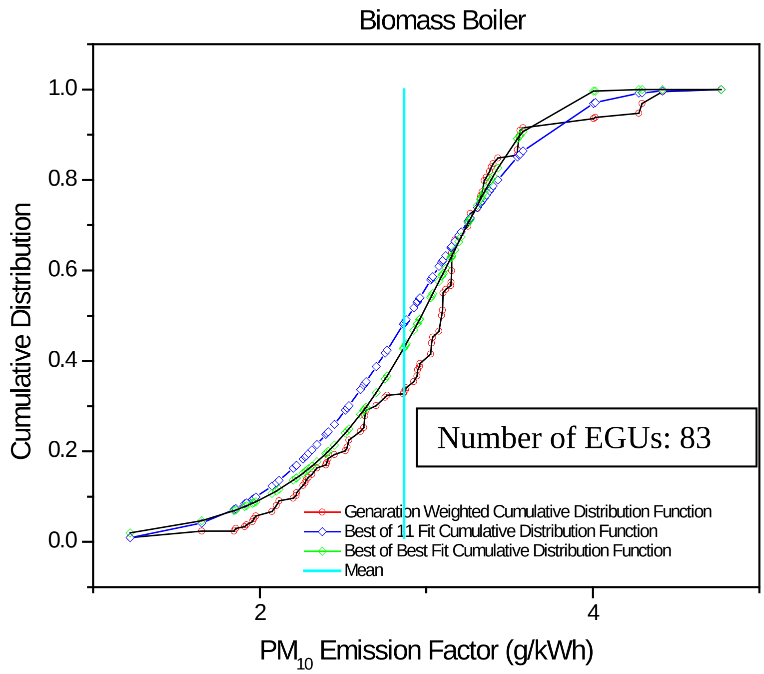
FIGURE A8 Best-fit CDFs of electricity-generation-weighted GHG and CAP emission factors for oil-fired internal combustion engines.

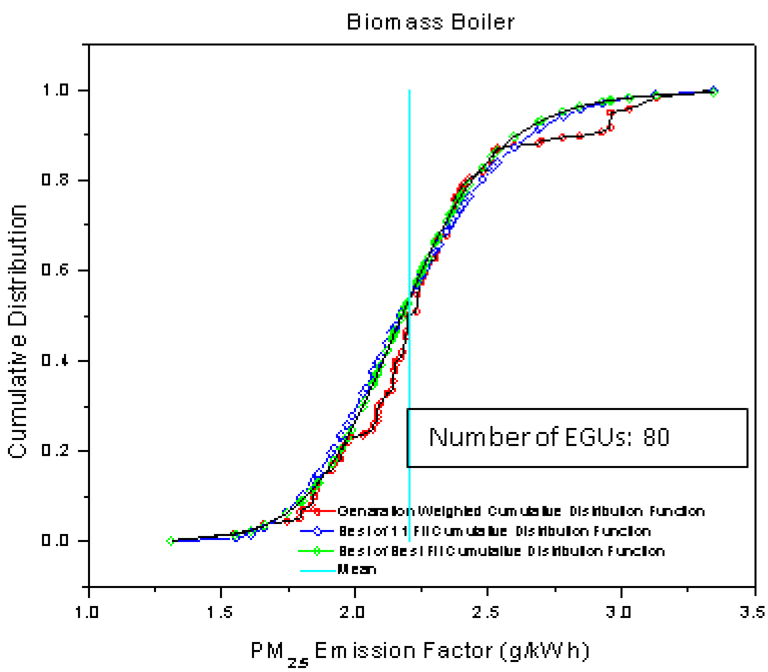

Biomass Boiler
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Number of EGUs: 82
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
CH_4 Emission Factor (g/kWh)

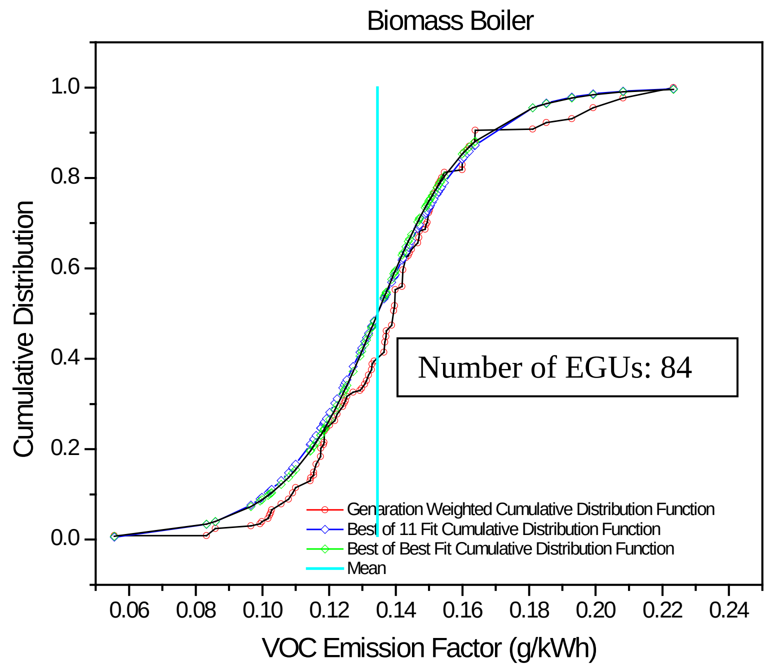

Biomass Boiler
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Number of EGUs: 82
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
0.04
0.06
0.08
0.10
0.12
N_2O Emission Factor (g/kWh)


Biomass Boiler
Cumulative Distribution
NO$_x$ Emission Factor (g/kWh)
Number of EGUs: 87
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean


Biomass Boiler
Cumulative Distribution
SO$_x$ Emission Factor (g/kWh)
Number of EGUs: 88
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean


Biomass Boiler
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
2
4
PM_{10} Emission Factor (g/kWh)
Number of EGUs: 83
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean


Biomass Boiler
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
1.0
1.5
2.0
2.5
3.0
3.5
$PM_{2.5}$ Emission Factor (g/kWh)
Number of EGUs: 80
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean



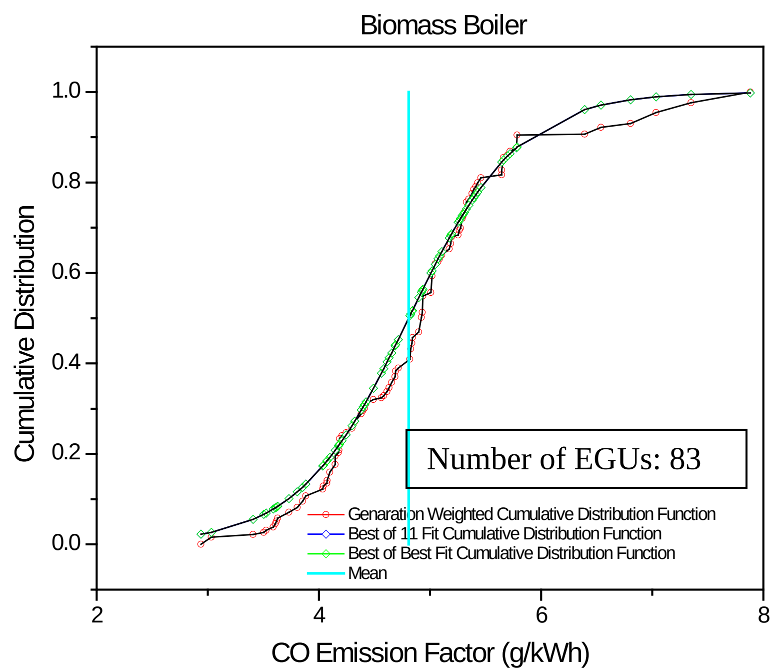
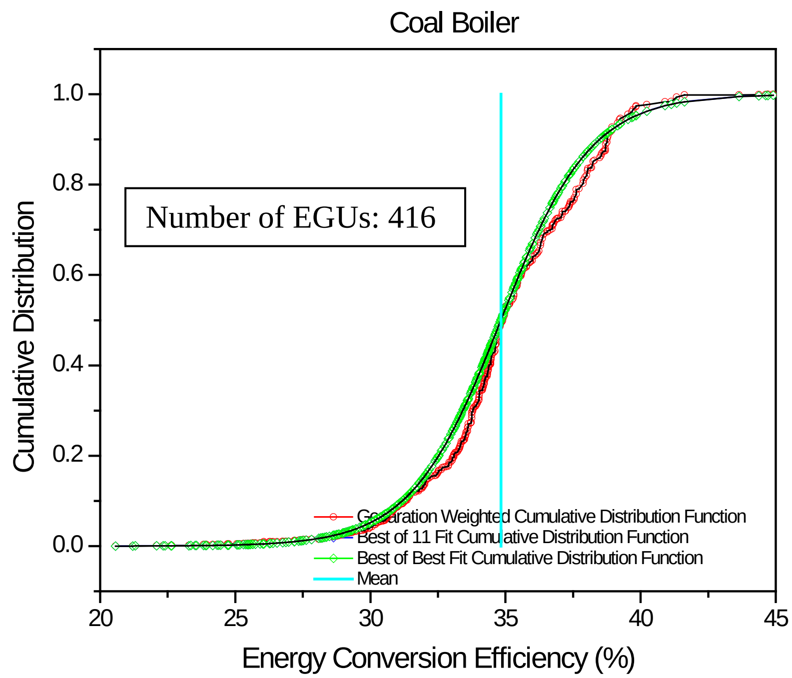
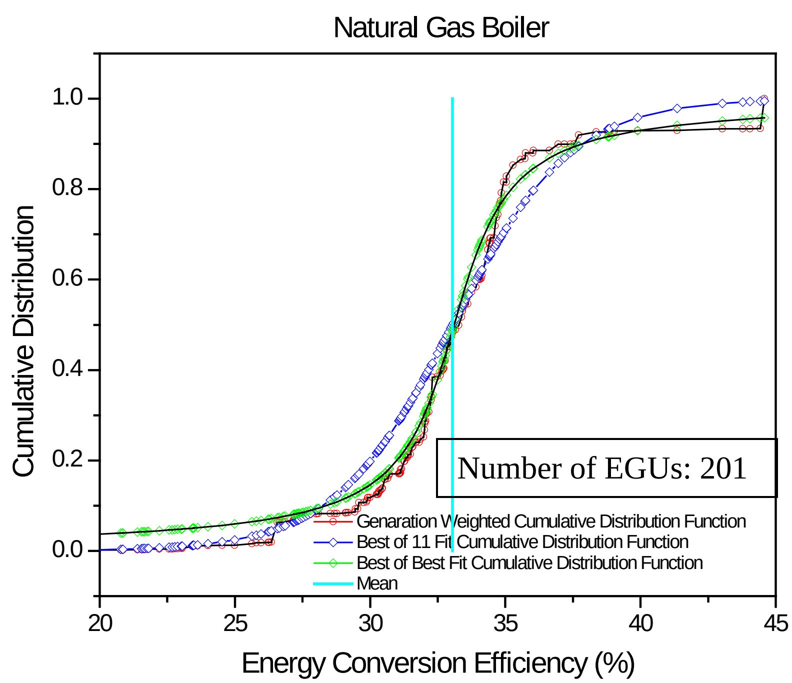
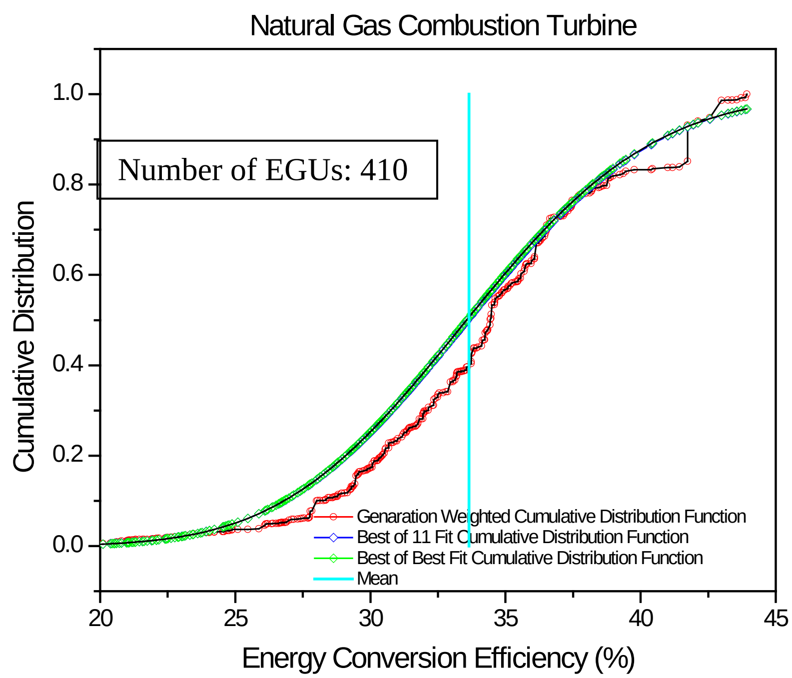


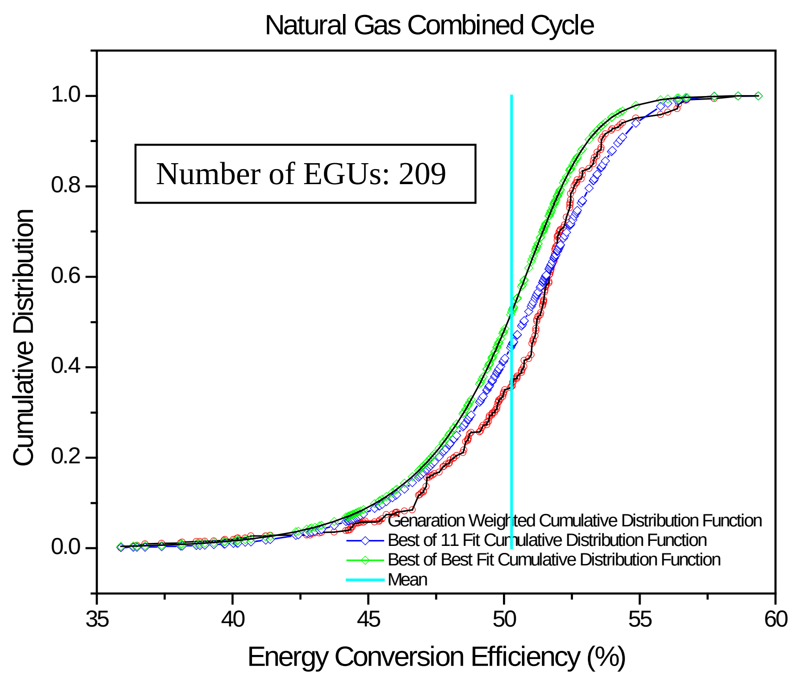
FIGURE A9 Best-fit CDFs of electricity-generation-weighted GHG and CAP emission factors for biomass-fired boilers.


Coal Boiler
Number of EGUs: 416
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
20
25
30
35
40
45
Energy Conversion Efficiency (%)

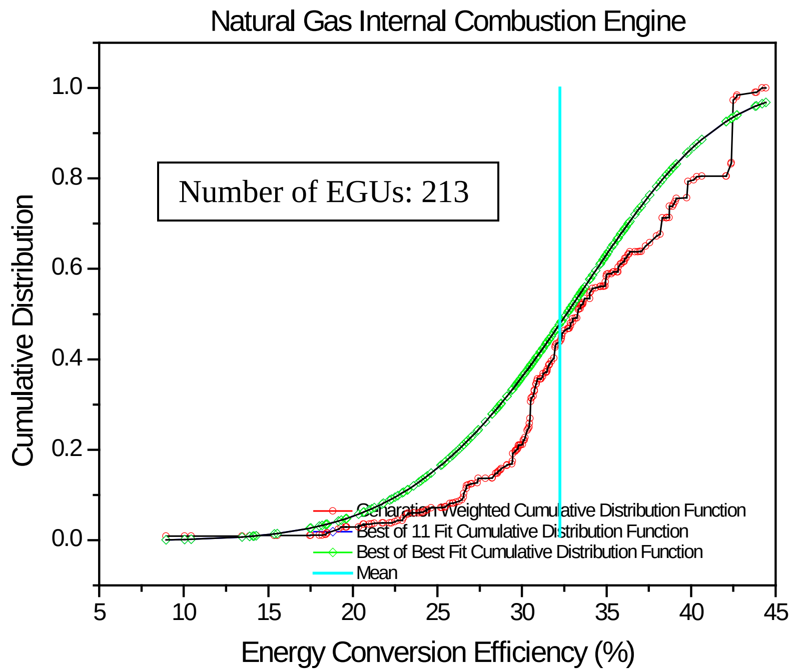

Natural Gas Boiler
Number of EGUs: 201
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
20
25
30
35
40
45
Energy Conversion Efficiency (%)

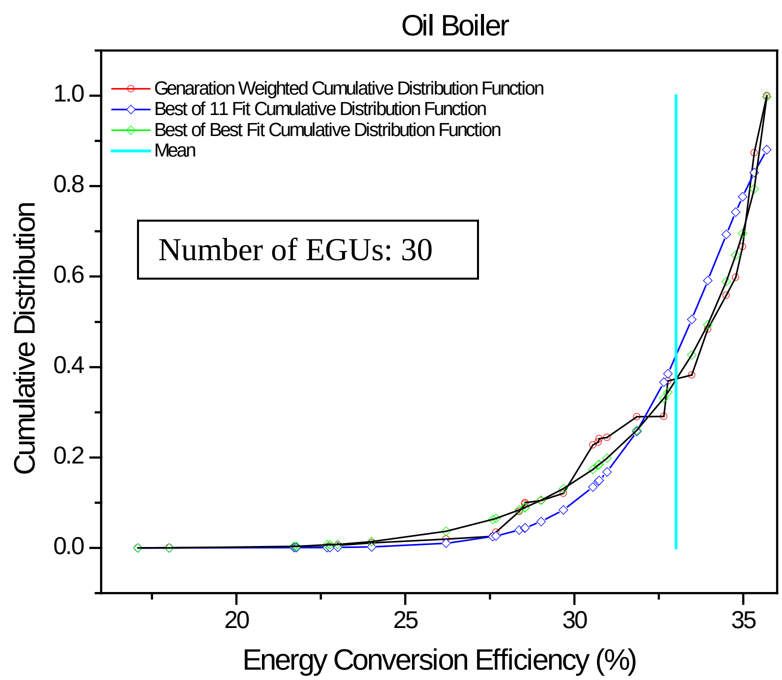


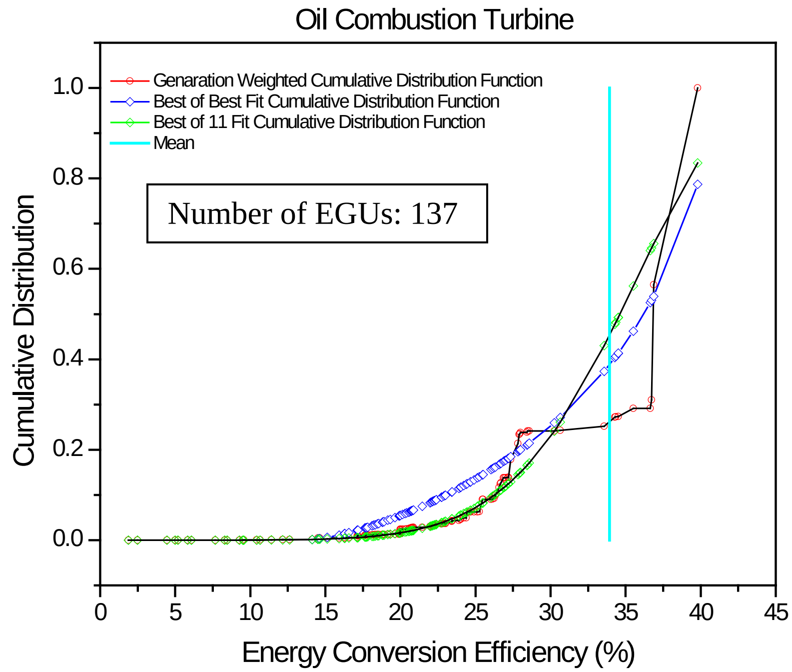
Natural Gas Combustion Turbine
Number of EGUs: 410
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
20
25
30
35
40
45
Energy Conversion Efficiency (%)

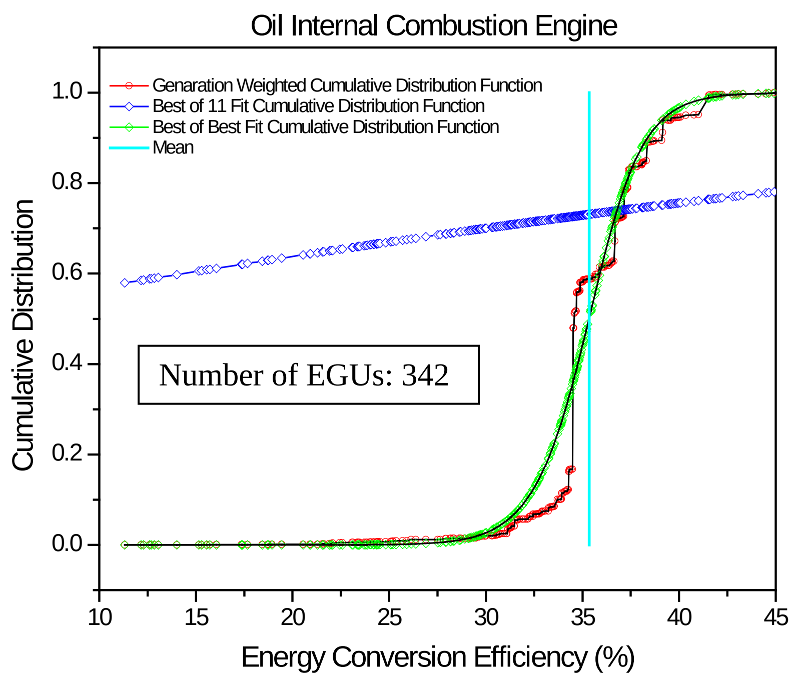


Natural Gas Combined Cycle
Number of EGUs: 209
Cumulative Distribution
1.0
0.8
0.6
0.4
0.2
0.0
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
35
40
45
50
55
60
Energy Conversion Efficiency (%)


Natural Gas Internal Combustion Engine
Number of EGUs: 213
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
Cumulative Distribution
Energy Conversion Efficiency (%)
1.0
0.8
0.6
0.4
0.2
0.0
5
10
15
20
25
30
35
40
45


Oil Boiler
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
Number of EGUs: 30
Cumulative Distribution
Energy Conversion Efficiency (%)
1.0
0.8
0.6
0.4
0.2
0.0
20
25
30
35


Oil Combustion Turbine
Genaration Weighted Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Mean
Number of EGUs: 137
Cumulative Distribution
Energy Conversion Efficiency (%)


Oil Internal Combustion Engine
Genaration Weighted Cumulative Distribution Function
Best of 11 Fit Cumulative Distribution Function
Best of Best Fit Cumulative Distribution Function
Mean
Number of EGUs: 342
Cumulative Distribution
Energy Conversion Efficiency (%)

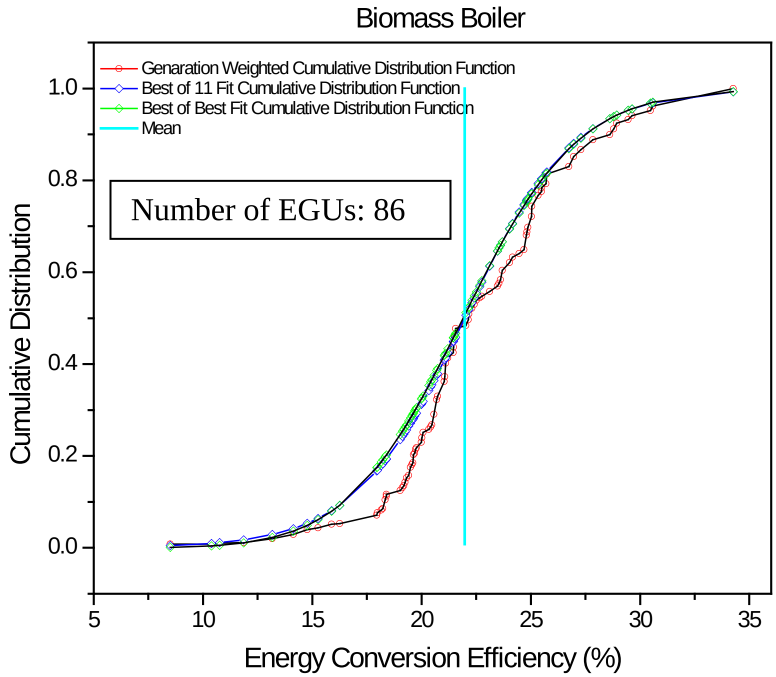


FIGURE A10 **Best-fit CDFs of electricity-generation-weighted energy conversion efficiencies for coal-, natural gas-, oil- and biomass-fired boilers, combustion turbines, combined-cycle plants and internal combustion engines.**

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