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Source Energy and Emission Factors for Building Energy Consumption

Prepared for

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1.0 Introduction and Overview

To properly evaluate the energy and environmental impacts of building energy use, conversion factors are required to account not only for site energy use but also for source (full fuel cycle) energy consumption and related emissions. Source energy accounts for "upstream" energy processes such as natural gas extraction, processing, transmission, and delivery to the building along with similar processes needed for electricity use in the building —taking into account energy conversion to electricity at power plants, transmission and distribution line losses, and pre-combustion energy associated with mining/extraction, processing and transportation of coal or other fuels used in the power plant[1].

The importance of site versus source efficiency is seen when comparing national energy use for natural gas and electricity in the residential and commercial sectors. According to the Energy Information Administration (EIA), buildings consume nearly 40 percent of the primary energy resources and 74 percent of the electricity generated each year in the United States. As shown in Figure 1, site use of natural gas and electricity in buildings in 2008 totaled 8.28 and 9.37 quadrillion Btu's (Quads) respectively – a sum of 17.65 Quads. However, losses associated with electricity production and delivery exceeded 20 quads of energy – an amount greater than the total site energy demand. Notably, there can be strong regional differences in source energy efficiency, driven by differences in the electric power generation mix. For example, the proportion of energy loss is higher in coal power-dominated regions and lower in regions that are more reliant on natural gas or renewable sources such as hydropower.

Homes and commercial businesses have been growing contributors to CO_2 emissions for the last 15 years—a trend that is projected to continue for the next two decades. As shown in Figure 2, the increasing CO_2 emissions of residential and commercial buildings is being driven by growing consumption of electricity, including generation losses. Much of the increased carbon impact from residential and commercial electricity use comes from power plants and the relatively inefficient "full fuel cycle" of production and delivery of electricity to the buildings. Aggregate CO_2 emissions from natural gas consumption in U.S. buildings are currently at 1990 levels, and are projected to remain nearly flat through 2030 despite projected growth in the number of gas customers.

Given the magnitude of source-to-site energy impacts, it is important for energy efficiency and environmental programs to account for total national energy use accurately. Specifically, there is a need for a defensible and easily implemented methodology for calculating building or appliance energy efficiency based on source energy factors for electricity and fossil fuels like natural gas. California has recognized the need to include total energy use in their building energy codes. California Title 24 Energy Efficiency Standards for Residential and Nonresidential Buildings incorporate source energy efficiency supplemented by Time Dependent Valuation in their building energy budget methodology.

Further underscoring the importance of source energy considerations, a recent recommendation by the National Research Council (NRC)'s Board on Energy and Environmental Systems to the U.S. Department of Energy recommended shifting toward a source energy (or full fuel cycle) basis for appliance standards calculations. The NRC stated "using that metric could provide the public with more comprehensive information on the impacts of energy consumption on the environment." That

1 The source energy conversion factor is the inverse of the cumulative full fuel cycle (or source) energy efficiency that includes all losses from extraction, processing, transportation, generation, transmission, and distribution to the building, but does not include appliance efficiency. The definition of source energy used by US EPA varies slightly as it does not explicitly identify fuel extraction efficiency as one of the factors accounted for when calculating the overall source energy factor. The EPA ENERGY STAR® performance ratings methodology uses fuel-specific national average "source energy" factors to simplify calculations while recognizing that specific power plants and regions of the country will have different values. EPA's definition and supplemental information are at http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_benchmark_comm_bldgs.

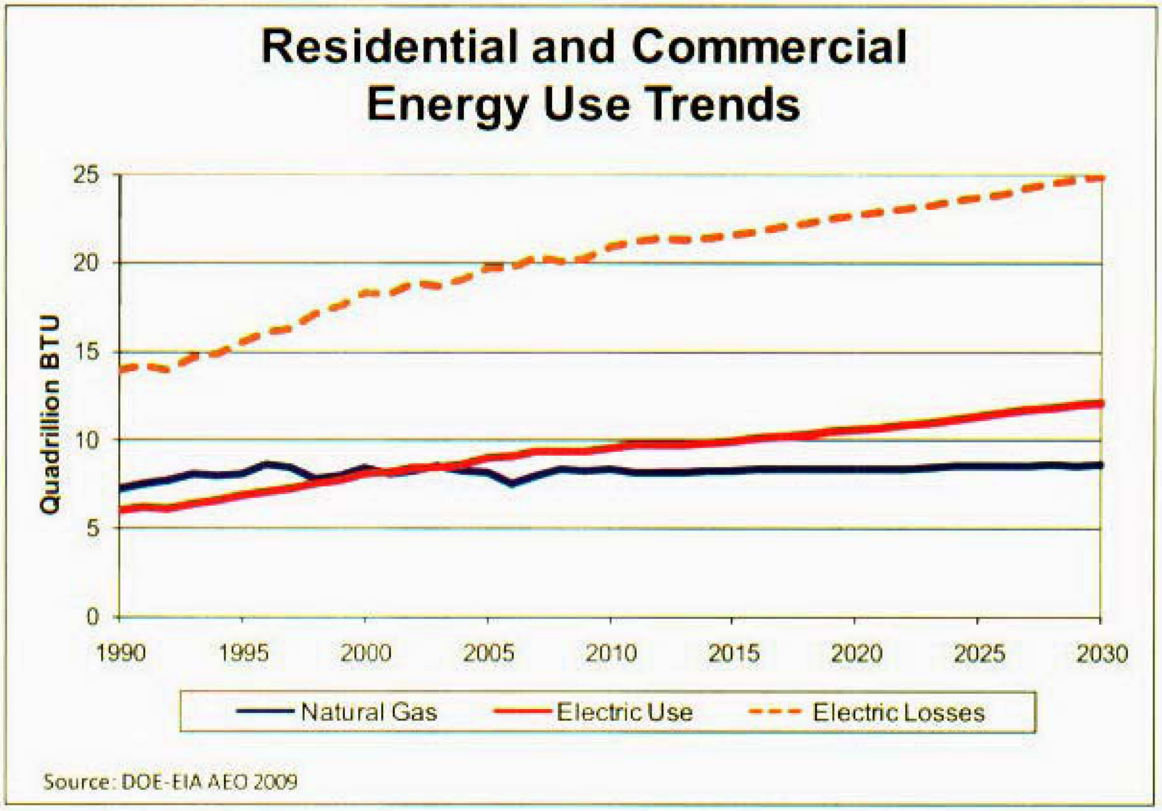

Figure 1 Residential and Commercial Building Energy Usage Trends

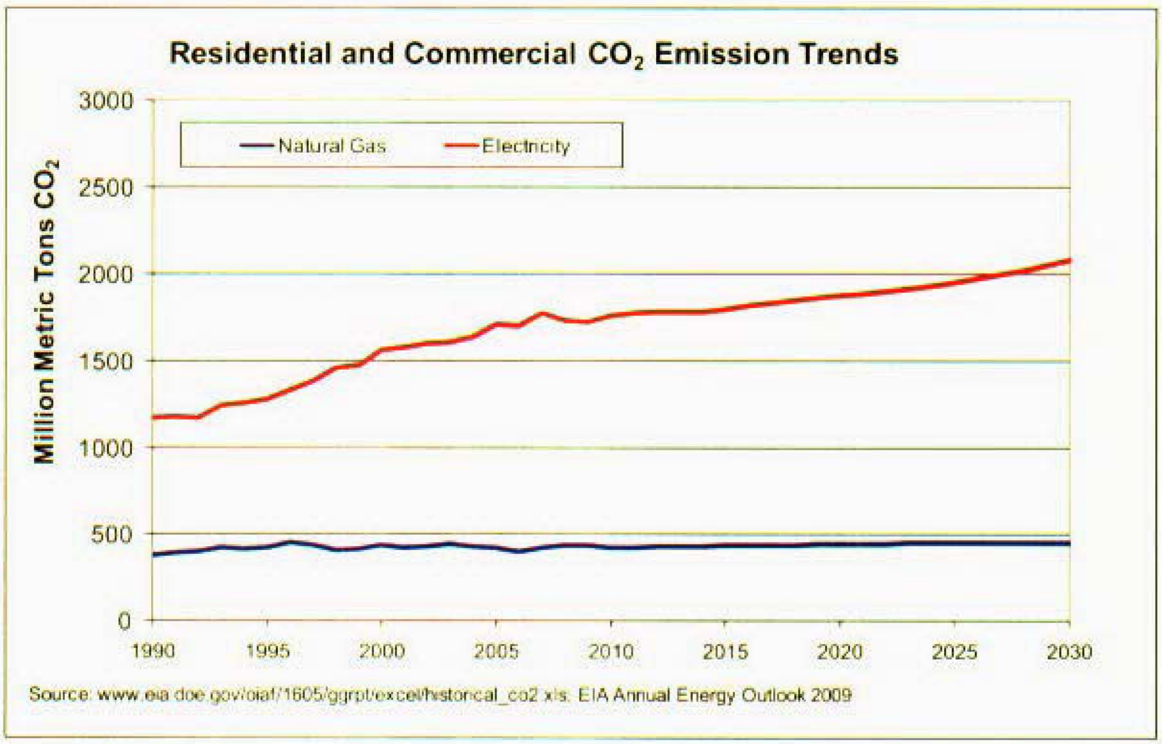

Figure 2 Gas and Electric CO_2 Emission Trends in Residential and Commercial Buildings

recommendation may have significant impact on future DOE federal appliance energy efficiency rulemaking and standards.

This report updates factors included in the AGA 2000 report entitled "Source Energy and Emission factors for Residential Energy Consumption" and the AGA 1990 report entitled "A comparison of Carbon Dioxide Emissions Attributable to New Natural Gas and All-Electric Homes" based on current information. Information includes source energy and emission factors for natural gas, liquefied petroleum gas, fuel oil, and electricity. Regional and state-specific source energy and emission factors are also presented. These factors permit analysis of the total national impact of using various energy sources in buildings.

Case studies are included that compare typical residential water heaters – including source energy consumption and CO_2 emissions by state, region, and US. Figure 3 and Figure 4 provide examples from the case studies of the substantial differences between electricity and natural gas source energy efficiency and CO_2 emissions along with the variability that results from differences in each state's power generation mix. The methodology used in the water heater case study can be applied to a full spectrum of end use equipment and appliances, providing a comprehensive understanding of energy efficiency and environmental impact associated with energy use.

A number of relevant data sources, listed in the Reference section, were analyzed in preparation of this report. From this list, six sources provided most of the data compiled for this report. These sources were selected because they were recently updated, and because they provided useful information in calculating source energy and emission conversion factors for electricity and fossil fuels typically used in buildings. The six primary sources of data include:

- US Environmental Protection Agency (EPA)
- EIA
- Argonne National Laboratory (ANL)
- National Renewable Energy Laboratory (NREL)
- National Hydropower Association
- American Gas Association (AGA) Data

The EPA 2007 Emissions & Generation Resources Integrated Database (eGRID2007) Version 1.1 database provides detailed and aggregate data on electric power plant generation and emissions for the year 2005. Data is available for nearly all US power plants and aggregated at state, National Electric Reliability Council (NERC) sub-region, NERC region, and national levels. Relevant emissions data includes CO_2, NO_x, SO_2, Hg, CH_4, and N_2O emissions. In addition, the database includes the percentage of power supplied by coal, oil, natural gas, hydro, nuclear, and other renewable sources. This generation mix data is useful to estimate source energy conversion factors at state, regional, and national levels. Heat rates for electricity generation using fossil fuels like coal, natural gas, and oil as well as electricity transmission and distribution (T&D) losses are also available from eGRID2007 Version 1.1.

The EPA AP-42 Fifth Edition of Compilation of Air Pollutant Emission Factors provides fossil fuel combustion emission factors. EPA AP-42 data is also used and referenced by EIA, ANL, and NREL.

The EIA Annual Energy Review 2007 provides heat rates for electricity generation using nuclear power, and geothermal energy.

NREL U.S. Life-Cycle Inventory (LCI) database provides data needed to calculate source energy conversion factors for the three major types of coal (bituminous, subbituminous, and lignite) used in US power plants. Related supplemental data are provided in NREL report TP-550-38617 "Source Energy and Emission Factors for Energy Use in Buildings". That report also provides data needed to calculate the percentage of coal fuel mix (bituminous, subbituminous, and lignite) used in electric power generation at state, regional, and national levels.

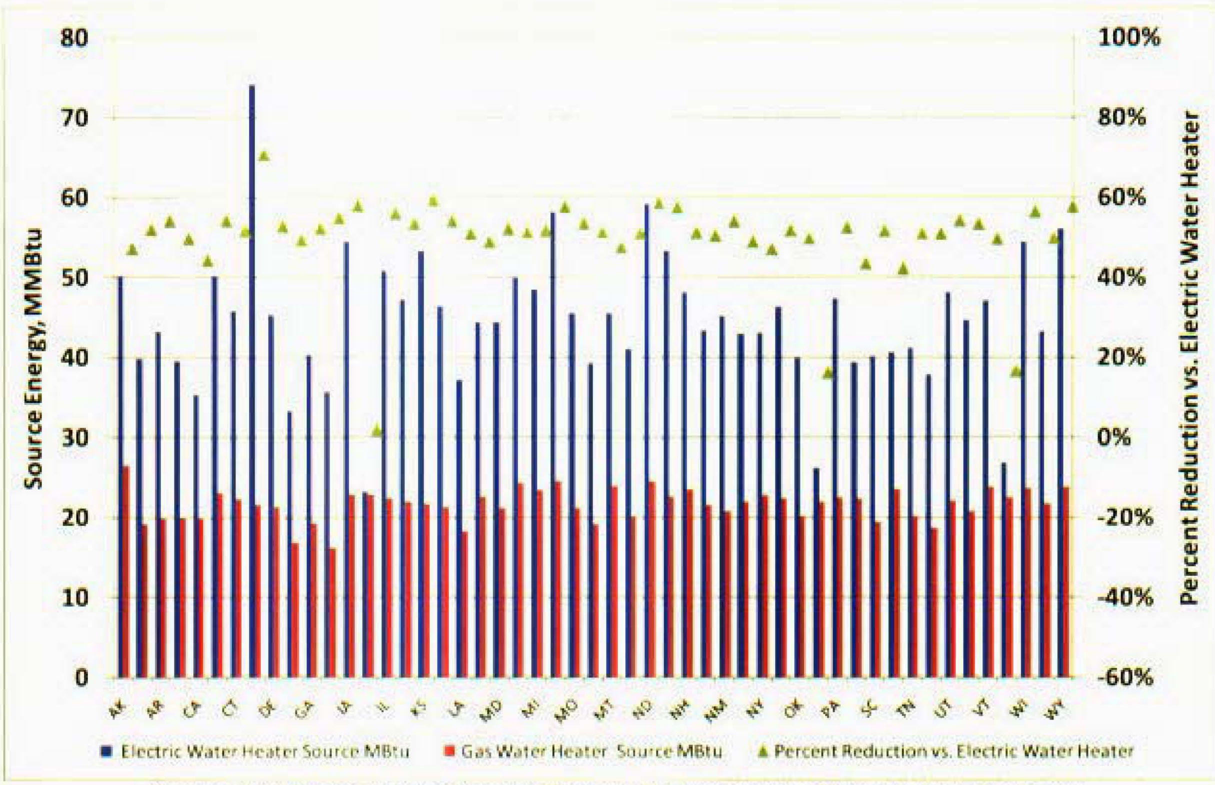

Figure 3 Water Heater Source Energy Consumption Comparison by State

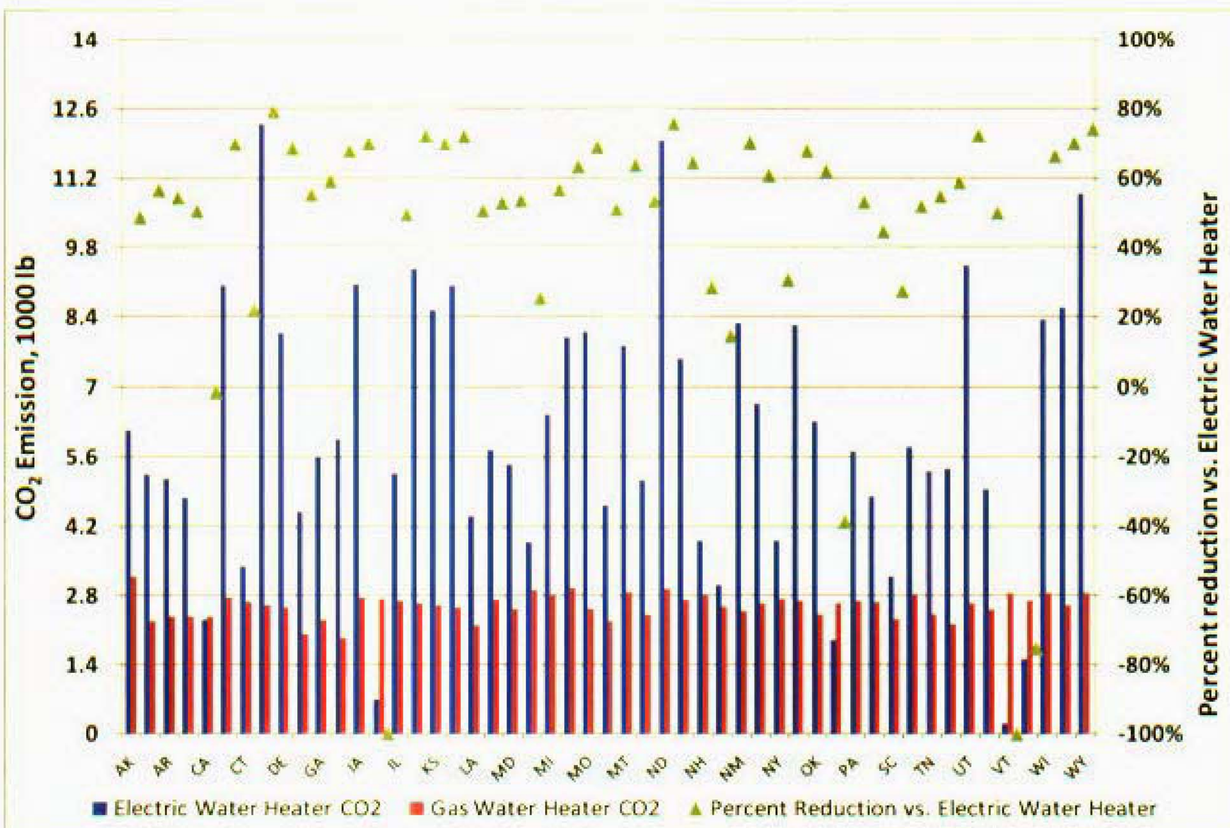

Figure 4 Water Heater CO_2 Emission Comparison by State

The ANL Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation model version 1.8c (GREET) provides data on pre-combustion (extraction, processing, and transportation) energy consumption and associated air emissions associated with fossil fuel use in power plants and buildings[2].

Hydropower generation efficiency information is available from the National Hydropower Association and linked data sources.

2 GREET version 1.8c released March 23, 2009 references current US EIA and EPA data sources as well as database of information developed by Argonne National Laboratory during the past 15 years. The GREET program, sponsored by the U.S. DOE Office of Energy Efficiency and Renewable Energy (EERE), is being used by DOE for modeling emissions and energy use in transportation (http://www.transportation.anl.gov/modeling_simulation/GREET).

2.0 Source Energy Conversion Factors

Site energy based rating methods are often used over a source energy rating approach due to perceived lack of reliable sources on source-to-site energy conversion factors. This is argued especially with electricity, where the delivered product is generated from thousands of sources. However, due to the increasing importance of environmental and energy efficiency reporting requirements, there are a number of publicly available and regularly updated sources of data allowing calculation of source energy conversion factors for electricity and fossil fuels. Among these are information databases and reports from the EPA, EIA, ANL, NREL, National Hydropower Association, California Energy Commission, and AGA. Protocols for mapping site to full fuel cycle energy have been developed by these and other organizations. Details differ in these protocols, but there is reasonable precision, accuracy, flexibility, and stability to permit rational comparisons.

In 1990, AGA published a report that included source energy conversion factors that formed the basis of AGA estimates of source energy efficiency for residential applications. Table 1 extracted from that report shows the source energy efficiencies for electricity, natural gas, and oil, including the cumulative impact of extraction, processing, transportation, generation, transmission, and distribution losses on overall efficiency. Conversion efficiency is the net generation efficiency at the power plant. Cumulative efficiency is the full fuel cycle efficiency for residential applications, including all losses from extraction through distribution to the site. The source energy conversion factor is the inverse of the cumulative efficiency. Table 5 and Table 9 in this report update the 1990 factors shown in Table 1 using more recent data.

Table 1 Source Energy Efficiency Factors from AGA 1990 Report

Source Energy Type	Process energy efficiency (percent)						Source Energy Conversion Factor
	Extraction	Processing	Transportation	Conversion	Distribution	Cumulative Efficiency	
Electricity							
Coal based	99.4	90.0	97.5	33.4	92.0	26.8	3.7
Natural Gas Based	96.8	97.6	97.3	31.8	92.0	26.9	3.7
Oil based	96.8	90.2	98.4	32.5	92.0	25.7	3.9
Fossil Fuels Used in Buildings							
Natural Gas	96.8	97.6	97.3	100	98.4	90.5	1.1
Oil	96.8	90.2	98.4	100	99.8	85.7	1.2

Source: AGA report EA 1990-05, "A comparison of Carbon Dioxide Emissions Attributable to New Natural Gas and All-Electric Homes." American Gas Association, October 31, 1990.

The following sections provide a review and compilation of the latest available data for calculations of source-to-site (or pre-combustion) energy efficiency and emission factors as well as overall source energy conversion factors for electricity and fossil fuels used in US buildings. This includes detailed information on national, regional, and state-level electricity and fossil fuel factors.

2.1 Electricity Generation Fuel Mix

The EPA eGRID2007 version 1.1 database provides data for the year 2005 on US electric power plant generation output and percentage of power supplied by coal, oil, natural gas, hydro, nuclear, and other renewable sources. Table 2 shows the eGRID2007 electricity generation resource mix by NERC Region shown in Figure 5 as well as the US composite resource mix. Table 3 shows state level data. The generation mix data shown in both tables is useful to calculate source energy conversion factors for electricity at state, regional, and national levels.

Table 2 Electricity Generation Resource Mix by NERC Region and US

NERC region		Generation resource mix (percent)										
		Coal	Oil	Gas	Other fossil	Biomass	Hydro	Nuclear	Wind	Solar	Geo-thermal	Other
ASCC	Alaska Systems Coordinating Council	9.5	11.6	56.6	0.00	0.08	22.3	0.0	0.01	0.00	0.00	0.00
FRCC	Florida Reliability Coordinating Council	26.2	17.9	39.0	0.64	1.54	0.0	13.8	0.00	0.00	0.00	0.84
HICC	Hawaiian Islands Coordinating Council	14.2	78.8	0.0	1.65	2.61	0.8	0.0	0.06	0.00	1.92	0.00
MRO	Midwest Reliability Organization	72.7	0.8	5.2	0.21	1.18	4.1	14.0	1.79	0.00	0.00	0.04
NPCC	Northeast Power Coordinating Council	14.4	13.2	29.2	1.06	3.16	11.7	27.2	0.04	0.00	0.00	0.00
RFC	Reliability First Corporation	64.4	1.4	5.8	0.73	0.70	0.6	26.2	0.07	0.00	0.00	0.05
SERC	SERC Reliability Corporation	57.1	1.5	11.7	0.42	1.75	3.3	24.2	0.00	0.00	0.00	0.05
SPP	Southwest Power Pool	62.6	0.7	27.7	0.20	1.05	2.6	4.1	0.85	0.00	0.00	0.12
TRE	Texas Regional Entity	37.1	0.5	47.5	1.24	0.07	0.3	11.9	1.24	0.00	0.00	0.17
WECC	Western Electricity Coordinating Council	33.4	0.5	26.3	0.44	1.30	24.7	10.1	1.08	0.08	2.08	0.05
US		**49.6**	**3.0**	**18.8**	**0.60**	**1.30**	**6.5**	**19.3**	**0.44**	**0.01**	**0.36**	**0.10**

Source: EPA eGRID 2007 Version 1.1

Figure 5 US NERC Regions

Table 3 Electricity Generation Resource Mix by State

State	Generation resource mix (percent)										
	Coal	Oil	Gas	Other fossil	Biomass	Hydro	Nuclear	Wind	Solar	Geo-thermal	Other
AK	9.5	11.6	56.6	0.00	0.08	22.3	0.0	0.01	0.00	0.00	0.00
AL	56.9	0.1	10.1	0.09	2.35	7.4	23.1	0.00	0.00	0.00	0.01
AR	48.2	0.4	12.6	0.03	3.63	6.5	28.6	0.00	0.00	0.00	0.00
AZ	39.6	0.0	28.5	0.00	0.06	6.4	25.4	0.00	0.01	0.00	0.00
CA	1.0	1.3	46.7	1.13	2.91	19.9	18.1	2.13	0.27	6.51	0.10
CO	71.7	0.0	24.1	0.00	0.07	2.6	0.0	1.56	0.00	0.00	0.00
CT	11.9	9.4	26.4	2.30	2.12	1.4	46.4	0.00	0.00	0.00	0.03
DC	0.0	100.0	0.0	0.00	0.00	0.0	0.0	0.00	0.00	0.00	0.00
DE	59.4	15.0	19.6	6.10	0.00	0.0	0.0	0.00	0.00	0.00	0.00
FL	28.4	16.9	38.1	0.62	1.97	0.1	13.1	0.00	0.00	0.00	0.79
GA	63.9	0.7	7.2	0.04	2.34	2.8	23.1	0.00	0.00	0.00	0.00
HI	14.2	78.8	0.0	1.65	2.61	0.8	0.0	0.06	0.00	1.92	0.00
IA	77.5	0.3	5.6	0.03	0.26	2.2	10.3	3.74	0.00	0.00	0.00
ID	0.9	0.0	14.3	0.00	5.33	78.9	0.0	0.00	0.00	0.00	0.56
IL	47.5	0.2	3.7	0.12	0.35	0.1	48.0	0.07	0.00	0.00	0.00
IN	94.2	0.2	2.8	2.07	0.05	0.3	0.0	0.00	0.00	0.00	0.33
KS	75.2	2.2	2.5	0.00	0.00	0.0	19.2	0.93	0.00	0.00	0.00
KY	91.1	3.8	1.7	0.02	0.43	3.0	0.0	0.00	0.00	0.00	0.00
LA	24.9	3.8	47.3	3.04	2.89	0.9	16.9	0.00	0.00	0.00	0.34
MA	25.3	15.0	42.7	1.75	2.53	1.2	11.5	0.00	0.00	0.00	0.00
MD	55.7	7.3	3.6	1.25	1.04	3.2	27.9	0.00	0.00	0.00	0.00
ME	1.8	8.6	42.6	1.74	21.93	23.3	0.0	0.00	0.00	0.00	0.00
MI	57.8	0.7	11.2	0.83	2.09	0.3	27.0	0.00	0.00	0.00	0.00
MN	62.1	1.5	5.1	0.56	1.89	1.5	24.3	2.99	0.00	0.00	0.09
MO	85.2	0.2	4.3	0.08	0.01	1.4	8.8	0.00	0.00	0.00	0.00
MS	36.9	3.2	34.0	0.04	3.48	0.0	22.4	0.00	0.00	0.00	0.00
MT	63.8	1.5	0.1	0.05	0.23	34.3	0.0	0.00	0.00	0.00	0.00
NC	60.5	0.4	2.4	0.06	1.42	4.3	30.8	0.00	0.00	0.00	0.18
ND	94.8	0.1	0.0	0.18	0.03	4.2	0.0	0.69	0.00	0.00	0.00
NE	66.2	0.1	2.6	0.00	0.14	2.8	28.0	0.31	0.00	0.00	0.00
NH	16.7	5.6	27.8	0.26	3.84	7.1	38.7	0.00	0.00	0.00	0.00
NJ	19.1	1.8	25.1	0.95	1.38	0.0	51.6	0.00	0.00	0.00	0.10
NM	85.2	0.1	11.9	0.00	0.01	0.5	0.0	2.26	0.00	0.00	0.00
NV	44.9	0.1	47.4	0.27	0.00	4.2	0.0	0.00	0.00	3.09	0.00
NY	13.8	16.2	22.5	0.70	1.24	16.9	28.7	0.07	0.00	0.00	0.00
OH	87.2	0.9	1.7	0.19	0.25	0.3	9.4	0.01	0.00	0.00	0.00
OK	51.7	0.1	43.0	0.03	0.41	3.5	0.0	1.21	0.00	0.00	0.01
OR	7.0	0.1	27.0	0.09	1.77	62.5	0.0	1.48	0.00	0.00	0.00
PA	55.4	2.3	5.0	0.58	0.91	0.7	35.0	0.13	0.00	0.00	0.01
RI	0.0	0.9	99.0	0.00	0.00	0.1	0.0	0.00	0.00	0.00	0.00
SC	38.7	0.7	5.3	0.09	1.74	1.7	51.8	0.00	0.00	0.00	0.00
SD	46.0	0.3	4.2	0.00	0.00	47.2	0.0	2.42	0.00	0.00	0.00
TN	61.0	0.2	0.5	0.00	0.57	9.0	28.7	0.00	0.00	0.00	0.00
TX	37.3	0.6	49.3	1.30	0.28	0.3	9.6	1.07	0.00	0.00	0.21
UT	94.3	0.1	3.1	0.00	0.00	2.1	0.0	0.00	0.00	0.48	0.00
VA	44.9	5.4	10.4	0.65	3.12	0.1	35.4	0.00	0.00	0.00	0.00
VT	0.0	0.2	0.0	0.00	7.18	21.2	71.2	0.20	0.00	0.00	0.00
WA	10.3	0.1	8.4	0.37	1.56	70.7	8.1	0.49	0.00	0.00	0.00
WI	67.3	1.1	10.5	0.12	1.89	2.8	16.0	0.15	0.00	0.00	0.07
WV	97.7	0.2	0.3	0.10	0.00	1.5	0.0	0.16	0.00	0.00	0.00
WY	95.1	0.1	0.7	0.58	0.00	1.8	0.0	1.57	0.00	0.00	0.14
U.S.	**49.6**	**3.0**	**18.8**	**0.60**	**1.30**	**6.5**	**19.3**	**0.44**	**0.01**	**0.36**	**0.10**

Source: *EPA eGRID 2007 Version 1.1*

As shown in Table 2, coal was used to generate half the electricity in the US in 2005. Since the eGRID2007 database does not provide details on the type of coal used, a supplemental set of data was compiled from the NREL U.S. LCI database and report TP-550-38617 "Source Energy and Emission Factors for Energy Use in Buildings." Table 4 shows the percentage of each coal type (bituminous, subbituminous, and lignite) used in the overall coal fuel mix for electric power generation by state and the composite for the US. This information was useful in calculating source energy conversion factors for electricity generated using coal at state, regional, and national levels.

2.2 Electricity Generation Source Energy Conversion Factors

Table 5 through Table 7 show composite source energy factors for electricity generated with different fuel types using the EPA eGRID2007 Version 1.1 data, supplemented with the relevant data from NREL, DOE, and ANL. The NREL LCI database provided information on transportation and extraction source energy factors for bituminous, subbituminous, and lignite coal used in US power plants. Average coal processing energy requirements were calculated using the DOE Office of Energy Efficiency and Renewable Energy report "Energy and Environmental Profile of the US Mining Industry – Coal 2002." The 2007 version of NREL report TP-550-38617 "Source Energy and Emission Factors for Energy Use in Buildings" provided data needed to calculate the percentage of coal fuel mix used in electric power generation at state, regional, and national levels.

Natural gas and fuel oil pre-combustion (extraction, processing, and transportation) energy efficiency data were extracted from the ANL GREET model version 1.8c.

Heat rates/conversion efficiency for electricity generation using fossil fuels like coal, natural gas, and oil and electricity T&D losses are derived from the EPA eGRID2007 Version 1.1.

Conversion factors to electricity for nuclear and renewable fuels were provided by EIA Annual Energy Review 2007 Tables A6, 8.2a and A4a.

Hydropower generation conversion efficiency data were provided by National Hydropower Association and linked data sources. The estimate of 85% conversion efficiency included in Table 5 is intended to account for the current mix of newer and older turbine technologies and hydroelectric pumped storage power.

Table 8 shows US electric power generation heat rates and the corresponding plant energy conversion factors based on data provided in the EIA 2007 Annual Energy Review. The net conversion efficiency values are very close to those provided in Table 5 for all fuel types except hydropower generation. Modern hydropower plant conversion efficiency is actually much higher (state of the art plants are over 90% efficient) than the 33.3% conversion efficiency used by EIA.

Table 4 Electricity Generation Coal Type Mix by State

State	Percent of total coal use		
	Bituminous	Subbituminous	Lignite
AK	0.0	100	0.0
AL	73.9	26.1	0.0
AR	0.4	99.6	0.0
AZ	46.3	53.7	0.0
CA	100	0.0	0.0
CO	34.9	65.1	0.0
CT	37.4	62.6	0.0
DC	0.0	0.0	0.0
DE	100	0.0	0.0
FL	100	0.0	0.0
GA	70.9	29.1	0.0
HI	7.1	92.9	0.0
IA	4.8	95.2	0.0
ID	44.4	55.6	0.0
IL	21.3	78.7	0.0
IN	70.2	29.8	0.0
KS	1.9	98.1	0.0
KY	96.7	3.3	0.0
LA	0.0	80.1	19.9
MA	100	0.0	0.0
MD	100	0.0	0.0
ME	100	0.0	0.0
MI	32.1	67.9	0.0
MN	1.7	98.3	0.0
MO	4.2	95.8	0.0
MS	81.8	0.0	18.3
MT	1.7	96.5	1.9
NC	100	0.0	0.0
ND	0.0	2.0	98.0
NE	0.0	100	0.0
NH	100	0.0	0.0
NJ	100	0.0	0.0
NM	0.1	99.9	0.0
NV	100	0.0	0.0
NY	84.1	15.9	0.0
OH	91.8	8.2	0.0
OK	6.7	93.3	0.0
OR	0.0	100	0.0
PA	100	0.0	0.0
RI	0.0	0.0	0.0
SC	100	0.0	0.0
SD	0.0	100	0.0
TN	79.3	20.7	0.0
TX	0.0	64.3	35.7
UT	100	0.0	0.0
VA	100	0.0	0.0
VT	0.0	0.0	0.0
WA	0.0	100	0.0
WI	14.6	85.4	0.0
WV	100	0.0	0.0
WY	0.5	99.5	0.0
US Total	**55.8**	**39.7**	**4.4**

Source: NREL Report TP-550-38617

Table 5 US Average Electricity Generation Source Energy Factors by Fuel Type

Fuel Type	Process energy efficiency (percent)						Source Energy Conversion Factor
	Extraction	Processing	Transportation	Conversion	Electricity T & D	Cumulative Efficiency	
Coal	98.0	98.6	99.0	32.7	93.8	29.3	3.41
Natural Gas	97.0	96.9	99.0	42.1	93.8	36.7	2.72
Fuel Oil	96.3	93.8	98.8	31.7	93.8	26.5	3.77
Nuclear	99.0	96.2	99.9	32.7	93.8	29.2	3.43
Hydro	100	100	100	85.0	93.8	79.7	1.25
Biomass	99.4	95.0	97.5	32.1	93.8	27.7	3.61

Sources: EPA eGRID 2007 Version 1.1, ANL GREET model version 1.8c, NREL LCI database and Report TP-550-38617, EIA Natural Gas Annual 2007 and Annual Energy Review 2007 tables ES1, A6, 8.2a, 8.4a

Table 6 Electricity Generation Source Energy Factors by NERC Region and US

NERC Region	NERC name	Process energy efficiency (percent)				Source Energy Conversion Factor
		Precombustion	Conversion	Transmission	Cummulative Effciency	
ASCC	Alaska Systems Coordinating Council	94.3	37.7	97.2	34.5	2.90
FRCC	Florida Reliability Coordinating Council	93.6	37.5	93.6	32.8	3.05
HICC	Hawaiian Islands Coordinating Council	90.5	34.1	96.3	29.7	3.36
MRO	Midwest Reliability Organization	95.3	31.6	93.6	28.2	3.54
NPCC	Northeast Power Coordinating Council	94.3	37.9	93.6	33.5	2.99
RFC	Reliability First Corporation	95.9	34.3	93.6	30.8	3.25
SERC	SERC Reliability Corporation	95.7	34.6	93.6	31.0	3.23
SPP	Southwest Power Pool	94.9	33.6	93.7	29.9	3.35
TRE	Texas Regional Entity	93.9	36.1	93.8	31.8	3.15
WECC	Western Electricity Coordinating Council	96.2	41.5	94.7	37.8	2.65
US		**95.1**	**35.8**	**93.8**	**31.9**	**3.13**

Sources: EPA eGRID 2007 Version 1.1, ANL GREET model version 1.8c, NREL LCI database and Report TP-550-38617, EIA Natural Gas Annual 2007

Table 7 Electricity Generation Source Energy Factors by State

State	Process energy efficiency (percent)				Source Energy Conversion Factor
	Precombustion	Conversion	Transmission	Cummulative Effciency	
AK	94.3	37.7	97.2	34.5	2.90
AL	96.0	35.0	93.6	31.4	3.18
AR	95.4	33.8	93.6	30.2	3.32
AZ	95.3	36.2	94.7	32.6	3.06
CA	95.3	45.3	94.7	40.8	2.45
CO	95.6	33.3	94.7	30.1	3.32
CT	94.1	35.0	93.6	30.8	3.24
DC	89.3	22.7	93.6	18.9	5.28
DE	94.6	32.4	93.6	28.7	3.48
FL	93.7	37.3	93.6	32.8	3.05
GA	95.9	34.8	93.6	31.2	3.20
HI	90.5	34.1	96.3	29.7	3.36
IA	95.9	31.6	93.6	28.4	3.52
ID	98.5	71.0	94.7	66.2	1.51
IL	95.5	32.0	93.6	28.6	3.50
IN	96.4	32.7	93.6	29.5	3.38
KS	95.5	29.8	93.6	26.7	3.75
KY	96.6	33.0	93.6	29.8	3.35
LA	93.8	35.3	93.6	31.0	3.23
MA	93.7	37.3	93.6	32.7	3.06
MD	95.7	34.3	93.6	30.7	3.25
ME	94.0	38.2	93.6	33.6	2.97
MI	95.4	35.0	93.6	31.2	3.20
MN	95.5	31.7	93.6	28.3	3.53
MO	95.7	33.7	93.6	30.2	3.31
MS	94.5	36.0	93.6	31.8	3.14
MT	97.1	37.4	94.7	34.4	2.91
NC	96.3	35.5	93.6	32.0	3.13
ND	92.9	31.2	93.6	27.1	3.68
NE	95.7	30.9	93.6	27.7	3.61
NH	94.7	36.1	93.6	32.0	3.13
NJ	94.8	36.0	93.6	31.9	3.13
NM	95.6	33.7	94.7	30.5	3.27
NV	95.2	37.9	94.7	34.2	2.92
NY	94.6	38.9	93.6	34.4	2.91
OH	96.5	34.6	93.6	31.3	3.20
OK	94.8	37.2	93.6	33.0	3.03
OR	97.6	61.6	94.7	56.9	1.76
PA	95.9	34.3	93.6	30.8	3.25
RI	93.0	42.1	93.6	36.6	2.73
SC	95.7	35.2	93.6	31.6	3.17
SD	97.7	42.8	93.6	39.2	2.55
TN	96.5	35.4	93.6	32.0	3.13
TX	93.9	36.0	93.8	31.7	3.16
UT	96.9	32.6	94.7	29.9	3.35
VA	95.3	34.0	93.6	30.3	3.30
VT	95.9	37.6	93.6	33.7	2.96
WA	98.4	59.4	94.7	55.3	1.81
WI	95.5	31.8	93.6	28.4	3.52
WV	97.0	36.0	93.6	32.7	3.06
WY	95.9	30.6	94.7	27.8	3.60

Sources: EPA eGRID 2007 Version 1.1, ANL GREET model version 1.8c, NREL LCI database and Report TP-550-38617, EIA Natural Gas Annual 2007

Table 8 Electricity Generation Heat Rates by Fuel Type

Fuel Type	Annual Heat Input (MMBtu)	Net Generation (MWh)	Plant Heat Rate (Btu/kWh)	Net Conversion Efficiency (%)	Energy Conversion Factor
Coal	2.080E+10	2.013E+09	10,334	33.0%	3.03
Natural Gas	6.212E+09	7.610E+08	8,163	41.8%	2.39
Fuel Oil	1.269E+09	1.222E+08	10,382	32.9%	3.04
Nuclear	8.160E+09	7.820E+08	10,435	32.7%	3.06
Hydro	2.703E+09	2.638E+08	10,248	33.3%	3.00
Biomass	5.850E+08	5.428E+07	10,778	31.7%	3.16

Source: EIA Annual Energy Review 2007 tables 8.2a and 8.4a

2.3 Fossil Fuel Source Energy Conversion Factors

GREET provides detailed data on energy needed for pre-combustion processes i.e. extraction, processing, and transportation and distribution of natural gas, oil, and LPG as shown in Table 9. The GREET model allows calculations of various sources of energy consumed during a specific fuel pre-combustion phase as well as associated pollutant emissions. GREET model information was supplemented with EIA Natural Gas Annual 2007 data to calculate natural gas distribution efficiency since the GREET model concentrates on transportation fuels with delivery to a central plant or fueling station rather than a building through a local distribution system. Table 9 lists energy efficiency as percentage of energy of fuel leaving each stage to the total energy entering each stage including energy of other fuels spent in the process. Efficiency of end-use conversion to useful work inside the building was not included in this table as it varies depending on specific equipment efficiency.

Table 9 US Average Building Fuels Pre-combustion Source Energy Factors by Fuel Type

Fuel Type	Process energy efficiency (percent)						Source Energy Conversion Factor
	Extraction	Processing	Transportation	Distribution	Conversion	Cumulative Efficiency	
Natural Gas	97.0	96.9	99.0	98.8	100	91.9	1.09
Fuel Oil	96.3	93.8	98.8	99.3	100	88.6	1.13
LPG	95.9	95.3	98.6	99.2	100	89.3	1.12

Sources: ANL GREET model version 1.8c, EIA Natural Gas Annual 2007

3.0 Source Energy Emission Factors

Information on source emissions due to electricity and natural gas consumption is available from public databases and includes CO_2, NOx, SO_2, Hg, CH_4, and N_2O emissions based on the full fuel cycle. National, regional, and state level electricity source emission factors are derived from the EPA eGRID2007 Version 1.1 database, GREET, and the NREL LCI database. Emission factors for fossil fuel consumption are derived from GREET and EPA report AP-42.

3.1 Electricity Generation Emission Factors

The eGRID2007 Version 1.1 database provides information on pollutant emissions associated with US electric power plants. The latest data are for year 2005 and are reported for nearly all US power plants and aggregated at several levels including state, NERC region, and national level. Table 10 shows CO_2, NOx, SO_2, Hg, CH_4, and N_2O emissions in pounds of pollutant per unit of generated electricity (MWh or GWh) by NERC Region and US average. Table 11 shows similar data at the state level. Table 12 and Table 13 show emissions of CO_2, NOx, SO_2, and Hg in pounds of pollutant per MMBtu of fossil fuel used to generate electricity. The emission factors shown in Table 10 and Table 11 are based on electricity output and include the total fuel mix used by power plants, while factors shown in Table 12 and Table 13 include power plant emissions related only to fossil fuel input.

Table 10 Electricity Generation Emission Rate by NERC Region and US - All Fuels

NERC region	NERC name	NOx output emission rate (lb/MWh)	SO_2 output emission rate (lb/MWh)	CO_2 output emission rate (lb/MWh)	CH_4 output emission rate (lb/GWh)	N_2O output emission rate (lb/GWh)	Hg output emission rate (lb/GWh)
ASCC	Alaska Systems Coordinating Council	3.317	1.080	1,089.8	24.66	6.04	0.0017
FRCC	Florida Reliability Coordinating Council	2.073	3.578	1,318.6	45.92	16.94	0.0092
HICC	Hawaiian Islands Coordinating Council	3.880	4.167	1,731.0	165.40	29.96	0.0116
MRO	Midwest Reliability Organization	3.575	5.865	1,823.7	27.94	30.66	0.0391
NPCC	Northeast Power Coordinating Council	0.876	2.408	875.7	60.56	13.55	0.0105
RFC	Reliability First Corporation	2.288	8.985	1,427.2	23.19	23.87	0.0420
SERC	SERC Reliability Corporation	1.926	6.244	1,368.9	23.32	22.54	0.0277
SPP	Southwest Power Pool	2.824	4.455	1,751.4	24.62	25.52	0.0344
TRE	Texas Regional Entity	0.876	3.196	1,324.3	18.65	15.11	0.0246
WECC	Western Electricity Coordinating Council	1.519	1.083	1,033.1	22.62	14.77	0.0135
US		**1.937**	**5.259**	**1,329.4**	**27.27**	**20.60**	**0.0272**

Source: EPA eGRID 2007 Version 1.1

Table 11 Electricity Generation Emission Rate by State - All Fuels

State	NOx output emission rate (lb/MWh)	SO_2 output emission rate (lb/MWh)	CO_2 output emission rate (lb/MWh)	CH_4 output emission rate (lb/GWh)	N_2O output emission rate (lb/GWh)	Hg output emission rate (lb/GWh)
AK	3.317	1.080	1,089.8	24.66	6.04	0.0017
AL	2.014	6.789	1,340.5	25.10	23.08	0.0398
AR	1.591	2.977	1,229.2	31.98	22.30	0.0213
AZ	1.616	1.049	1,158.6	15.53	15.93	0.0148
CA	0.223	0.136	540.1	30.60	4.50	0.0020
CO	2.922	2.535	1,910.9	23.48	29.26	0.0164
CT	0.601	0.546	803.9	67.79	13.63	0.0158
DC	3.654	8.090	2,432.3	104.97	21.00	N/A
DE	3.330	7.997	2,018.0	36.49	26.52	0.0398
FL	2.114	3.888	1,340.5	45.73	17.68	0.0104
GA	1.735	9.457	1,402.5	22.02	23.93	0.0274
HI	3.880	4.167	1,731.0	165.40	29.96	0.0116
IA	3.444	6.271	1,907.2	22.38	31.62	0.0505
ID	0.140	0.175	133.7	19.16	3.44	N/A
IL	1.370	3.613	1,126.0	13.15	18.50	0.0427
IN	3.289	13.457	2,087.8	24.54	34.76	0.0450
KS	3.924	5.954	1,894.9	23.25	31.31	0.0444
KY	3.426	10.300	2,057.4	24.13	34.91	0.0375
LA	1.630	2.470	1,175.5	25.45	13.42	0.0127
MA	1.109	3.524	1,262.9	68.41	17.23	0.0149
MD	2.462	10.938	1,352.3	34.58	22.73	0.0388
ME	1.027	1.222	739.7	229.01	32.49	0.0028
MI	2.081	6.420	1,347.5	29.65	23.65	0.0310
MN	3.345	3.991	1,594.7	38.72	28.49	0.0289
MO	2.829	6.494	1,846.9	21.31	30.71	0.0429
MS	1.961	3.428	1,225.8	26.49	17.42	0.0131
MT	2.920	1.559	1,592.0	19.73	27.20	0.0362
NC	1.784	7.869	1,225.0	19.82	21.32	0.0271
ND	4.828	8.699	2,325.2	25.10	37.35	0.0715
NE	3.440	4.717	1,605.9	18.58	26.69	0.0222
NH	0.942	4.524	788.3	61.00	15.01	0.0025
NJ	0.986	1.921	718.6	30.22	10.79	0.0132
NM	4.344	1.746	1,935.9	23.28	30.53	0.0639
NV	2.245	2.617	1,440.8	20.02	17.85	0.0149
NY	0.887	2.453	828.3	36.96	10.41	0.0110
OH	3.317	14.223	1,771.8	20.99	29.90	0.0482
OK	2.482	3.094	1,562.8	21.67	20.44	0.0277
OR	0.444	0.522	401.4	16.97	4.80	0.0036
PA	1.691	9.148	1,244.5	25.42	20.94	0.0488
RI	0.213	0.055	964.7	19.21	1.98	N/A
SC	1.085	4.412	893.9	14.92	15.17	0.0119
SD	4.540	3.515	1,181.4	13.96	19.03	0.0142
TN	2.132	5.526	1,259.1	16.41	21.69	0.0284
TX	0.987	3.008	1,355.4	19.75	15.35	0.0245
UT	3.710	1.940	2,103.0	24.14	35.19	0.0076
VA	1.789	5.764	1,196.0	40.99	21.27	0.0159
VT	0.203	0.017	4.7	88.61	11.83	N/A
WA	0.424	0.089	331.1	16.40	6.04	0.0066
WI	2.405	6.144	1,720.1	25.52	28.28	0.0372
WV	3.468	10.088	1,928.1	21.89	32.72	0.0535
WY	4.011	3.963	2,251.5	25.68	37.24	0.0407

Source: EPA eGRID 2007 Version 1.1

Table 12 Electricity Generation Emission Rate by NERC Region and US - Fossil Fuels

NERC region	NERC name	NOx input emission rate (lb/MMBtu)	SO_2 input emission rate (lb/MMBtu)	CO_2 input emission rate (lb/MMBtu)	Hg input emission rate (lb/BBtu)
ASCC	Alaska Systems Coordinating Council	0.405	0.132	133.19	0.0002
FRCC	Florida Reliability Coordinating Council	0.256	0.462	165.65	0.0008
HICC	Hawaiian Islands Coordinating Council	0.376	0.431	174.70	0.0002
MRO	Midwest Reliability Organization	0.396	0.651	202.48	0.0043
NPCC	Northeast Power Coordinating Council	0.137	0.443	153.87	0.0011
RFC	Reliability First Corporation	0.318	1.262	198.79	0.0057
SERC	SERC Reliability Corporation	0.267	0.873	192.59	0.0039
SPP	Southwest Power Pool	0.295	0.465	183.71	0.0036
TRE	Texas Regional Entity	0.109	0.399	165.49	0.0031
WECC	Western Electricity Coordinating Council	0.253	0.181	173.67	0.0022
US		**0.267**	**0.736**	**185.32**	**0.0037**

Source: EPA eGRID 2007 Version 1.1

Table 13 Electricity Generation Emission Rate by State - Fossil Fuels

State	NOx input emission rate (lb/MMBtu)	SO_2 input emission rate (lb/MMBtu)	CO_2 input emission rate (lb/MMBtu)	Hg input emission rate (lb/BBtu)
AK	0.405	0.132	133.19	0.0002
AL	0.281	0.948	187.23	0.0056
AR	0.228	0.427	176.32	0.0031
AZ	0.247	0.160	176.87	0.0023
CA	0.048	0.029	116.88	0.0004
CO	0.290	0.251	189.39	0.0016
CT	0.117	0.106	155.89	0.0031
DC	0.243	0.538	161.68	N/A
DE	0.284	0.682	172.13	0.0034
FL	0.260	0.478	164.78	0.0013
GA	0.239	1.304	193.42	0.0038
HI	0.363	0.390	161.95	0.0011
IA	0.363	0.660	200.71	0.0053
ID	0.092	0.115	87.63	N/A
IL	0.242	0.638	198.78	0.0075
IN	0.316	1.295	200.87	0.0043
KS	0.418	0.634	201.72	0.0047
KY	0.337	1.012	202.05	0.0037
LA	0.209	0.316	150.30	0.0016
MA	0.136	0.431	154.34	0.0018
MD	0.351	1.559	192.70	0.0055
ME	0.123	0.147	88.75	0.0003
MI	0.297	0.915	192.09	0.0044
MN	0.410	0.489	195.42	0.0035
MO	0.309	0.710	202.03	0.0047
MS	0.268	0.468	167.23	0.0018
MT	0.376	0.201	205.04	0.0047
NC	0.287	1.264	196.79	0.0043
ND	0.451	0.812	216.97	0.0067
NE	0.431	0.591	201.04	0.0028
NH	0.167	0.804	140.16	0.0004
NJ	0.228	0.445	166.56	0.0031
NM	0.434	0.174	193.36	0.0064
NV	0.261	0.304	167.46	0.0017
NY	0.169	0.469	158.27	0.0021
OH	0.380	1.630	203.10	0.0055
OK	0.272	0.340	171.45	0.0030
OR	0.151	0.177	136.21	0.0012
PA	0.268	1.448	197.03	0.0077
RI	0.026	0.007	119.02	N/A
SC	0.232	0.944	191.31	0.0025
SD	0.761	0.589	197.98	0.0024
TN	0.343	0.888	202.38	0.0046
TX	0.119	0.363	163.52	0.0030
UT	0.358	0.187	202.72	0.0007
VA	0.277	0.891	184.89	0.0025
VT	0.157	0.013	3.59	N/A
WA	0.204	0.043	159.06	0.0031
WI	0.268	0.684	191.55	0.0041
WV	0.369	1.072	204.90	0.0057
WY	0.363	0.359	203.77	0.0037

Source: EPA eGRID 2007 Version 1.1

3.2 *Electricity Generation Pre-combustion Emission Factors*

EPA eGRID2007 Version 1.1, GREET, and the NREL LCI database were sources of information on pre-combustion air emissions associated with US electric power generation. Table 14 provides pre-combustion emission factors associated with electricity generation by NERC Region and US average. Table 15 shows similar data at the state level.

Table 14 Electricity Generation Pre-combustion Emission Rate by NERC Region and US, All Fuels

NERC region		NOx input emission rate (lb/MWh)	SO_2 input emission rate (lb/MWh)	CO_2 input emission rate (lb/MWh)	Hg input emission rate (lb/GWh)
ASCC	Alaska Systems Coordinating Council	0.453	0.227	101.88	0.0000
FRCC	Florida Reliability Coordinating Council	0.427	0.223	98.64	0.0000
HICC	Hawaiian Islands Coordinating Council	0.874	0.444	219.38	0.0000
MRO	Midwest Reliability Organization	0.384	0.207	54.93	0.0000
NPCC	Northeast Power Coordinating Council	0.341	0.193	85.00	0.0000
RFC	Reliability First Corporation	0.226	0.125	37.73	0.0000
SERC	SERC Reliability Corporation	0.250	0.140	44.66	0.0000
SPP	Southwest Power Pool	0.396	0.206	63.46	0.0000
TRE	Texas Regional Entity	0.402	0.211	73.75	0.0000
WECC	Western Electricity Coordinating Council	0.256	0.150	51.12	0.0000
US		**0.289**	**0.159**	**53.97**	**0.0000**

Source: EPA eGRID2007 Version 1.1, ANL GREET model version 1.8c, NREL LCI database

Table 15 Electricity Generation Pre-combustion Emission Rate by State – All Fuels

State	NOx input emission rate (lb/MWh)	SO_2 input emission rate (lb/MWh)	CO_2 input emission rate (lb/MWh)	Hg input emission rate (lb/GWh)
AK	0.453	0.227	101.88	0.000
AL	0.230	0.132	40.13	0.000
AR	0.277	0.163	50.89	0.000
AZ	0.253	0.136	47.21	0.000
CA	0.292	0.203	80.10	0.000
CO	0.349	0.179	51.42	0.000
CT	0.294	0.173	76.11	0.000
DC	1.529	0.743	387.71	0.000
DE	0.420	0.207	81.32	0.000
FL	0.421	0.222	96.49	0.000
GA	0.235	0.135	40.07	0.000
HI	0.874	0.444	219.38	0.000
IA	0.351	0.193	50.44	0.000
ID	0.082	0.063	23.08	0.000
IL	0.217	0.127	39.76	0.000
IN	0.282	0.139	32.58	0.000
KS	0.353	0.185	50.78	0.000
KY	0.291	0.144	40.10	0.000
LA	0.389	0.213	81.70	0.000
MA	0.417	0.222	95.88	0.000
MD	0.246	0.136	48.12	0.000
ME	0.494	0.338	136.78	0.000
MI	0.246	0.140	41.50	0.000
MN	0.326	0.190	56.09	0.000
MO	0.316	0.159	39.35	0.000
MS	0.319	0.182	66.04	0.000
MT	0.276	0.136	34.28	0.000
NC	0.183	0.108	32.56	0.000
ND	0.670	0.331	74.07	0.000
NE	0.293	0.157	42.65	0.000
NH	0.275	0.168	70.18	0.000
NJ	0.193	0.122	49.79	0.000
NM	0.368	0.191	51.71	0.000
NV	0.332	0.179	63.88	0.000
NY	0.328	0.179	81.54	0.000
OH	0.246	0.126	33.77	0.000
OK	0.374	0.193	65.51	0.000
OR	0.147	0.087	33.07	0.000
PA	0.205	0.119	39.64	0.000
RI	0.430	0.217	96.53	0.000
SC	0.158	0.106	38.02	0.000
SD	0.227	0.122	32.49	0.000
TN	0.188	0.106	30.28	0.000
TX	0.413	0.215	75.66	0.000
UT	0.259	0.129	30.85	0.000
VA	0.241	0.146	52.35	0.000
VT	0.088	0.103	41.19	0.000
WA	0.090	0.056	19.09	0.000
WI	0.329	0.177	51.15	0.000
WV	0.231	0.114	25.81	0.000
WY	0.371	0.188	43.39	0.000

Source: EPA eGRID2007 Version 1.1, ANL GREET model version 1.8c, NREL LCI database

3.3 Fossil Fuel Pre-combustion Emission Factors

Table 16 lists fossil fuel pre-combustion emissions factors, including extraction, processing, and transportation, based on information provided in GREET. Relevant emissions data include CO_2, CH_4, N_2O, NOx, SOx, PM_{10}, and $PM_{2.5}$ emissions in pounds of pollutant per MMBtu of fuel. Emission factors were calculated using HHV of all fuels involved in pre-combustion stages of preparing a specific fuel for combustion. Table 17 lists LHV and HHV as well as specific density for several fossil fuels. Data provided in Table 16 is useful to calculate total pre-combustion pollutant emissions associated with fossil fuel consumption.

Table 16 Fossil Fuel Pre-combustion Emission Factors

Pollutant	Pre-Combustion Emission Factors of Fossil Fuels (lbs per MMBtu HHV)						
	Coal to Power Plants	Natural Gas to Power Plant	Natural Gas as Stationary Fuel	Residual Oil as Stationary Fuel	Distillate Oil as Stationary Fuel	LPG as Stationary Fuel	LNG as Stationary Fuel
CO_2	3.38	10.29	10.48	21.52	31.48	21.59	22.87
CH_4	0.2493	0.3493	0.3913	0.2037	0.2148	0.2027	0.4223
N_2O	0.0001	0.0002	0.0002	0.0004	0.0005	0.0004	0.0005
NOx	0.0312	0.0459	0.0473	0.0849	0.0905	0.0853	0.1114
SOx	0.0153	0.0232	0.0234	0.0412	0.0448	0.0377	0.0390
PM_{10}	0.3549	0.0017	0.0018	0.0119	0.0181	0.0119	0.0039
$PM_{2.5}$	0.0884	0.0010	0.0011	0.0050	0.0073	0.0051	0.0023

Source: ANL GREET model version 1.8c, NREL LCI database

Table 17 Heating Value and Density of Fossil Fuels

Fuel	Heating Value		Density
	LHV	HHV	
Liquid Fuels:	**Btu/gal**	**Btu/gal**	**lb/gal**
Crude oil	129,670	138,350	7.0670
Distillate oil	128,450	137,380	6.9832
Residual oil	140,353	150,110	8.2732
Conventional gasoline	116,090	124,340	6.2159
Liquefied petroleum gas (LPG)	84,950	91,410	4.2402
Liquefied natural gas (LNG)	74,720	84,820	3.5743
Gaseous Fuels (at 60°F and 14.7 psia):	**Btu/ft3**	**Btu/ft3**	**lb/ft3**
Natural gas	930	1,029	0.04584
Solid Fuels:	**Btu/ton**	**Btu/ton**	
Coal	19,546,300	20,608,570	

Source: ANL GREET model version 1.8c

3.4 Fossil Fuel Stationary Combustion Emission Factors

Table 18 lists fossil fuel stationary combustion emissions data derived from GREET. In combination with the pre-combustion emission factors provided in Table 15, the data are useful in evaluating total emissions from fossil fuel consumption in buildings.

Table 18 Fossil Fuel Combustion Emission Factors

Pollutant	Combustion Emission Factors of Fossil Fuels (lbs per MMBtu HHV)				
	Natural Gas as Stationary Fuel	Residual Oil as Stationary Fuel	Distillate Oil as Stationary Fuel	LPG as Stationary Fuel	LNG as Stationary Fuel
CO_2	118.29	175.34	161.15	139.42	118.29
CH_4	0.0022	0.0032	0.0016	0.0022	0.0022
N_2O	0.0022	0.0007	0.0008	0.0100	0.0022
NOx	0.0598	0.2577	0.1695	0.1734	0.0598
SOx	0.0005	0.4177	0.0166	0.0000	0.0005
PM_{10}	0.0059	0.1237	0.0877	0.0050	0.0059
$PM_{2.5}$	0.0059	0.0804	0.0783	0.0050	0.0059

Note; LNG emissions assumed equivalent to natural gas emissions

Source: ANL GREET model version 1.8c, EPA

4.0 Case Studies

Site energy consumption by fuel type for each energy consuming device and for the whole building forms the basis of a source energy and emissions calculation methodology that accounts for primary energy consumption and related emissions for the full fuel cycle of extraction, processing, transportation, conversion, distribution, and consumption. The methodology permits aggregate average emission estimates as well as marginal analysis of incremental changes in consumption by fuel type. Using sources identified above, full fuel cycle energy efficiency factors and CO_2, SO_2, and NOx emission factors can be calculated locally, regionally, and nationally. Figure 6 shows a flow diagram of the calculation process that provides the sequence of calculations to estimate energy use within the building boundary and to evaluate resulting environmental impacts based on full fuel cycle energy use and associated CO_2 emissions.

User Input - Select location for analysis
Zip code, city, state, eGrid subregion, NERC region, or US
↓
User Input - Define building annual energy use *
Electricity, natural gas, fuel oil, propane
↓
Program processes annual electricity use data and calculates location-specific:
Efficiency of electric transmission and distribution and corresponding electric power generation required
Power plant source fuel mix
Conversion efficiency for each fuel used for power generation, and corresponding pollutant emissions
Energy efficiency of fuel extraction, processing, and transportation, and corresponding pollutant emissions
↓
Program processes annual natural gas, fuel oil, propane use data and calculates location-specific:
Energy efficiency of fuel extraction, processing, transportation, and distribution, and corresponding pollutant emissions
↓
Output reports provide:
Annual source energy and emissions of CO_2, NOx, SO_2, and Hg associated with building electricity and other fuel use
Power generation fuel mix, source energy efficiency and emission factors for each fuel
Location-specific composite source energy factors for electricity and other fuels used in the building.
** Auxliary module can estimate location-specific site consumption for residential building types, sizes, and appliance loads*

Figure 6 Energy and CO_2 Emission Calculation Methodology Flow Diagram

The following examples show selected input parameters and application of the calculation methodology to compare the site energy, full fuel cycle energy, and pollutant emissions of an electric water heater with an energy factor (EF) of 0.90 and a natural gas water heater with an EF of 0.59. The annual load on each water heater was identical at the same geographical location, but varied slightly among geographical locations due to supply water temperature differences around the country. Source energy consumption and associated emissions are presented at the state, NERC region, and US average levels.

The intent of these examples is to illustrate the potential societal benefit of optimizing the use of the nation's primary energy in buildings. While there is no single best choice for the entire country, it is possible to demonstrate the societal value of decisions that increase site energy consumption but reduce the nation's primary energy consumption as well as CO_2 emissions.

4.1 Average Source Energy and Emissions Sample Calculations

Table 19 shows the source energy consumption comparison calculated using NERC region and US average source energy factors based on electricity and natural gas site energy consumption. Table 20 compares corresponding emissions for CO_2, SO_2, and NOx using NERC region and US average source energy factors. Table 21 and Table 22 compare source energy consumption and emissions at the state level. Figure 7 through Figure 14 provide graphical representations of selected data from Table 19 through Table 22.

The results of the regional and national comparison indicate that the source energy consumption of the gas water heater was significantly less than the electric water heater. The difference ranged from 43 to 54 percent in the NERC regions, and for the U.S. average generation mix, the difference was 47 percent. Corresponding CO_2 emissions from the gas water heater were also significantly lower than the electric water heater in all NERC regions as well as for the U.S. average. The variability was wider than the source energy consumption, ranging from 28 to 66 percent across NERC regions, with the US average reduction of 53 percent. The SO_2 and NOx emission reductions were even more significant, varying from 89 to 99 percent for SO_2 and 50 to 88 percent for NOx.

State level calculations illustrate the range of average energy consumption and CO_2 emissions associated with in-state electricity generation. With the exception of Idaho, which has nearly 80 percent hydropower with a source energy efficiency of 80 percent, source energy consumption of the gas water heater was less than the electric water heater. In most states the difference ranged from 35 to 55 percent, with the highest difference of 69 percent in Washington, DC, which has local coal generation.

Emissions from the gas water heater were also much lower than the electric water heater in nearly all states, but the variability was wider than the source energy consumption due to the impact of nuclear energy and hydropower on emissions. For instance, Vermont has nearly 80 percent nuclear generation, with the rest almost all hydropower. As a result, there are almost no emissions associated with electricity generation in Vermont, so the electric water heater would have near zero emissions from power generated in Vermont. On the other hand, in Indiana, which has nearly 95 percent coal generation, the gas water heater has 70 percent lower CO_2 emissions than the electric water heater. SO_2 emissions were over 90 percent lower in most states. The NOx emission reductions ranged from 55 to 90 percent except for a few states with significant hydropower or nuclear generation. In 5 states (CA, ID, OR, VT, and WA), the comparison based on the state average power generation mix resulted in the electric water heater source energy CO_2 emissions being lower than the natural gas water heater.

Protocols offered by different organizations do not choose the same aggregation level for calculations. As seen in this illustration, it is important to understand the basis of the calculation to be able to interpret the results. Another factor for consideration, especially if choosing to use state level data, is whether the state is importing or exporting electricity. For instance, California imported 26 percent of its electricity from neighboring states in the WECC region in 2006. By ignoring that contribution to the state's electricity consumption, the resulting calculation may be quite misleading. On the other hand, for a state such as Alabama that exported 37 percent of its electricity to neighboring states in 2006, it may be more reasonable to use state level data than regional or national averages.

Table 19 Water Heater Source Energy Consumption Comparison by NERC Region and US

NERC Region	Electric Water Heater kWh	Natural Gas Water Heater MMBtu	Electric Water Heater Source MMBtu	Natural Gas Water Heater Source MMBtu	Source Energy Reduction vs. Electric Water Heater %
ASCC	4,941	25.72	49.24	27.98	43.17
FRCC	3,147	16.38	32.38	17.82	44.96
HICC	3,007	15.65	34.54	17.03	50.70
MRO	4,398	22.89	53.79	24.91	53.70
NPCC	4,288	22.32	43.30	24.29	43.92
RFC	4,179	21.75	45.96	23.66	48.51
SERC	3,715	19.33	40.67	21.03	48.29
SPP	3,861	20.09	44.24	21.86	50.59
TRE	3,396	17.67	36.30	19.23	47.04
WECC	4,102	21.35	38.18	23.23	39.16
US Average	**3,516**	**18.3**	**37.60**	**19.91**	**47.04**

Table 20 Water Heater Source Emissions Comparison by NERC Region and US

NERC Region	Electric Water Heater CO_2 (lb)	Natural Gas Water Heater CO_2 (lb)	CO_2 Reduction vs. Electric Water Heater (%)	Electric Water Heater SO_2 (lb)	Natural Gas Water Heater SO_2 (lb)	SO_2 Reduction vs. Electric Water Heater (%)	Electric Water Heater NO_x (lb)	Natural Gas Water Heater NO_X (lb)	NOx Reduction vs. Electric Water Heater (%)
ASCC	6,032	3,336	44.70	6.59	0.69	89.58	19.06	2.71	85.77
FRCC	4,344	2,124	51.10	11.81	0.44	96.30	7.37	1.73	76.56
HICC	5,818	2,030	65.11	14.10	0.42	97.04	13.73	1.65	87.98
MRO	8,698	2,969	65.87	27.94	0.61	97.81	18.33	2.41	86.83
NPCC	4,019	2,895	27.98	11.11	0.60	94.64	4.70	2.35	49.92
RFC	6,404	2,821	55.95	40.32	0.58	98.56	10.96	2.29	79.07
SERC	5,450	2,507	54.00	24.22	0.52	97.87	8.22	2.04	75.21
SPP	7,295	2,605	64.28	18.26	0.54	97.06	12.80	2.12	83.45
TRE	5,050	2,292	54.62	12.17	0.47	96.13	4.55	1.86	59.09
WECC	4,638	2,769	40.30	5.24	0.57	89.13	7.50	2.25	70.00
US Average	**5,054**	**2,373**	**53.04**	**19.74**	**0.49**	**97.53**	**8.08**	**1.93**	**76.13**

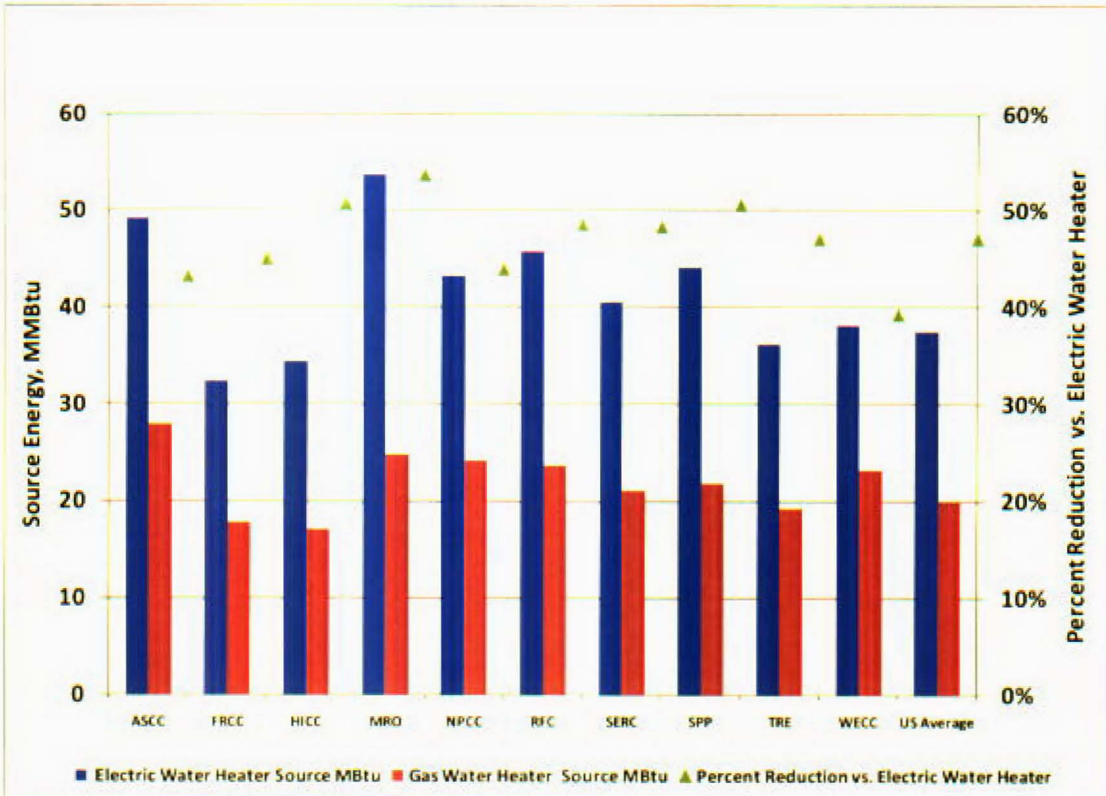

Figure 7 Water Heater Source Energy Consumption Comparison by NERC Region and US

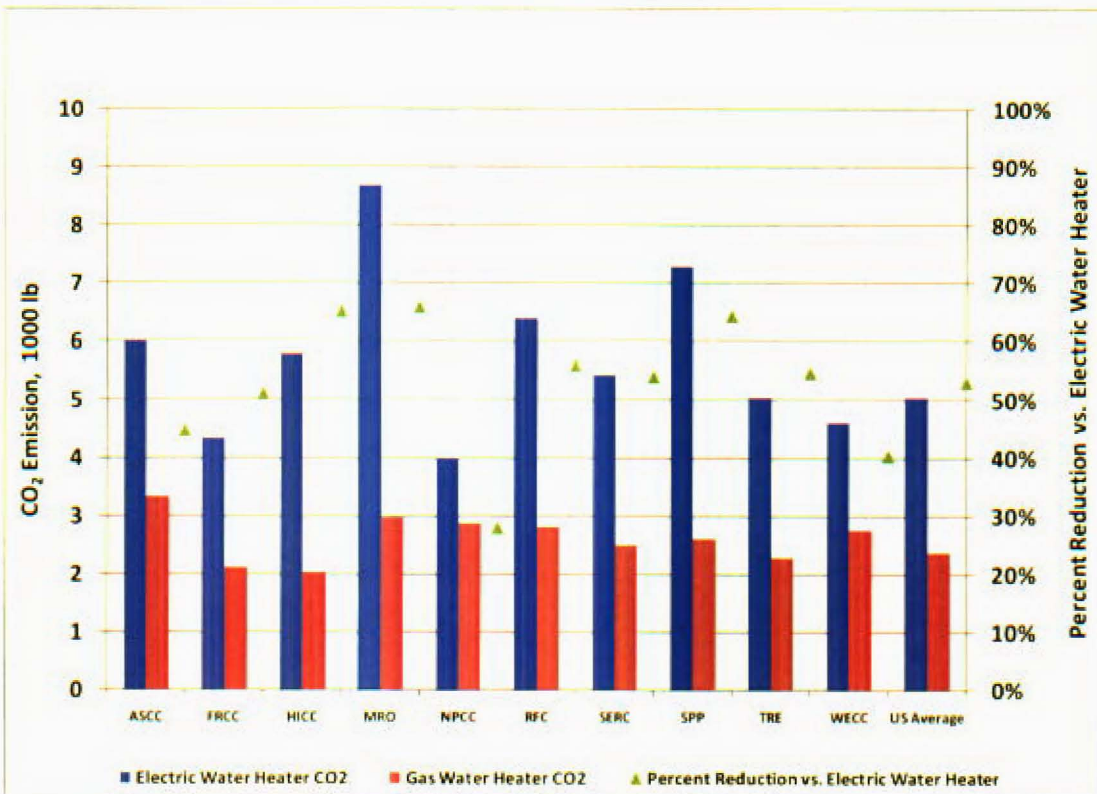

Figure 8 Water Heater CO_2 Emission Comparison by NERC Region and US

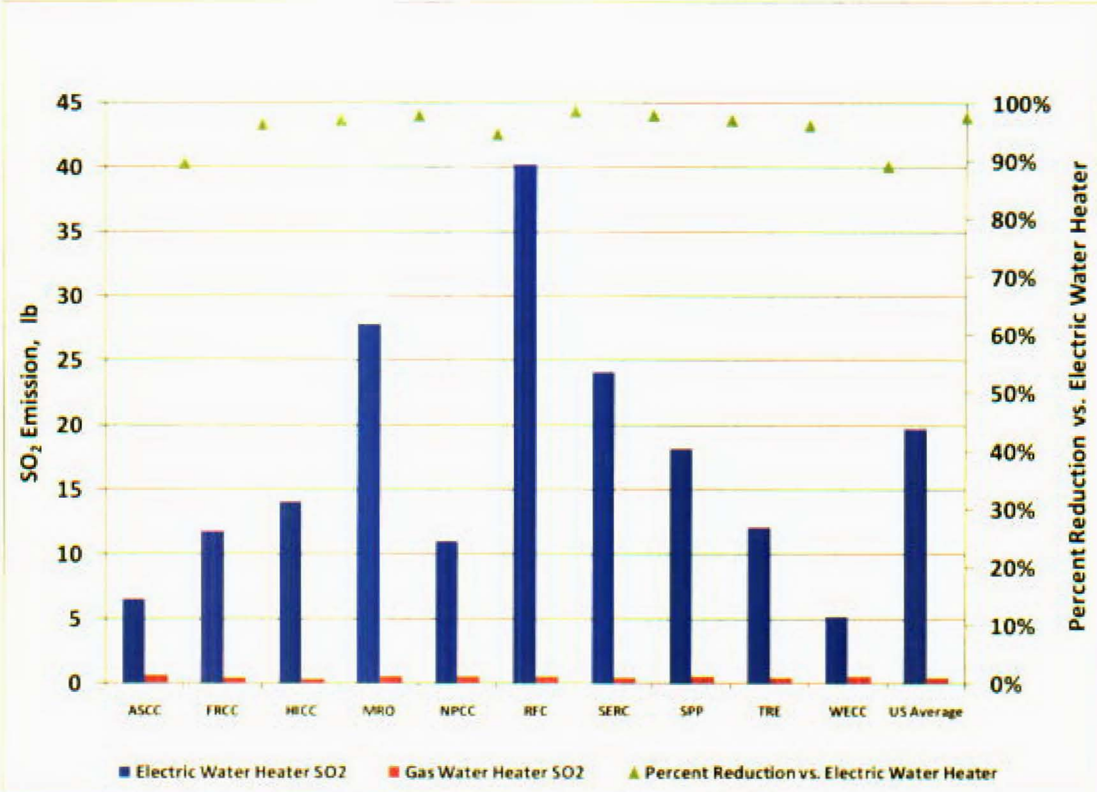

Figure 9 Water Heater SO_2 Emission Comparison by NERC Region and US

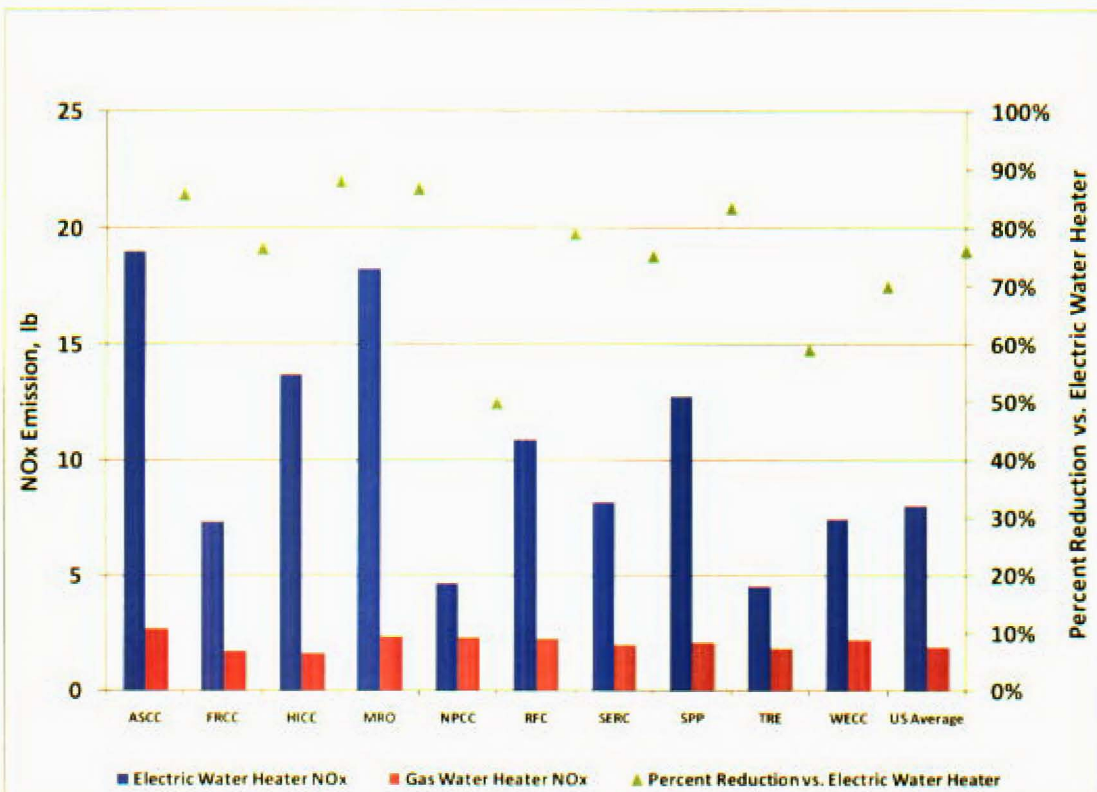

Figure 10 Water Heater NOx Emission Comparison by NERC Region and US

Table 21 Water Heater Source Energy Consumption Comparison by State

State	Electric Water Heater kWh	Natural Gas Water Heater MMBtu	Electric Water Heater Source MMBtu	Natural Gas Water Heater Source MMBtu	Source Energy Reduction vs. Electric Water Heater (%)
AK	5,053	25.72	49.24	27.98	43.2
AL	3,644	18.54	38.68	20.17	47.8
AR	3,779	19.23	41.84	20.92	50.0
AZ	3,787	19.27	38.67	20.97	45.8
CA	3,763	19.15	33.28	20.84	37.4
CO	4,384	22.31	48.96	24.27	50.4
CT	4,225	21.5	44.55	23.39	47.5
DC	4,121	20.97	72.51	22.82	68.5
DE	4,073	20.73	44.32	22.56	49.1
FL	3,219	16.38	32.47	17.82	45.1
GA	3,665	18.65	39.14	20.29	48.2
HI	3,075	15.65	34.54	17.03	50.7
IA	4,363	22.2	52.71	24.15	54.2
ID	4,360	22.19	22.11	24.14	(9.2)
IL	4,268	21.72	49.74	23.63	52.5
IN	4,189	21.32	46.26	23.20	49.9
KS	4,133	21.03	52.05	22.88	56.0
KY	4,058	20.65	45.36	22.47	50.5
LA	3,477	17.69	36.11	19.25	46.7
MA	4,320	21.99	43.17	23.93	44.6
MD	4,042	20.57	43.27	22.38	48.3
ME	4,630	23.56	45.65	25.63	43.8
MI	4,467	22.73	47.20	24.73	47.6
MN	4,688	23.86	56.16	25.96	53.8
MO	4,042	20.57	44.66	22.38	49.9
MS	3,636	18.5	37.99	20.13	47.0
MT	4,556	23.19	44.57	25.23	43.4
NC	3,840	19.54	40.08	21.26	46.9
ND	4,673	23.78	57.83	25.87	55.3
NE	4,312	21.94	52.07	23.87	54.2
NH	4,471	22.75	46.55	24.75	46.8
NJ	4,105	20.89	42.35	22.73	46.3
NM	3,954	20.12	43.93	21.89	50.2
NV	4,190	21.32	41.76	23.20	44.5
NY	4,344	22.11	42.01	24.06	42.7
OH	4,256	21.66	45.28	23.57	48.0
OK	3,835	19.52	39.10	21.24	45.7
OR	4,191	21.33	25.30	23.21	8.3
PA	4,286	21.81	46.24	23.73	48.7
RI	4,248	21.62	38.75	23.52	39.3
SC	3,702	18.84	39.14	20.50	47.6
SD	4,475	22.77	39.46	24.77	37.2
TN	3,851	19.6	40.28	21.33	47.1
TX	3,539	18.01	37.00	19.60	47.0
UT	4,201	21.38	47.05	23.26	50.6
VA	3,972	20.21	43.37	21.99	49.3
VT	4,519	23	45.03	25.03	44.4
WA	4,274	21.75	26.07	23.66	9.2
WI	4,513	22.96	52.96	24.98	52.8
WV	4,132	21.03	42.28	22.88	45.9
WY	4,528	23.05	54.68	25.08	54.1

Table 22 Water Heater Source Emissions Comparison by State

State	Electric Water Heater CO_2 (lb)	Natural Gas Water Heater CO_2 (lb)	CO_2 Reduction vs. Electric Water Heater (%)	Electric Water Heater SO_2 (lb)	Natural Gas Water Heater SO_2 (lb)	SO_2 Reduction vs. Electric Water Heater (%)	Electric Water Heater NOx (lb)	Natural Gas Water Heater NOx (lb)	NOx Reduction vs. Electric Water Heater (%)
AK	6,032	3,336	44.7	6.59	0.69	89.6	19.06	2.71	85.8
AL	5,125	2,404	53.1	24.92	0.49	98.0	8.08	1.96	75.8
AR	5,048	2,494	50.6	11.60	0.51	95.6	7.36	2.03	72.4
AZ	4,673	2,499	46.5	4.56	0.51	88.7	7.18	2.03	71.7
CA	2,265	2,484	(9.7)	1.22	0.51	58.0	1.74	2.02	(16.4)
CO	8,847	2,893	67.3	12.19	0.60	95.1	14.72	2.35	84.0
CT	3,315	2,788	15.9	3.02	0.57	81.0	2.95	2.27	23.2
DC	12,024	2,720	77.4	37.80	0.56	98.5	21.87	2.21	89.9
DE	7,914	2,688	66.0	36.26	0.55	98.5	15.30	2.19	85.7
FL	4,398	2,124	51.7	12.55	0.44	96.5	7.44	1.73	76.8
GA	5,472	2,419	55.8	36.40	0.50	98.6	7.28	1.97	73.0
HI	5,818	2,030	65.1	14.10	0.42	97.0	13.73	1.65	88.0
IA	8,868	2,879	67.5	29.22	0.59	98.0	17.10	2.34	86.3
ID	677	2,878	(325.2)	0.46	0.59	(28.5)	0.65	2.34	(258.2)
IL	5,160	2,817	45.4	16.55	0.58	96.5	7.08	2.29	67.7
IN	9,163	2,765	69.8	59.09	0.57	99.0	15.26	2.25	85.3
KS	8,368	2,727	67.4	25.99	0.56	97.8	18.35	2.22	87.9
KY	8,845	2,678	69.7	43.69	0.55	98.7	15.59	2.18	86.0
LA	4,303	2,294	46.7	8.76	0.47	94.6	6.80	1.87	72.6
MA	5,607	2,852	49.1	17.53	0.59	96.7	6.07	2.32	61.8
MD	5,323	2,668	49.9	41.72	0.55	98.7	10.30	2.17	78.9
ME	3,769	3,056	18.9	5.48	0.63	88.5	4.09	2.48	39.3
MI	6,304	2,948	53.2	29.27	0.61	97.9	10.30	2.40	76.7
MN	7,798	3,094	60.3	19.86	0.64	96.8	17.44	2.52	85.6
MO	7,937	2,668	66.4	27.86	0.55	98.0	13.32	2.17	83.7
MS	4,526	2,399	47.0	10.98	0.49	95.5	7.05	1.95	72.3
MT	7,660	3,008	60.7	7.86	0.62	92.1	14.92	2.45	83.6
NC	5,024	2,534	49.6	31.67	0.52	98.4	7.76	2.06	73.4
ND	11,702	3,084	73.6	44.02	0.63	98.6	26.66	2.51	90.6
NE	7,405	2,845	61.6	21.84	0.59	97.3	16.75	2.31	86.2
NH	3,824	2,950	22.8	20.80	0.61	97.1	4.73	2.40	49.3
NJ	2,944	2,709	8.0	8.31	0.56	93.3	4.57	2.20	51.8
NM	8,090	2,609	67.7	7.84	0.54	93.2	19.23	2.12	89.0
NV	6,539	2,765	57.7	12.01	0.57	95.3	11.24	2.25	80.0
NY	3,834	2,867	25.2	11.13	0.59	94.7	4.94	2.33	52.8
OH	8,060	2,809	65.1	63.14	0.58	99.1	16.59	2.28	86.2
OK	6,180	2,532	59.0	11.44	0.52	95.4	10.76	2.06	80.9
OR	1,852	2,766	(49.3)	2.46	0.57	76.9	2.37	2.25	5.1
PA	5,587	2,829	49.4	41.20	0.58	98.6	8.28	2.30	72.2
RI	4,715	2,804	40.5	1.23	0.58	53.0	2.87	2.28	20.5
SC	3,122	2,443	21.7	14.67	0.50	96.6	4.14	1.99	52.1
SD	5,678	2,953	48.0	16.96	0.61	96.4	22.27	2.40	89.2
TN	5,201	2,542	51.1	22.49	0.52	97.7	9.25	2.07	77.7
TX	5,256	2,336	55.6	11.73	0.48	95.9	5.08	1.90	62.6
UT	9,240	2,773	70.0	8.93	0.57	93.6	17.20	2.25	86.9
VA	4,842	2,621	45.9	22.79	0.54	97.6	7.58	2.13	71.9
VT	182	2,983	(1,536.3)	0.42	0.61	(47.6)	0.38	2.43	(536.9)
WA	1,493	2,821	(88.9)	0.53	0.58	(10.6)	2.13	2.29	(7.8)
WI	8,170	2,978	63.6	28.73	0.61	97.9	13.24	2.42	81.7
WV	8,408	2,727	67.6	43.92	0.56	98.7	15.87	2.22	86.0
WY	10,661	2,989	72.0	19.32	0.62	96.8	20.28	2.43	88.0

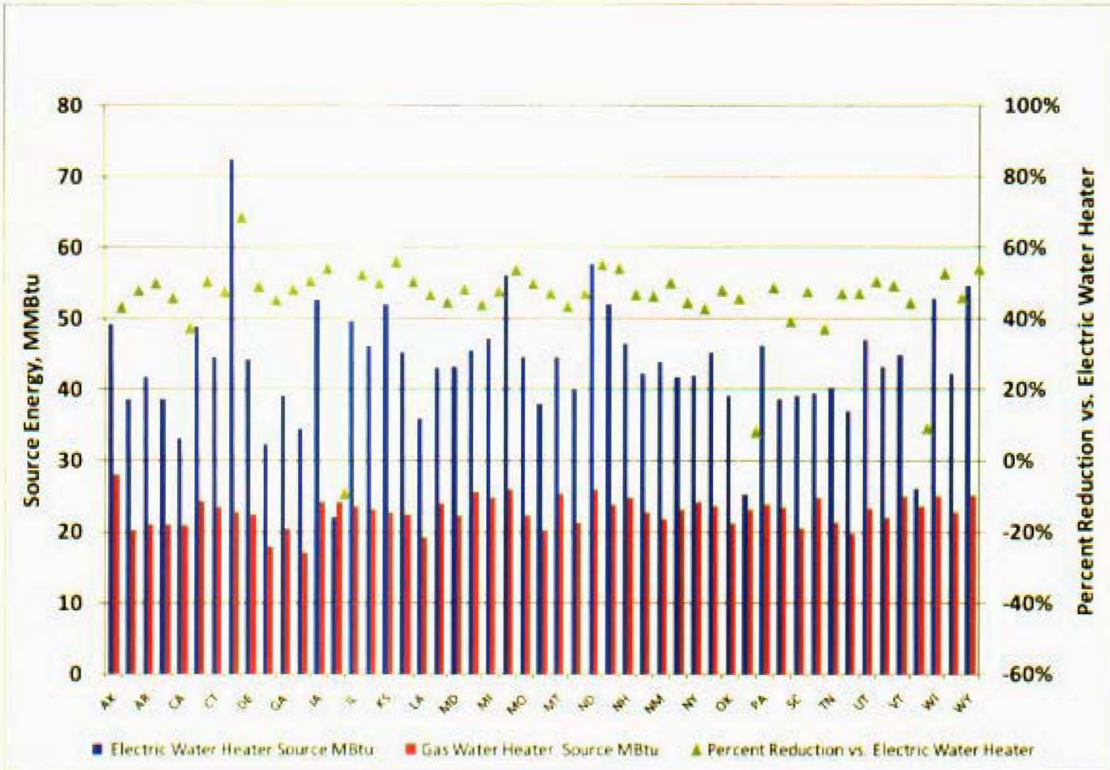

Figure 11 Water Heater Source Energy Consumption Comparison by State

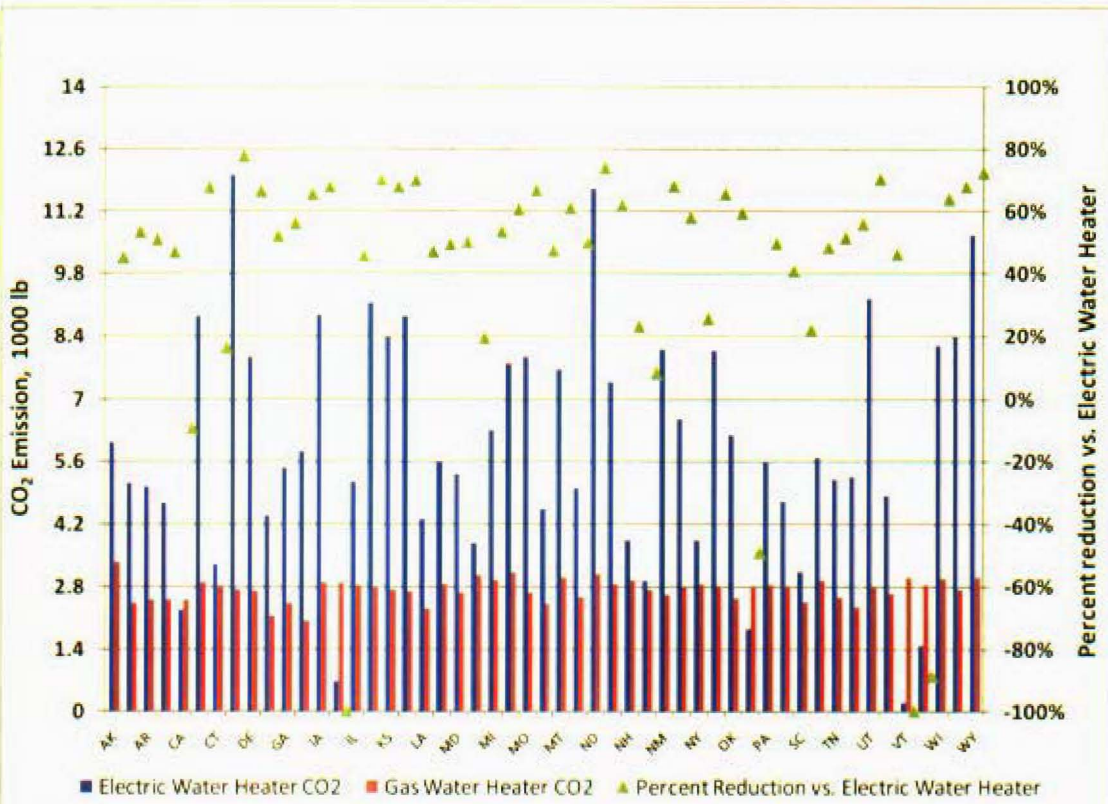

Figure 12 Water Heater CO_2 Emission Comparison by State

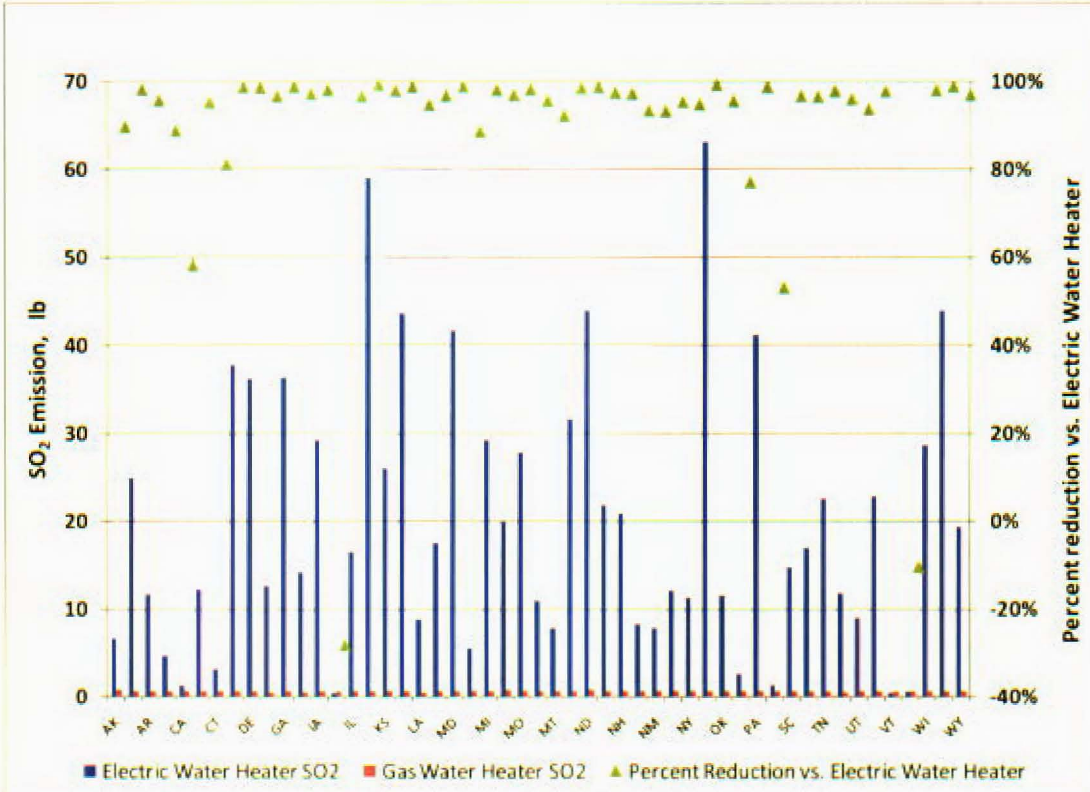

Figure 13 Water Heater SO_2 Emission Comparison by State

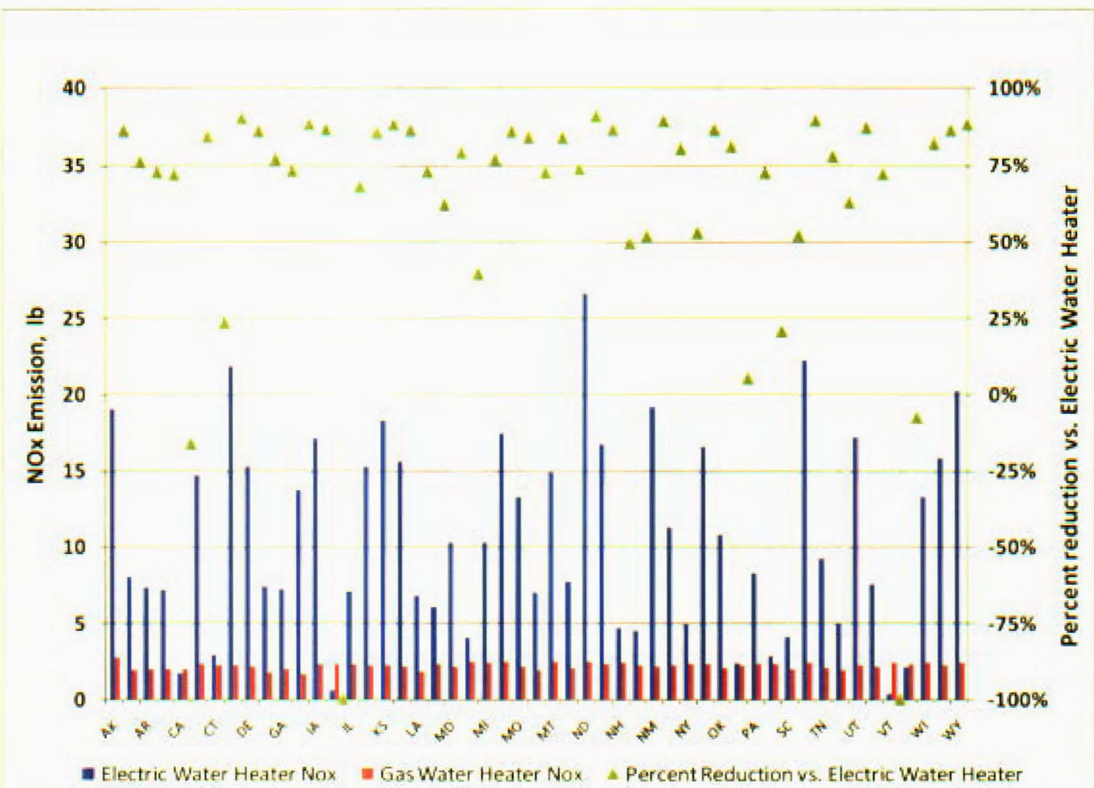

Figure 14 Water Heater NOx Emission Comparison by State

4.2 Marginal Emissions Sensitivity Analysis

Average energy and emissions calculations may be appropriate for inventory purposes, but they do not necessarily provide good information when evaluating competing energy efficiency measures. For instance, the average 2005 generation mix in Pennsylvania was 55 percent coal and 35 percent nuclear, with gas and oil contributing 7 percent combined. Using averages, the impact of a reduction in electricity consumption would seem to be shared mainly by coal and nuclear. However, according to Exelon, economic dispatch of electricity typically brings on plants through the PJM interconnect in the following order: renewable first, then nuclear, followed by coal, and finally gas and oil plants come online last. In this case, the electricity saved would likely be from either a gas or oil plant during peak periods. During baseload periods (evenings, weekends), the marginal plant would likely be either gas or coal. It is highly unlikely that either hydro or nuclear plants would be affected by the power reduction unless it were a very significant step change such as an industrial plant going offline. Even in that case, the power would likely be exported to another area, offsetting their marginal power requirements. Marginal generation can also represent the next generation plant built or avoided with that particular fuel type and heat rate, and may be location specific. Marginal generation is a more appropriate increment than average generation mix when making energy investment decisions and avoiding new generation. To examine the impact of marginal changes in electricity consumption associated with switching from electric water heating to gas water heating, an illustrative sensitivity analysis was conducted.

The sensitivity analysis compared a residential natural gas tank-based (0.59 EF) water heater to an electric resistance tank-based water heater (0.90 EF) using U.S. national data, and state data for Indiana, Washington, and Alabama. U.S. composite generation is 50 percent coal and 19 percent gas. Indiana is a coal-dominated electricity generation state, at 95 percent coal generation, with 3 percent gas generation. Alabama generation is 56 percent coal with 10 percent natural gas, and Washington has only about 10 percent coal generation, with 8 percent natural gas, 8 percent nuclear, and 71 percent hydropower. Cases were run for each location using average grid mix, marginal coal generation in the grid, and marginal natural gas generation in the grid to evaluate the differences in source energy consumption and CO_2 emissions with fixed annual site consumption. For all locations, all marginal and average cases, site energy use was 18.3 MMBtu for the gas water heater and 3,516 kWh (12.0 MMBtu) for the electric water heater.

Table 23 shows the results of the sensitivity analysis. Marginal CO_2 emission reductions were significantly different from average reductions, especially in Washington. Also, as expected, displacing coal plants has a much higher impact on CO_2 emissions than displacing natural gas plants.

For all cases except the average Washington hydro and nuclear based generation, the CO_2 savings were positive for gas water heating compared to electric resistance water heating, ranging from 0.6 to 3.0 metric tons of CO_2 savings per house per year depending on location and displaced generation. Source energy use was reduced as well, even in the Washington average case. The changes were not as dramatic as the CO_2 reductions, but still illustrate the importance of selecting the appropriate generation mix for comparative analyses.

Table 23 Sensitivity Analysis of Coal and Natural Gas Marginal Generation

State	Average or Marginal Fuel	Electricity - Site MMBtu	Gas - Site MMBtu	Electricity - Source MMBtu	Gas -Source MMBtu	CO_2 Electric (lb)	CO_2 - Gas (lb)	Net CO_2 electric - gas (lb)
U.S.	Average	12.0	18.3	37.6	19.9	5,050	2,370	2,680
	Marginal - Coal	12.0	18.3	40.9	19.9	8,150	2,370	5,780
	Marginal - Gas	12.0	18.3	32.6	19.9	3,980	2,370	1,610
Indiana	Average	12.0	18.3	39.7	19.9	7,870	2,370	5,500
	Marginal - Coal	12.0	18.3	40.8	19.9	8,190	2,370	5,820
	Marginal - Gas	12.0	18.3	39.4	19.9	4,740	2,370	2,370
Washington	Average	12.0	18.3	21.9	19.9	1,260	2,370	-1,110
	Marginal - Coal	12.0	18.3	45	19.9	8,910	2,370	6,540
	Marginal - Gas	12.0	18.3	30.5	19.9	3,680	2,370	1,310
Alabama	Average	12.0	18.3	38.2	19.9	5,060	2,370	2,690
	Marginal - Coal	12.0	18.3	40.8	19.9	8,100	2,370	5,730
	Marginal - Gas	12.0	18.3	32.4	19.9	3,940	2,370	1,570

5.0 Summary

Source energy efficiency and environmental considerations are growing in importance. In the residential and commercial buildings sector, EIA data point to a continuing trend of increasing source-to-site energy losses associated with electricity generation and delivery – an amount that is greater than the site use of electricity and natural gas combined.

State and federal agencies are recognizing the importance of source energy. California incorporates source energy considerations within its building energy codes. A recent report by the National Research Council of the National Academies further supports source energy and recommends that the DOE use source energy impacts in the preparation of future appliance efficiency standards.

Within this report, an extensive set of data were compiled using publicly available sources to support calculation of the source energy consumption and associated pollutant emissions for electricity generation and fossil fuel energy use. The factors for calculating source energy consumption and related emissions for the full fuel cycle of extraction, processing, transportation, conversion, distribution, and consumption were developed at the state, NERC region, and US average level.

Multiple data sets provided in the report allow various environmental emissions end energy efficiency impacts analysis for each of the intermediate stages of energy processing and end-use for both electricity and fossil fuels typically used in buildings. Data permitting calculation of cumulative source energy impacts of electric energy consumption are provided in tables throughout this report.

Comparison of the US average source energy factors in the AGA report published in 2000 with the corresponding new datasets shows modest source energy efficiency changes. The fossil fuels source emission factors compiled in this report are more detailed than those provided in the 2000 AGA report and differ only slightly depending on type of fuel.

The case studies of residential electric and natural gas water heaters provide examples of the application of the tabulated source energy and emissions factors to evaluate impacts of energy choice on full fuel cycle energy consumption and pollutant emissions, including CO_2. The case studies illustrate the importance of selecting the appropriate energy and fuel type as well as geographical conversion factors when evaluating benefits of optimizing energy use in buildings.

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