Full-Fuel-Cycle Energy and Emission Factors for Building Energy Consumption – 2018 Update

Prepared for

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Disclaimer

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Executive Summary

A significant shift in the power generation mix, consumer energy use trends, natural gas and electricity prices, and renewable technology options has occurred since 2008. In response to these changes, this report updates previous full-fuel-cycle (FFC) energy and pollutant emission factors for determining and comparing building energy performance based on current public domain information and the United States (U.S.) Environmental Protection Agency (EPA) Emissions & Generation Resource Integrated Database using 2016 data (eGRID2016). FFC factors and supporting information in this report are intended to provide technically defensible reference documentation for use by American Gas Association (AGA) and other stakeholders. The report also includes updated carbon dioxide equivalent (CO_2e) emissions factors (including carbon dioxide, methane, and nitrous oxide), annual average pollutant emission factors for sulfur dioxide and nitrogen oxides, as well as non-baseload (marginal) FFC energy and emission factors.

The definition of FFC energy used throughout this report is as follows:

> **Full-fuel-cycle energy is the energy consumed by an appliance, system, or building as measured at the building site plus the energy consumed in the extraction, processing, and transport of primary energy forms such as coal, oil, natural gas, biomass, and nuclear fuel; energy consumed in conversion to electricity in power-generation plants; and energy consumed in transmission and distribution to the building site.**

In consideration of the United States Department of Energy (DOE) accounting methodology guidance published in 2016, tables in this report use the Captured Energy Efficiency approach to determine the FFC conversion efficiency for non-combustible renewable power generation from the electric grid.

This update adds new information on average and marginal energy prices, forecasting options, renewable natural gas calculations, and use of an energy, emissions, and economic (EEE) impacts framework for comparisons.

Sample calculations in this report compare the FFC energy, CO_2e emissions, and economic performance of residential gas and electric storage water heaters in selected cities for average and marginal (non-baseload) generation mixes from the eGRID2016 database. The analysis compares annual energy costs, FFC energy use, CO_2e emissions, and EEE impacts. The methodologies used in the water heater example can be applied to a full spectrum of direct-use equipment, appliances, and buildings, providing a comprehensive understanding of EEE impacts associated with building energy use.

Updated factors for calculating FFC energy consumption and related emissions are based on EPA eGRID2016 database information and include state, eGRID sub-region, North American Electric Reliability Corporation (NERC) region, and U.S. average levels for electricity for all power plants. Factors for non-baseload power plants include eGRID sub-region levels for electricity. Factors for fossil fuels include only U.S. average levels based on DOE Energy Information Administration (EIA) and EPA database information.

The electricity grid is undergoing a long-term shift away from coal power generation toward natural gas and renewable power generation. In its 2018 Annual Energy Outlook (AEO) reference case, EIA expects the shift from coal-fired power generation to natural gas generation and renewable power generation to continue through 2050. To understand the impact of alternative analytical assumptions about the makeup of the electric grid, two new forecasting options for alternative FFC energy and emission factors along with sample calculations are included in this report:

- EIA Annual Energy Outlook Reference Case projected generation mix at current generation efficiencies by energy form; and
- 85% natural gas @ 50% power plant efficiency (based on higher heating value, HHV) coupled with 15% renewable power.

Energy cost is likely to be the metric of most interest to consumers and other stakeholders concerning energy tradeoffs. Energy cost historically has been viewed as a proxy for FFC energy use and has led to similar results. However, results are starting to diverge as natural gas prices have declined while its FFC energy efficiency and CO_2e emissions profiles have been stable. For economic analyses and comparisons, annual and marginal 2016 residential and commercial energy prices and sample calculations are included in this report.

In order to provide economic and societal benefits with minimum unintended consequences, energy performance indicators and related energy management initiatives would benefit from metrics, methods, and values that are technically defensible, useable, easy to adopt, and enforceable. A key issue for balancing metrics, methodologies, and values for determining and comparing energy performance is how to provide an equitable comparison of different energy forms that can be used for the same energy services. With an increased focus on environmental impacts from stakeholders, a single performance metric that may be suitable for one economic or societal objective may be unsuitable or misleading when trying to achieve another economic or societal objective.

To address this complexity, an energy, emissions, and economics (EEE) impacts framework—and sample calculations—are included in this report. The EEE impacts framework incorporates multiple metrics into calculations that determine and compare the energy performance of competing options for the same energy service based on their weighted and aggregated impact on the metrics of choice to determine overall performance for decisions and comparisons. The EEE framework permits users to apply their own weighting factors to the individual metrics.

Table ES-1 lists U.S. national average FFC energy and pollutant emission factors for electricity, natural gas, fuel oil, and propane, all based on 2016 data. The FFC energy factor for electricity was calculated using the "Captured Energy Efficiency" methodology for non-combustible renewable power generation (i.e., generation efficiency for hydro, wind, solar, and geothermal power is deemed to be 100%).

Table ES-1 U.S. Average Electricity Generation FFC Energy Factors by Fuel Type

Energy Form	FFC Energy Factors (FFC Btu/Site Btu)	FFC Pollutant Emission Factors (lb/Site MMBtu)					
		CO_2e	CO_2	CH_4	N_2O	SO_2	NOx
Electricity	2.79	345	323	0.75	0.004	0.29	0.30
Natural Gas	1.09	149	130	0.65	0.003	0.03	0.17
Fuel Oil	1.19	201	192	0.27	0.005	0.06	1.21
Propane	1.15	170	163	0.13	0.011	0.06	0.23

Source: SEEAT Version 8.2

Tables ES-2 and ES-3 list non-baseload and average electricity FFC energy conversion and CO_2e emission factors using the Keith-Biewald capacity factor non-baseload methodology. Tables ES-4 and ES-5 tabulates 2016 state-level average and marginal energy prices for residential and commercial buildings.

Table ES-2 Non-Baseload and Average Electricity FFC Energy Factors

eGRID 2016 Sub-region Acronym	eGRID 2016 Sub-region Name	Non-Baseload FFC Energy Conversion Factor	Average FFC Energy Conversion Factor
AKGD	ASCC Alaska Grid	3.45	2.79
AKMS	ASCC Miscellaneous	3.50	1.93
ERCT	ERCOT All	2.83	2.59
FRCC	FRCC All	2.80	2.85
HIMS	HICC Miscellaneous	4.10	2.81
HIOA	HICC Oahu	3.69	3.48
MROE	MRO East	3.11	3.05
MROW	MRO West	3.25	2.72
NYLI	NPCC Long Island	3.64	3.35
NEWE	NPCC New England	2.82	2.83
NYCW	NPCC NYC/Westchester	2.99	2.93
NYUP	NPCC Upstate NY	2.75	2.27
RFCE	RFC East	3.10	3.04
RFCM	RFC Michigan	3.34	3.02
RFCW	RFC West	3.27	3.11
SRMW	SERC Midwest	3.20	3.16
SRMV	SERC Mississippi Valley	2.73	2.79
SRSO	SERC South	2.93	2.90
SRTV	SERC Tennessee Valley	3.15	3.00
SRVC	SERC Virginia/Carolina	2.92	3.04
SPNO	SPP North	3.49	2.91
SPSO	SPP South	3.32	2.61
CAMX	WECC California	2.68	2.12
NWPP	WECC Northwest	3.04	1.92
RMPA	WECC Rockies	3.21	2.63
AZNM	WECC Southwest	2.93	2.84
US Average			**2.79**

Source: SEEAT Version 8.2

Table ES-3 Non-Baseload and Average Electricity CO_2e Emission Factors

eGRID 2016 Sub-region Acronym	eGRID 2016 Sub-region Name	Non-Baseload CO_2e Emission Factor (lb/MWH)	Average CO_2e Emission Factor (lb/MWH)
AKGD	ASCC Alaska Grid	1,642	1,319
AKMS	ASCC Miscellaneous	1,965	655
ERCT	ERCOT All	1,625	1,210
FRCC	FRCC All	1,450	1,177
HIMS	HICC Miscellaneous	2,371	1,397
HIOA	HICC Oahu	1,954	2,019
MROE	MRO East	1,849	1,931
MROW	MRO West	2,108	1,415
NYLI	NPCC Long Island	1,676	1,479
NEWE	NPCC New England	1,331	732
NYCW	NPCC NYC/Westchester	1,351	832
NYUP	NPCC Upstate NY	1,316	391
RFCE	RFC East	1,692	931
RFCM	RFC Michigan	2,096	1,461
RFCW	RFC West	2,138	1,425
SRMW	SERC Midwest	2,176	1,832
SRMV	SERC Mississippi Valley	1,398	1,038
SRSO	SERC South	1,667	1,290
SRTV	SERC Tennessee Valley	1,997	1,354
SRVC	SERC Virginia/Carolina	1,659	960
SPNO	SPP North	2,341	1,599
SPSO	SPP South	1,930	1,410
CAMX	WECC California	1,235	646
NWPP	WECC Northwest	1,798	745
RMPA	WECC Rockies	2,007	1,540
AZNM	WECC Southwest	1,685	1,225
US Average			**1,176**

Source: SEEAT Version 8.2

Table ES-4 Average and Marginal 2016 Residential Energy Price Factors by State

State	Electricity ($/MMBtu)			Natural Gas ($/MMBtu)			Oil ($/MMBtu)	Propane ($/MMBtu)
	Average	Marginal		Average	Marginal			
		Summer	Winter		Summer	Winter	Average	Average
AL	35.1	31.2	29.4	13.7	13.2	13.6	16.4	27.6
AK	59.5	61.3	59.0	9.8	7.7	8.9	16.4	22.4
AZ	35.6	35.5	33.1	14.7	8.1	12.2	16.4	22.4
AR	29.1	28.2	26.2	11.0	6.7	9.8	16.4	21.4
CA	51.0	66.3	67.3	11.4	10.2	10.9	16.4	22.4
CO	35.4	34.9	33.1	6.9	4.3	5.9	16.4	20.8
CT	58.6	59.0	57.6	12.6	8.0	11.3	17.2	28.8
DE	39.3	38.0	35.4	11.4	7.3	10.4	16.9	30.5
DC	36.0	34.8	32.5	10.4	7.8	9.7	16.9	22.4
FL	32.2	29.6	29.3	19.8	14.3	16.3	15.7	51.7
GA	33.7	32.7	30.1	14.1	13.8	14.0	15.6	22.0
HI	80.5	88.6	87.7	37.2	33.2	33.5	16.4	22.4
ID	29.2	28.9	27.1	7.8	5.3	7.2	16.4	24.0
IL	36.7	34.8	33.7	7.6	5.0	6.7	14.0	15.1
IN	34.6	33.0	32.0	7.6	4.9	6.8	14.3	19.3
IA	35.0	33.1	31.0	7.7	4.7	6.7	12.5	11.3
KS	38.3	35.6	32.9	9.5	5.4	8.1	14.0	13.0
KY	30.7	27.3	25.7	9.8	4.8	8.3	13.7	20.0
LA	27.4	26.5	24.6	11.1	6.2	8.9	16.4	22.4
ME	46.4	46.7	45.6	13.5	3.7	10.9	14.1	24.7
MD	41.7	40.3	37.6	11.0	7.2	9.9	17.1	29.6
MA	55.7	54.7	53.3	12.1	10.7	11.7	16.6	31.8
MI	44.6	43.2	41.9	7.9	5.5	7.2	14.1	19.2
MN	37.1	35.2	32.9	7.7	5.5	7.1	13.3	14.3
MS	30.7	27.2	25.7	9.8	6.8	8.8	16.4	21.8
MO	32.9	30.4	27.9	10.7	4.5	8.6	14.0	15.0
MT	32.1	31.7	29.8	7.0	5.4	6.4	16.4	18.3
NE	31.8	29.5	27.3	7.6	4.7	6.6	12.8	11.4
NV	33.4	33.9	31.7	9.8	5.0	8.0	16.4	22.4
NH	53.9	54.2	52.9	13.8	7.0	11.4	15.3	33.8
NJ	46.1	46.2	44.4	8.0	6.4	7.6	17.1	36.0
NM	35.3	35.7	33.4	7.7	4.6	6.6	16.4	22.4
NY	51.5	50.5	49.2	10.5	5.4	8.7	18.5	28.1
NC	32.3	31.3	29.0	10.9	6.5	9.8	15.6	26.4
ND	29.8	28.2	26.4	6.7	2.8	5.3	14.0	11.5
OH	36.5	34.9	33.8	8.4	3.0	6.6	13.9	24.1
OK	29.9	29.0	26.9	10.1	6.2	8.3	14.0	16.8
OR	31.2	31.4	30.9	11.0	8.3	10.1	16.4	22.4
PA	40.6	40.7	39.2	9.8	6.7	8.9	14.4	30.1
RI	54.6	54.9	53.6	13.4	9.7	12.2	16.7	37.2
SC	37.1	35.9	33.2	12.3	7.3	10.9	15.7	22.4
SD	33.6	31.8	29.8	7.2	4.9	6.5	14.0	12.2
TN	30.5	26.8	25.4	8.9	5.5	8.0	14.0	33.8
TX	32.2	30.8	30.1	11.4	5.6	8.9	16.4	23.5
UT	32.3	32.0	30.0	8.8	6.4	8.2	16.4	26.4
VT	50.9	51.2	50.0	13.8	8.7	12.1	14.5	35.5
VA	33.3	31.9	29.5	10.3	6.6	9.2	15.7	30.1
WA	27.8	27.9	27.4	10.0	7.7	9.2	16.4	22.4
WV	33.5	34.1	32.2	8.4	5.7	7.7	15.7	22.4
WI	41.2	39.3	37.9	7.8	4.6	6.9	14.0	13.8
WY	32.6	32.3	30.3	7.9	5.6	7.0	16.4	22.4
U.S.	**36.8**	**36.0**	**34.2**	**9.7**	**6.5**	**8.6**	**16.4**	**22.5**

Source: EIA, DOE EERE, AGA

Table ES-5 Average and Marginal Commercial Energy Price Factors by State

State	Electricity ($/MMBtu)			Natural Gas ($/MMBtu)			Oil ($/MMBtu)	Propane ($/MMBtu)
	Average	Marginal		Average	Marginal			
		Summer	Winter		Summer	Winter	Average	Average
AL	32.6	28.9	27.2	10.3	9.9	10.2	14.7	24.9
AK	51.5	53.1	51.0	8.3	6.5	7.6	14.7	20.3
AZ	30.5	30.4	28.3	8.5	4.7	7.1	14.7	20.3
AR	24.1	23.4	21.7	7.0	4.3	6.2	14.7	19.3
CA	44.2	57.5	58.3	8.1	7.2	7.7	14.7	20.3
CO	28.1	27.8	26.3	6.0	3.7	5.1	14.7	18.7
CT	46.2	46.4	45.3	8.6	5.4	7.7	15.4	25.9
DE	29.5	28.5	26.6	9.2	5.9	8.4	15.3	27.5
DC	34.3	33.2	30.9	9.5	7.1	8.9	15.2	20.3
FL	26.1	24.0	23.8	10.2	7.3	8.4	14.1	46.5
GA	28.7	27.9	25.7	7.7	7.6	7.6	14.1	19.8
HI	72.2	79.5	78.7	27.5	24.5	24.8	14.7	20.3
ID	22.7	22.5	21.1	6.9	4.7	6.3	14.7	21.6
IL	26.4	25.0	24.2	6.9	4.6	6.1	12.6	13.6
IN	29.3	28.0	27.1	6.3	4.0	5.6	12.9	17.3
IA	26.9	25.4	23.8	5.7	3.5	5.0	11.3	10.1
KS	38.3	35.6	32.9	8.1	4.6	6.9	12.6	11.7
KY	28.0	24.9	23.4	7.7	3.8	6.5	12.3	18.0
LA	25.2	24.4	22.7	7.7	4.3	6.2	14.7	20.3
ME	35.4	35.6	34.8	10.4	2.9	8.4	12.7	22.2
MD	32.2	31.1	29.0	8.5	5.6	7.7	15.4	26.6
MA	45.7	44.9	43.8	9.2	8.1	8.9	14.9	28.6
MI	31.2	30.2	29.3	6.6	4.6	6.0	12.7	17.3
MN	28.9	27.4	25.6	6.2	4.4	5.7	12.0	12.9
MS	28.0	24.9	23.4	7.6	5.3	6.8	14.7	19.6
MO	27.1	25.1	23.0	7.7	3.2	6.2	12.6	13.5
MT	29.9	29.6	27.7	6.9	5.3	6.3	14.7	16.4
NE	25.8	24.0	22.2	5.1	3.2	4.4	11.5	10.3
NV	23.2	23.6	22.0	6.6	3.4	5.4	14.7	20.3
NH	42.3	42.5	41.5	11.0	5.6	9.1	13.8	30.4
NJ	35.9	36.0	34.6	7.6	6.1	7.2	15.4	32.4
NM	28.6	29.0	27.1	5.4	3.2	4.6	14.7	20.3
NY	13.0	12.8	12.5	6.0	3.1	4.9	16.6	25.4
NC	25.3	24.5	22.6	7.4	4.4	6.7	14.1	23.8
ND	26.8	25.4	23.8	5.0	2.1	4.0	12.6	10.4
OH	36.5	34.9	33.8	5.4	2.0	4.2	12.5	21.7
OK	22.4	21.8	20.2	7.4	4.6	6.0	12.6	15.1
OR	26.1	26.3	25.8	8.8	6.7	8.1	14.7	20.3
PA	27.0	27.0	26.0	7.8	5.3	7.1	13.0	27.2
RI	43.6	43.9	42.8	10.8	7.8	9.8	15.1	33.5
SC	30.1	29.2	27.0	8.2	4.8	7.3	14.1	20.3
SD	28.1	26.6	24.9	5.3	3.6	4.8	12.6	10.9
TN	29.9	26.3	24.9	7.6	4.7	6.8	12.6	30.4
TX	24.2	23.1	22.7	6.7	3.3	5.2	14.7	21.2
UT	25.6	25.4	23.8	7.1	5.2	6.6	14.7	23.8
VT	42.6	42.9	41.8	6.5	4.1	5.7	13.1	32.0
VA	23.2	22.3	20.6	6.9	4.4	6.2	14.1	27.2
WA	24.7	24.9	24.4	7.9	6.1	7.2	14.7	20.3
WV	27.4	27.9	26.3	7.1	4.8	6.5	14.1	20.3
WI	31.6	30.0	29.0	6.1	3.6	5.4	12.6	12.4
WY	27.5	27.3	25.6	6.1	4.3	5.4	14.7	20.3
U.S.	**30.6**	**29.9**	**28.5**	**7.0**	**4.7**	**6.2**	**14.7**	**20.3**

Source: EIA, DOE EERE, AGA

1 Introduction and Background

1.1 Overview and Objectives

The American Gas Association (AGA) has recognized the importance of using full-fuel-cycle (FFC) energy efficiency and pollutant emissions as an appropriate basis for setting public policy for decades. AGA has advocated for the use of FFC energy in numerous rulemakings and standards developments. AGA also has published key information on FFC energy efficiency and carbon dioxide (CO_2) emissions from buildings for nearly 30 years, including:

- EA 1990-5, "A comparison of Carbon Dioxide Emissions Attributable to New Natural Gas and All-Electric Homes," published in 1990,
- EA 1999-04, "Energy Efficiency, Economic, and Environmental Comparison of Natural Gas, Electric, and Oil Services in Residences," published in 1999,
- "Source Energy and Emission Factors for Residential Energy Consumption," published in 2000,
- "Source Energy and Emission Factors for Building Energy Consumption," published in 2009, and
- "Full-Fuel-Cycle Energy and Emission Factors for Building Energy Consumption – 2013 Update", published in 2013.

This report provides updated FFC energy and pollutant emission factors based on EPA eGRID2016 database information for use by AGA and other stakeholders. It also includes updated carbon dioxide equivalent (CO_2e) emissions factors (including carbon dioxide, methane, and nitrous oxide), as well as marginal (non-baseload) FFC energy and emission factors. It also provides FFC energy factors based on different underlying assumptions about non-combustible renewable power generation efficiency, along with projected national power generation conversion factors based on EIA Annual Energy Outlook (AEO) 2018 reference case projections. This update adds information on average and marginal energy prices, forecasting options, renewable natural gas calculations, and use of an energy, emissions, and economic (EEE) impacts framework for comparisons.

Sample calculations in this report compare the FFC energy, CO_2e emissions, and economic performance of residential gas and electric storage water heaters in selected cities for average and marginal (non-baseload) generation mixes from the eGRID2016 database. The analysis compares annual energy costs, FFC energy use, CO_2e emissions, and EEE impacts. The methodologies used in the water heater example can be applied to a full spectrum of direct-use equipment, appliances, and buildings, providing a comprehensive understanding of EEE impacts associated with building energy use.

1.2 Primary Energy, CO_2 Emissions, and Energy Price Trends

A comparison of national energy use and prices for natural gas and electricity in residential and commercial buildings illustrates the need for technically defensible FFC energy factors, emission factors, and energy prices for comparisons, compliance requirements, and investment decisions. According to the EIA, buildings were responsible for 39 percent of primary energy use, 73 percent of electricity generated, and 36 percent of CO_2 emissions in the U.S. in 2017. National average residential energy prices in 2017 were 12.9¢/kWh ($37.81/MMBtu) for electricity and $1.06/therm ($10.63/MMBtu) for natural gas, a price ratio of 3.56. National average commercial energy prices in 2017 were 10.7¢/kWh ($31.30/MMBtu) for electricity and $0.79/therm ($7.89/MMBtu) for natural gas, a price ratio of 4.10.

1.2.1 Primary Energy

According to EIA, site use of natural gas and electricity in buildings in 2017 totaled 7.6 and 9.3 quadrillion Btu's (Quads) respectively – a sum of 16.9 Quads. However, losses associated with electricity production and delivery were 18.3 quads of energy – an amount greater than total site energy use and almost two times greater than the total site electricity use. As shown in Figure 1, the EIA AEO 2018 reference case projects these electricity losses to continue to dominate building primary energy consumption through 2050.

A significant shift in the power generation mix since 2008 is worth examining to determine if EIA views it as a long-term trend due to shale gas impacts and increased renewable power generation. Figure 2 shows the shift in the power generation mix from coal to natural gas and renewable power generation since 2008. The increase in natural gas power generation reflects the impact of a significant reduction in natural gas prices starting in 2008 associated with new shale gas production. The increase in renewable power generation is predominantly due to improved economics and incentives for wind and solar power.

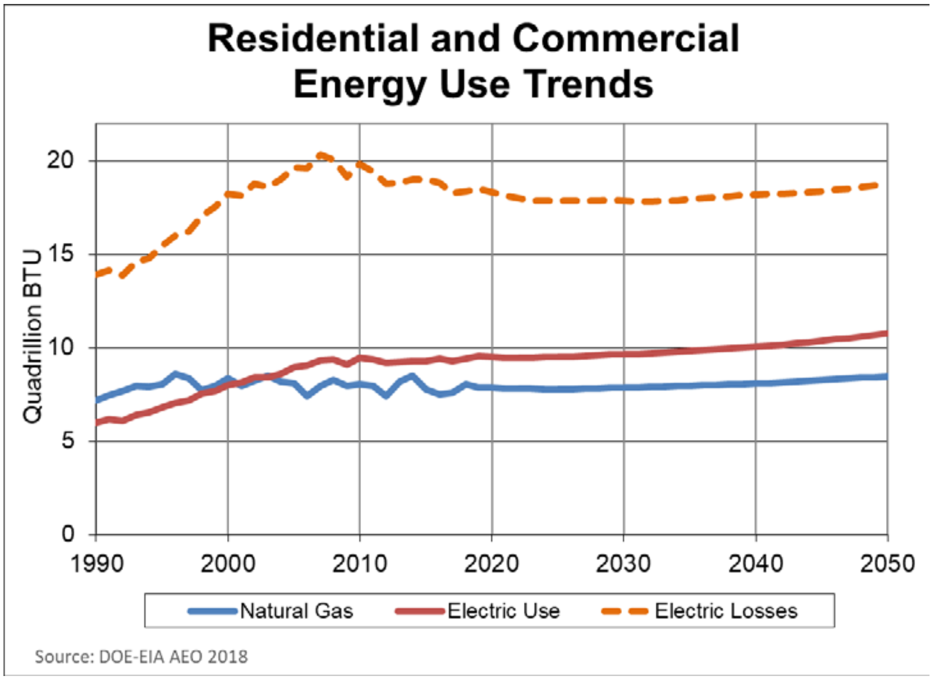

Figure 1 Residential and Commercial Building Energy Usage Trends

Source: EIA Monthly Energy Review October 2018; Annual Energy Outlook 2018

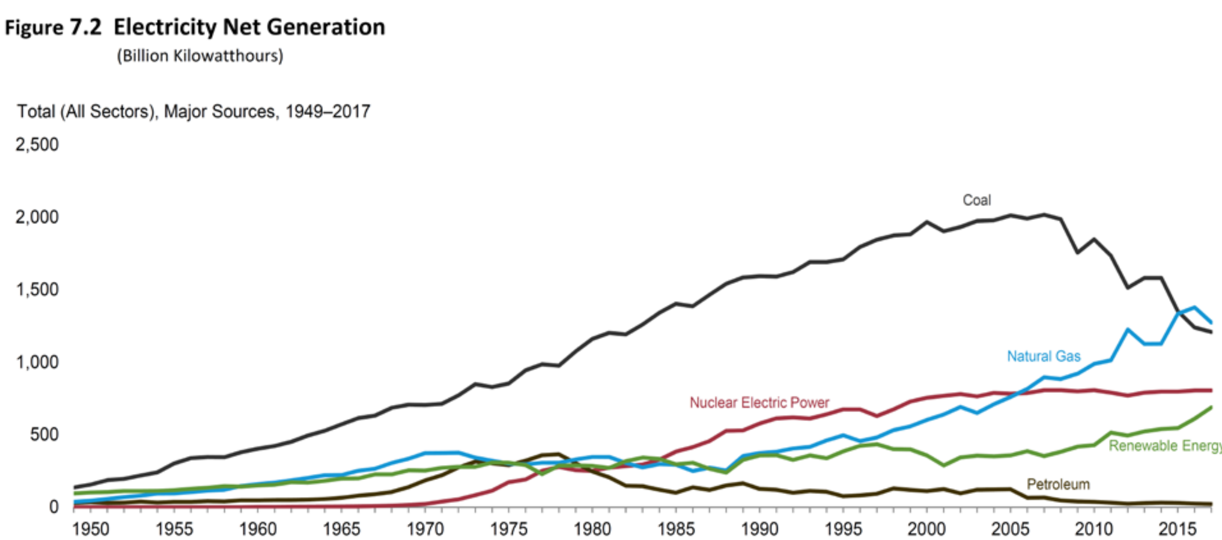

Figure 2 U.S. Power Generation Trends 1949 – 2017

Source: EIA Monthly Energy Review October 2018

In its AEO 2018 reference case, EIA expects the shift from coal-fired power generation to natural gas generation and renewable power generation to continue through 2050. Nonetheless, coal power generation is projected to be the third largest source of U.S. power generation energy source in 2050 in the reference case. As shown in Figure 3, coal-fired power generation fell from 48 percent of total generation in 2008 to 30 percent in 2017, and EIA projects it to fall to 21 percent of total generation by 2050. At the same time, the nuclear power generation fraction (with near-zero FFC CO_2e emissions) is projected to fall from 20 percent in 2017 to 12 percent in 2050. Natural gas power generation is projected to increase from 32 percent in 2017 to 36 percent in 2050. Renewable power generation (including hydroelectric, geothermal, wood, wood waste, all municipal waste, landfill gas, other biomass, solar, and wind power) is projected to increase from 17 percent in 2017 to 30 percent in 2050.

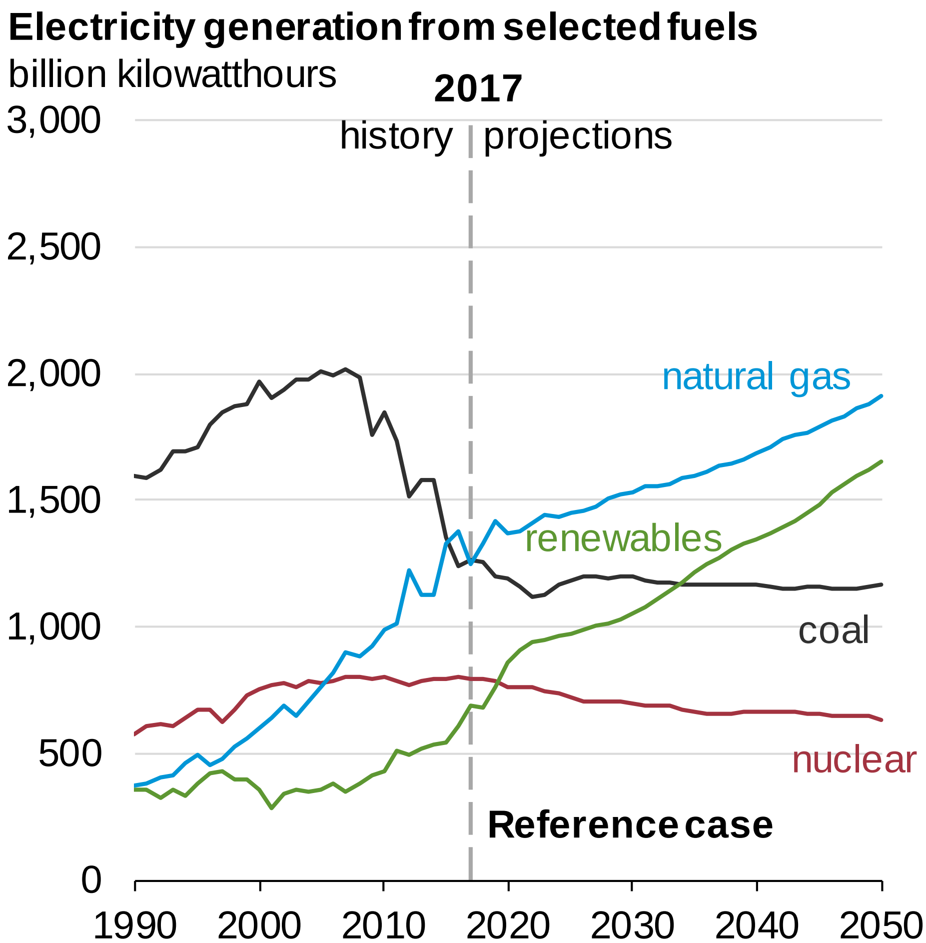

Figure 3 U.S. Power Generation Fuel Mix Trends and Projections through 2050

Source: EIA Annual Energy Outlook 2018

Under the AEO 2018 reference case, fossil fuel power generation comprises 57% of total generation in 2050. Figure 4 shows the resulting power generation efficiency (HHV basis) delivered to residential and commercial buildings projected by EIA, including transmission and distribution losses. The bulk generation efficiency is projected to increase modestly from 34 percent in 2017 to 37 percent in 2050, with natural gas and renewable power generation displacing coal and nuclear power generation.

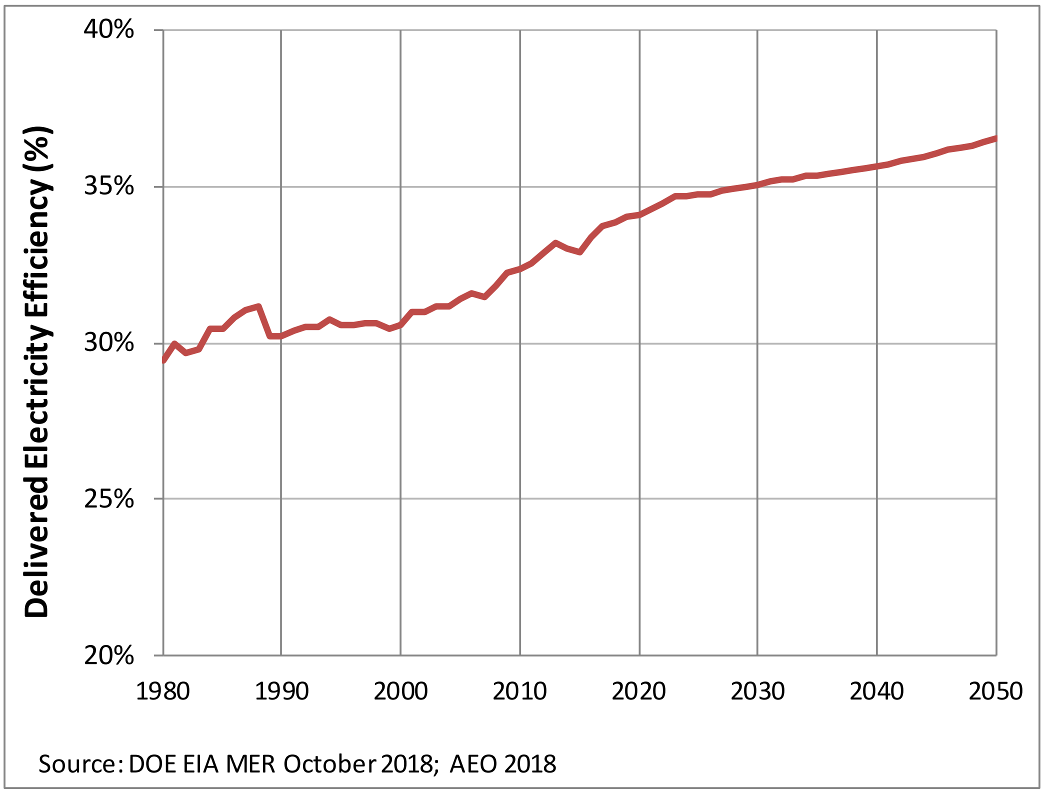

Figure 4 Power Generation Efficiency Delivered to Buildings through 2050

Source: EIA Monthly Energy Review October 2018; Annual Energy Outlook 2018

1.2.2 CO_2 Emissions

Homes and commercial businesses were growing contributors to CO_2 emissions from 1990 through 2008, as shown in Figure 5. The increasing CO_2 emissions attributable to residential and commercial buildings during that period were driven by growing consumption of electricity, including emissions associated with power generation as well as increased electricity consumption per building. Much of the increased carbon impact from residential and commercial electricity use came from power plants and the low FFC energy efficiency of production and delivery of electricity to residential and commercial buildings. The remaining growth in CO_2 emissions came from increased direct use of electricity for cooling and processes.

The shift away from coal to natural gas and renewable between 2008 and 2017 affected both the power generation efficiency shown in Figure 4 and the FFC CO_2 emissions shown in Figure 5 because natural gas power generation emits less CO_2 per megawatt-hour than coal-fired generation. In addition, residential and commercial demand for electricity was relatively flat from 2008 to 2017. The downward trend in CO_2 emissions is projected to continue through 2021 primarily due to coal plant retirements. After 2021, power plant emission factors are projected to stabilize, with increased electricity demand and nuclear power plant retirements balancing ongoing reductions in power generation CO_2 emission intensity through 2050 in the reference case.

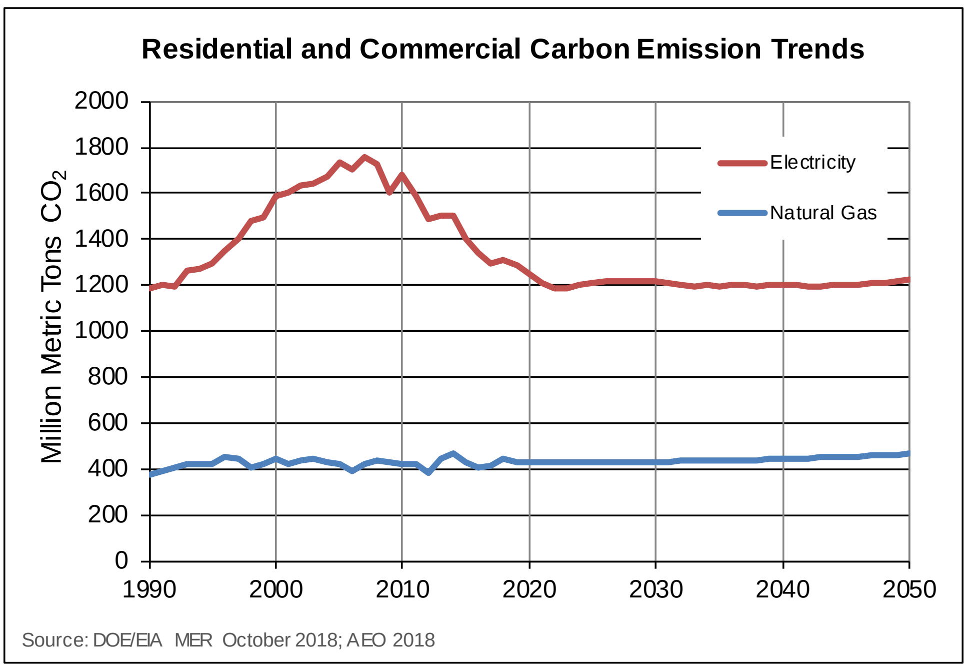

Figure 5 Electric and Gas CO_2 Emission Trends in Residential and Commercial Buildings

Source: EIA Monthly Energy Review October 2018; Annual Energy Outlook 2018

While energy efficiency improvements are expected to continue, the projected growth in the number of buildings in the U.S. is expected to offset the positive impact of these gains on overall national energy use and carbon emissions. EIA's 2018 projection indicates an increase to 150 U.S. million homes in 2050, compared to 117 million in 2017 (a nearly 29% increase). Commercial square footage is expected to grow from 90.7 billion square feet (ft^2) in 2017 to just over 126 billion ft^2 in 2050 (a 39% increase). These numbers indicate the positive impact of ongoing improvements in building energy intensity and improvements in CO_2 emission rates on a per home or per commercial square foot basis.

Aggregated CO_2 emissions from the natural gas direct use in residential and commercial buildings have been relatively flat for decades. The stable emissions profile reflects a balance between improved direct-use efficiency over time and the continued growth in the number of residential and commercial gas customers. Aggregate CO_2 emissions from natural gas consumption in residential and commercial buildings in the U.S. in 2017 are close to 1990 levels. During the same period, there were nearly 17 million more homes (from 52 million to 69 million homes, a 36.7% increase) and 1.23 million more commercial businesses (from 4.2 million to 5.5 million, a 29% increase) using natural gas. The average 2017 U.S. home using natural gas consumes 26.6% less natural gas per home than in 1990. CO_2 emissions from natural gas residential and commercial use are projected by EIA to grow slightly through 2050, even with projected direct-use efficiency improvements, based on projected growth in the number of gas customers. Similarly, EIA's AEO 2018 projection indicates that electricity use and CO_2 emissions in residential and commercial buildings are projected to be relatively flat after 2022 as electricity consumption from the additional buildings offsets the efficiency gains and evolving grid profile.

1.2.3 Energy Prices

Energy cost is likely to be the metric of most interest to consumers and other stakeholders for comparisons and investment decisions. Energy cost also has been viewed as a proxy for FFC energy use. Energy cost calculations have often led to similar results as FFC energy, although results are starting to diverge as natural gas prices have declined while its FFC energy efficiency and CO_2e emission profiles have been stable. As shown in Figure 6, electricity prices are increasing, and electricity is becoming more expensive compared to natural gas direct use even as electricity's FFC energy efficiency and CO_2e emission profiles have been improving.

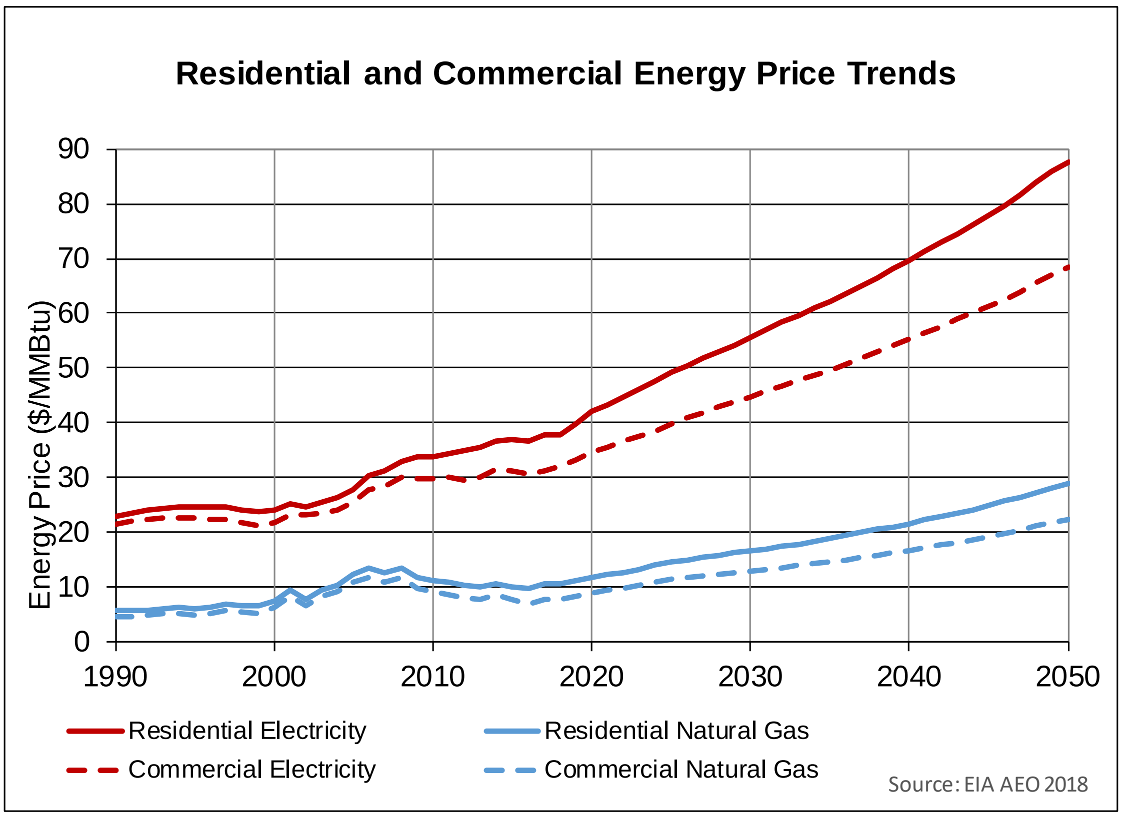

Figure 6 Electricity and Natural Gas Price Trends in Residential and Commercial Buildings

Source: EIA Monthly Energy Review October 2018; Annual Energy Outlook 2018

1.3 CO_2e Emissions and Calculation Options

According to EPA, U.S. greenhouse gas (GHG) emissions in 2016 totaled 6,511 million metric tons (MMT) CO_2e. As shown in Figure 7, CO_2 is responsible for the largest amount of CO_2e emissions in the U.S. (81%), followed by methane (10%), nitrous oxide (6%), and the group of fluorinated gases (3%). The building sector's contribution to GHG emissions in 2016 (747 MMT excluding electricity contributions) was 11% of total GHG emissions. Using the IPCC4 methane GWP factor of 25, residential and commercial building sector methane emissions (54 MMT excluding electricity contributions) represented less than 1% of total U.S. GHG emissions in 2016. In contrast, electricity generation accounted for 28% of total U.S. GHG emissions.

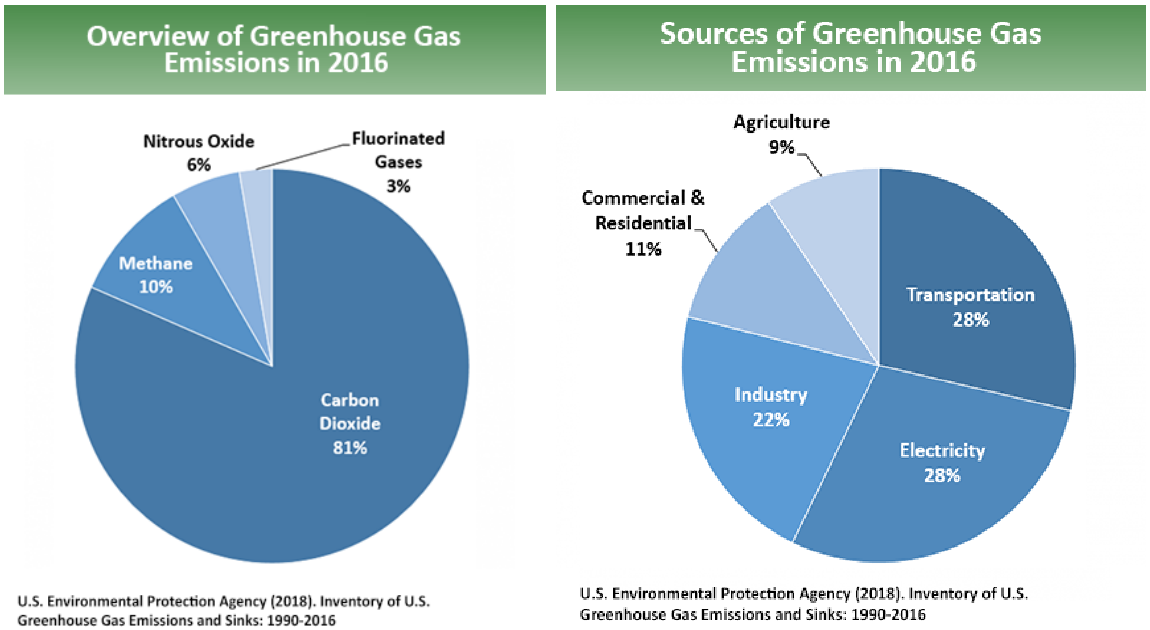

Figure 7: Constituents and Sources of U.S. GHG Emissions in 2016

Source: https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

1.3.1 Choice of Metric and Time Horizon for CO_2e Calculations

Water vapor is by far the dominant and most important GHG. However, other GHGs are of concern in part because they are influenced by human activity and also because they can create feedback loops with water vapor. Of these GHGs, CO_2 is of great interest because its concentration is increasing, and because higher concentrations of CO_2 will last in the atmosphere for a very long time. CO_2 is only one of the numerous GHGs, each of which has a different impact on global warming. CO_2e emission factors and calculations provide a potentially useful way to compare different GHGs (other than water vapor) relative to the impact of CO_2. Section 5.3.2 of the Intergovernmental Panel on Climate Change (IPCC) report "Climate Change 1994" (http://www.ipcc.ch/pdf/special-reports/cc1994/climate_change_1994.pdf) discusses the choice of metric and time horizon for determining CO_2e emissions at that time for use in their comparisons and reporting. Section 8.7 of the IPCC fifth assessment report (AR5) "Climate Change 2013 The Physical Science Basis" http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf provides an extensive discussion of the decisions made and limitations of different options. In AR5, IPCC notes that "Choices of time frames and climate impact are policy-related and cannot be based on science alone, but scientific studies can be used to analyze different approaches and policy choices."

The IPCC CO_2e emissions metric and time horizon were based on consideration of simplicity, precision, accuracy, and relevance to their policy goals. Based on IPCC judgments about these policy factors, Global Warming Potential (GWP) was selected as the default metric for reporting emissions of different gases on a common scale that accounts for varying levels of radiative forcing of each GHG relative to CO_2. Since the IPCC was most interested in minimizing the magnitude of long term impacts, they adopted the 100-year integration period (GWP_{100}) as the time horizon to implement the multi-gas approach in the 1997 Kyoto Protocol and subsequent agreements.

1.3.2 Global Warming Potential and Other CO_2e Metrics

The Global Warming Potential (GWP) concept for determining CO_2e emissions was introduced in the First IPCC Assessment in 1990, as described in AR5 Section 8.7.1.2:

> "The Global Warming Potential (GWP) is defined as the time-integrated RF [Radiative Forcing] due to a pulse emission of a given component, relative to a pulse emission of an equal mass of CO_2 …. The GWP was presented in the First IPCC Assessment (Houghton et al., 1990), stating 'It must be stressed that there is no universally accepted methodology for combining all the relevant factors into a single global warming potential for greenhouse gas emissions. A simple approach has been adopted here to illustrate the difficulties inherent in the concept,…"

The AR5 report also describes challenges and uncertainties when attempting to determine equivalent CO_2 emissions for other GHGs.

Technical issues with GWP discussed in the AR5 report include:

- The name 'Global Warming Potential' may be somewhat misleading, and 'relative cumulative forcing index' would be more appropriate.
- GWP is not directly related to a temperature limit such as the 2°C target.
- GWP_{100} was selected by policy but does not lead to equivalence with temperature or other climate variables.
- Global Temperature Potential (GTP), a more recent equivalency concept, may be a more direct indicator of temperature impact than GWP.

Recognizing these issues with GWP, IPCC AR5 provides values for GWP and GTP (Figure 8) should others wish to use that metric rather than GWP.

Table 8.7: GWP and GTP with and without inclusion of climate-carbon feedbacks (cc fb) in response to emissions of the indicated non-CO_2 gases (climate-carbon feedbacks in response to the reference gas CO_2 are always included).

	Lifetime (year)		GWP_{20}	GWP_{100}	GTP_{20}	GTP_{100}
CH_4	12.4[a]	No cc fb	84	28	67	4.3
		With cc fb	86	34	70	11
HFC-134a	13.4	No cc fb	3710	1300	3050	201
		With cc fb	3790	1550	3170	530
CFC-11	45.0	No cc fb	6900	4660	6890	2340
		With cc fb	7020	5350	7080	3490
N_2O	121.0[a]	No cc fb	264	265	277	234
		With cc fb	268	298	284	297
CF_4	50000.0	No cc fb	4880	6630	5270	8040
		With cc fb	4950	7350	5400	9570

Note:
Uncertainties related to the climate-carbon feedback are large, comparable in magnitude to the strength of the feedback for a single gas.
(a) Perturbation lifetime is used in calculation of metrics.

Figure 8: GWP and GTP Values in IPCC AR5 Report

Source: IPCC fifth assessment report (AR5) "Climate Change 2013 The Physical Science Basis"

Compared to the GWP, GTP, introduced in 2005, goes one step further down the cause-effect chain. GTP is defined as the change in global mean surface temperature at a chosen point in time in response to an emission pulse relative to CO_2. By accounting for climate sensitivity and exchange of heat between the atmosphere and the ocean, GTP includes physical processes that GWP does not. However, there are also issues with GTP for policy applications. The calculation of GTP is more complicated than that for GWP, as it requires modeling how much the climate system responds to increased concentrations of GHGs (the climate sensitivity) and how quickly the system responds (based in part on how the ocean absorbs heat). Thus, the relative uncertainty ranges are wider for GTP compared to GWP.

1.3.3 Time Horizon Options and Impacts

Choice of time horizon has a strong effect on GWP (and GTP) values and thus on the calculated contributions of CO_2e emissions by component, sector or nation. Discussion in the AR5 report suggests that a shorter (e.g., 20 year) time horizon may be useful if the speed of potential climate change is of greater interest than the eventual magnitude of the change. Since the IPCC was most interested in minimizing the magnitude of long-term impacts, they adopted the 100-year integration period (GWP_{100}) as the metric to implement the multi-gas approach in the 1997 Kyoto Protocol and subsequent agreements, including U.S. inventory and progress reporting.

For calculations involving methane and CO_2 impacts in building design comparisons, compliance requirements, and investment decisions, fuel substitution strategies to reduce methane emissions can result in increased emissions of other GHGs, most importantly CO_2. Because the climate forcing effect of CO_2 emissions is used as a baseline regardless of the time horizon chosen (CO_2 always has a GWP or GTP of 1), the impact of time horizon choices may appear to affect calculations of CO_2e only by adjusting the contributions of short-lived gases. However, this is the case only if reductions to those short-lived gas emissions occur independently of CO_2 emissions. If, however, technology choices or fuel substitution that reduce short-lived gas emissions simultaneously cause CO_2 emissions to increase, the choice of a short time horizon to reduce emissions of gases such as methane may cause the unintended consequence of increasing the long-term magnitude of climate change due to higher levels of long-life gases, especially CO_2.

Methane is a potent GHG in the short term compared to CO_2. With a lifetime of ~12.4 years, nearly all of methane's absolute global warming potential (AGWP) occurs during the first few decades after emissions, as shown in Figure 9. Because of the integrative nature of the GWP concept, the AGWP for CH_4 (yellow curve) reaches a constant level after about five decades. In contrast, the AGWP for long-life CO_2 continues to increase for centuries. Thus the ratio of AGWP for CH_4 and AGWP for CO_2, which defines the GWP for CH_4 (black curve), falls quickly with increasing time horizon of interest.

Because of this near-term impact, some stakeholders have expressed interest in reducing the time horizon of the Global Warming Potential (GWP) or Global Temperature Potential (GTP) metrics used for analysis, comparisons, and implementation in standards, codes, and regulations. Some agencies, such as the California Air Resources Board, have begun considering shorter-term impacts and have provided comparisons based on the 20-year integration period (GWP_{20}).

Figure 10 shows the GWP and GTP of methane vs. the time horizon chosen on a semi-log scale. It is important to point out that GWP does not estimate the global temperature change caused by this GHG compared to what would have been caused by the same amount of CO_2. GWP measures the amount of total amount of energy per unit area that would have been lost to space if the GHG was not present relative to what the same quantity of CO_2 would have done from time zero up to the chosen time horizon. That is the purpose of the GTP. For methane, because of the combination of its infrared absorption and its short lifetime, its potential to cause climate change decreases quite sharply compared to its GWP between 20 and ~50 years. Methane emission reduction is a worthy goal. However, for building energy performance comparisons and design decisions, it is generally not possible to reduce methane emissions without causing changes to emissions of other GHGs, most importantly CO_2. This unintended consequence can negatively impact the overall value of methane emission reduction strategies.

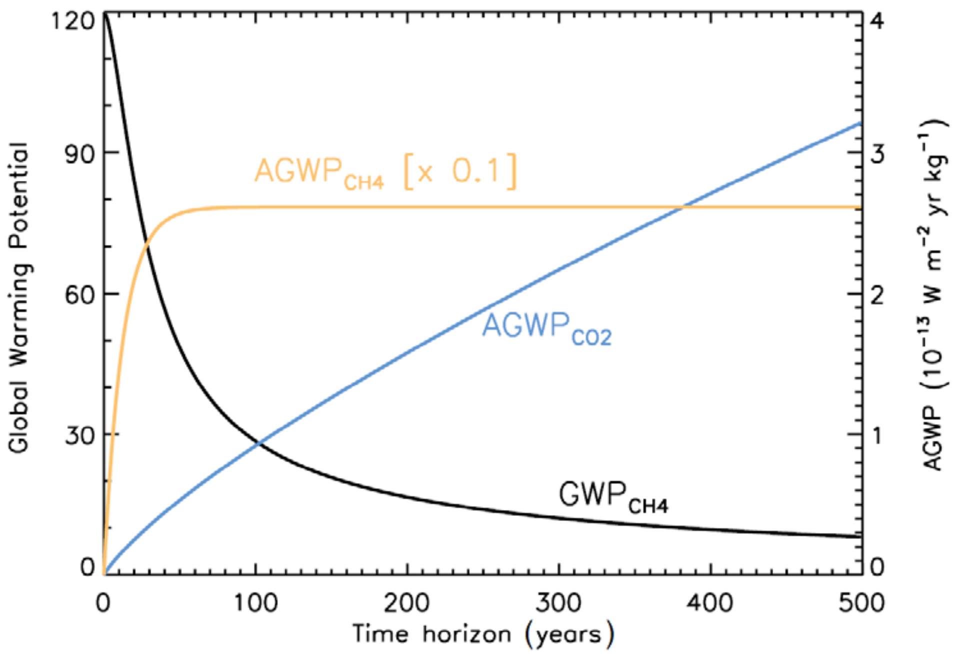

Figure 9: Time Horizon Impact on Methane AGWP and GWP

Source: IPCC fifth assessment report, pg. 712.
http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf

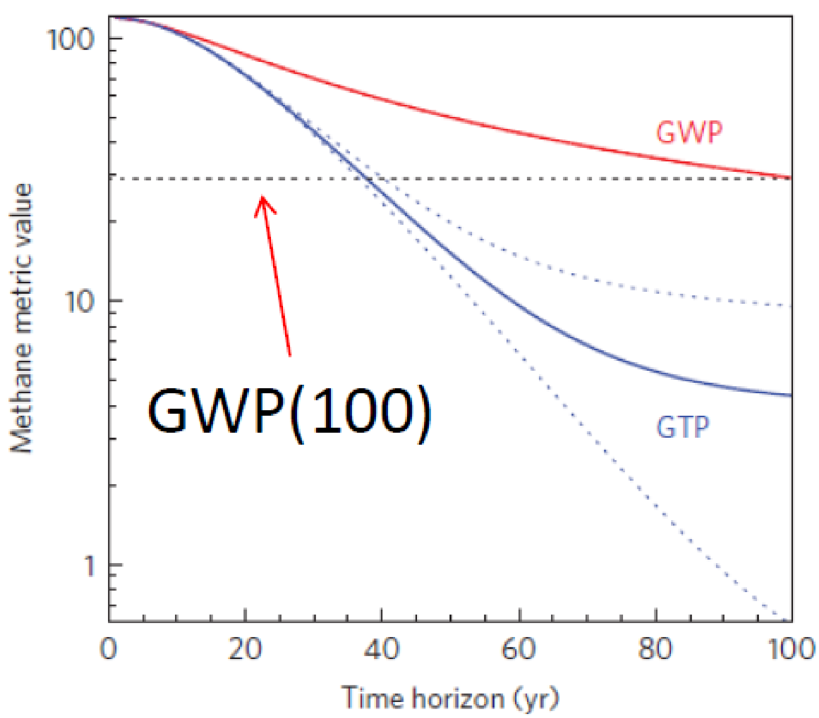

Figure 10: GWP and GTP of Methane

1.4 Allocation of Methane Emissions

1.4.1 EPA GHG Inventory Segmentation

The U.S. EPA collects and reports methane emissions data from companies through its Greenhouse Gas Reporting Program and its Greenhouse Gas Inventory (GHGI). Figure 11 shows the 2016 methane emissions for each major segment of the U.S. oil and gas systems. These systems (including extraction, processing, transmission, and distribution), are the second largest segmented contributor to overall methane emissions as shown in Figure 12 and Figure 13. EPA data indicates that the oil and natural gas production sectors combined are the largest contributors of methane emissions, accounting for 72% of oil and gas system emissions in 2016, with 145 million metric tons of CO_2 equivalent (MMT CO_2e) of a total of 202 MMT CO_2e for the industry. Natural gas emissions from production accounted for 107 MMT CO_2e (53%) of the total 145 MMT CO_2e from oil and gas production. This is followed by 33 MMT CO_2e for transmission and storage (17%), 11 MMT CO_2e for gas processing (6%), and 12 MMT CO_2e from gas distribution (5%).

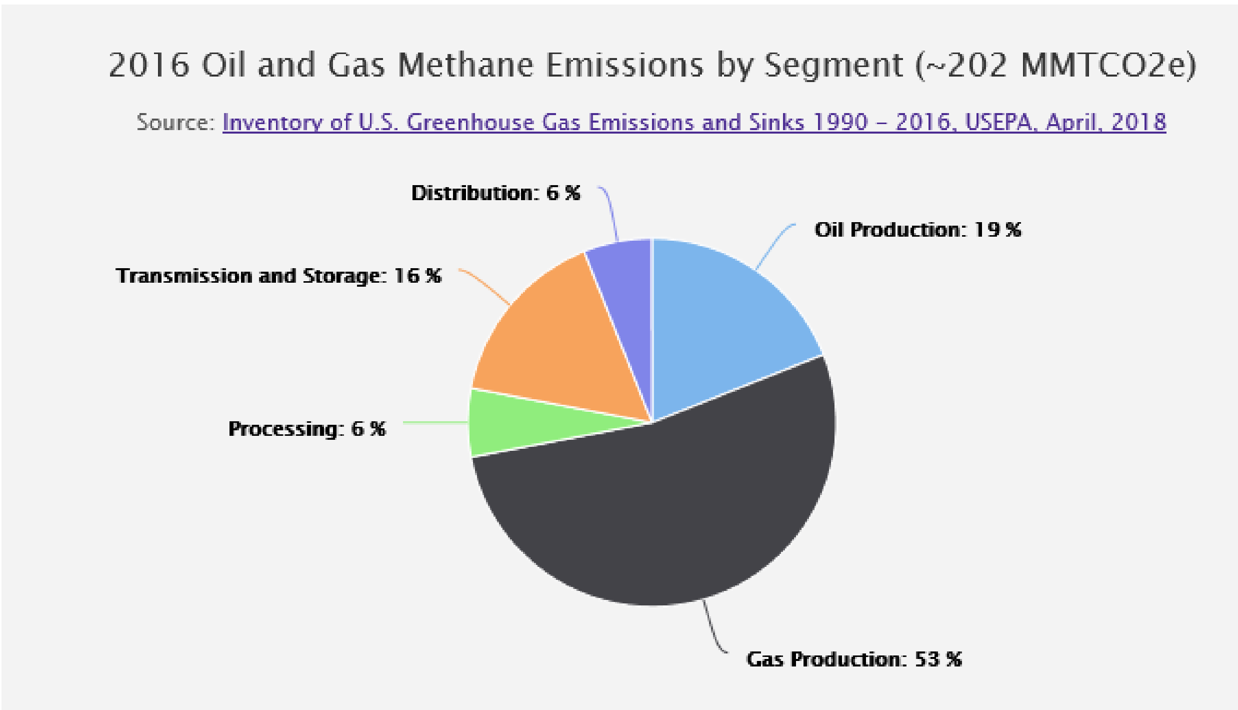

Figure 11: 2016 Oil and Gas Methane Emissions by Segment

Source: https://www.epa.gov/natural-gas-star-program/overview-oil-and-natural-gas-industry#sources

For comparisons among technology and fuel choices, methane emission calculations are intended to show the environmental benefit of reductions in natural gas direct-use, thereby reducing the impact of direct uses of natural gas on global methane emissions. However, it is unclear that such direct-use reductions based on these averaged inventory methane emission factors, especially for fuel substitution, actually result in any meaningful reduction of natural gas emissions in upstream processes such as pneumatic devices. Figure 14 shows the top emitters of natural gas. None of these gross emissions are associated directly with the combustion of natural gas in buildings. For instance, leaks are driven by pressure, not flow, and reductions in downstream natural gas usage will not meaningfully reduce these leaks. In that case, fuel substitution strategies designed to reduce natural gas use in buildings while increasing electricity use may result in little reduction in overall methane emissions.

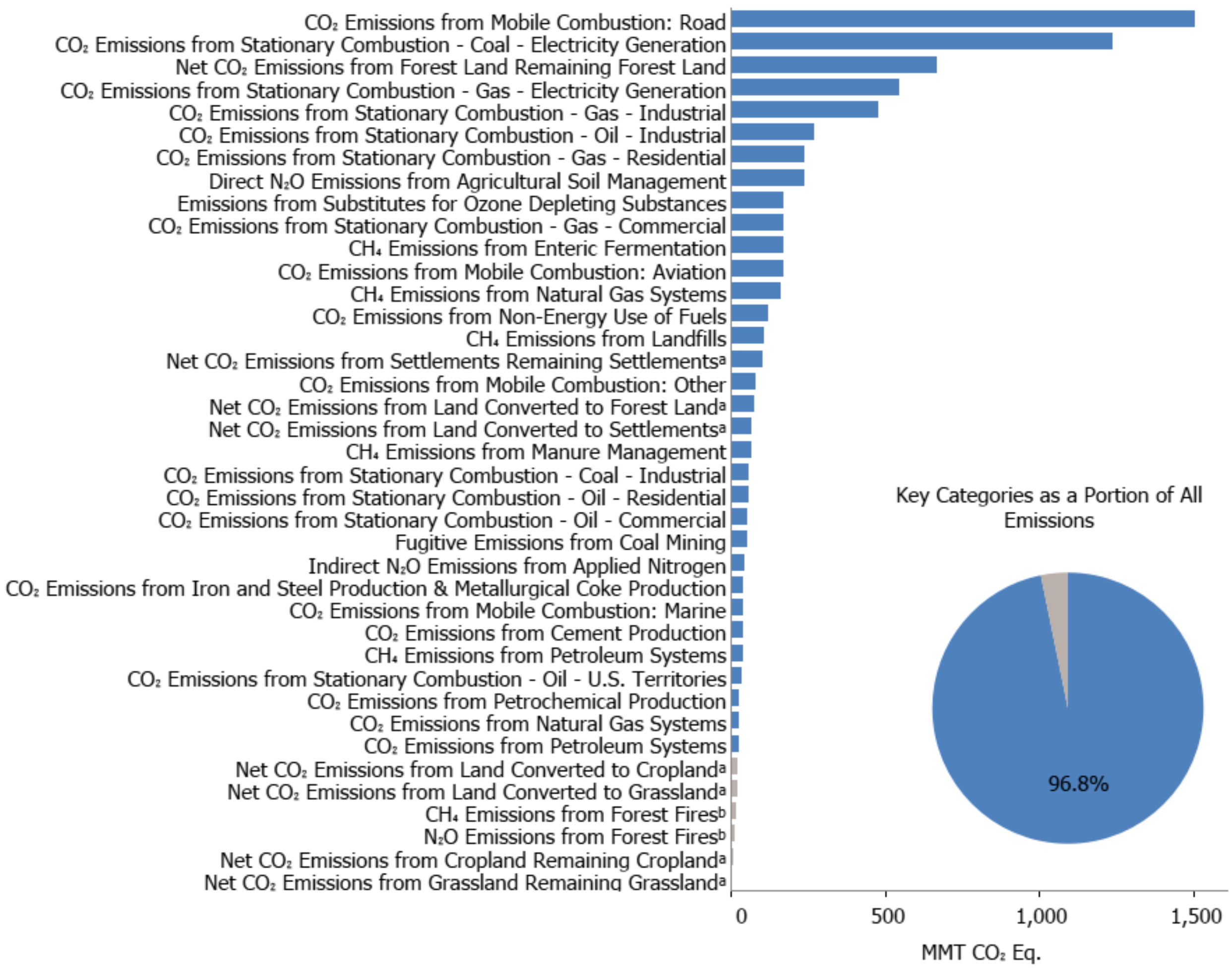

Figure 12: 2016 GHG Emissions by Key Categories (MMT CO_2 Eq.)

Source: https://www.epa.gov/sites/production/files/2018-01/documents/2018_complete_report.pdf

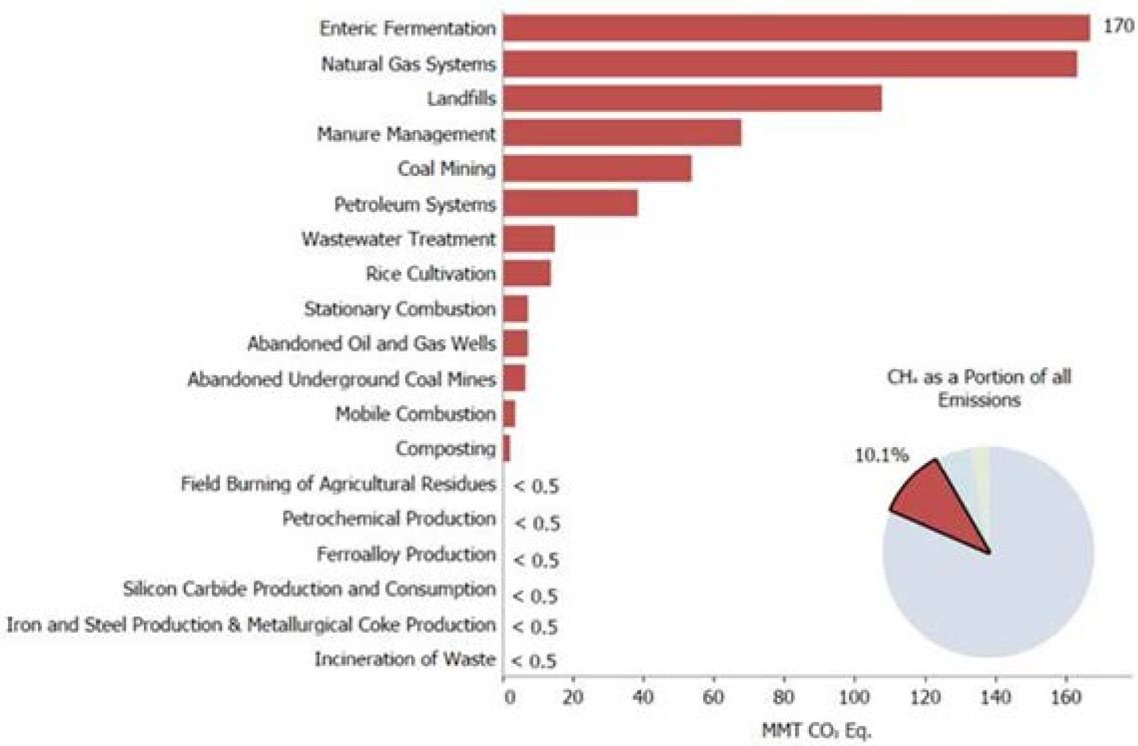

Figure 13: 2016 Sources of CH_4 Emissions (MMT CO_2 Eq.)

Source: https://www.epa.gov/sites/production/files/2018-01/documents/2018_complete_report.pdf

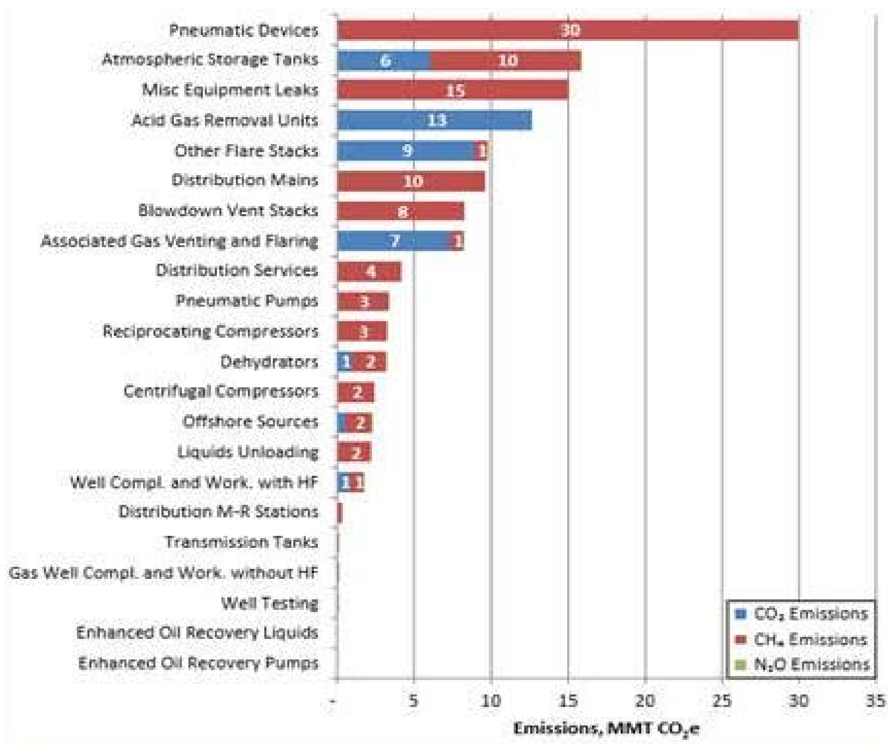

Figure 14: 2016 Reported Process Emissions Sources

Source: https://www.epa.gov/sites/production/files/2017-09/documents/subpart_w_2016_industrial_profile.pdf

Natural gas systems have made great progress in finding and fixing fugitive methane emissions through voluntary initiatives such as the EPA Gas Star program. As shown in Figure 15, methane emission intensity from natural gas systems has been reduced by 40% during the past three decades. Ongoing industry initiatives designed to identify and reduce or eliminate high emission sources are expected to achieve further reductions in methane emissions from these sources in the future.

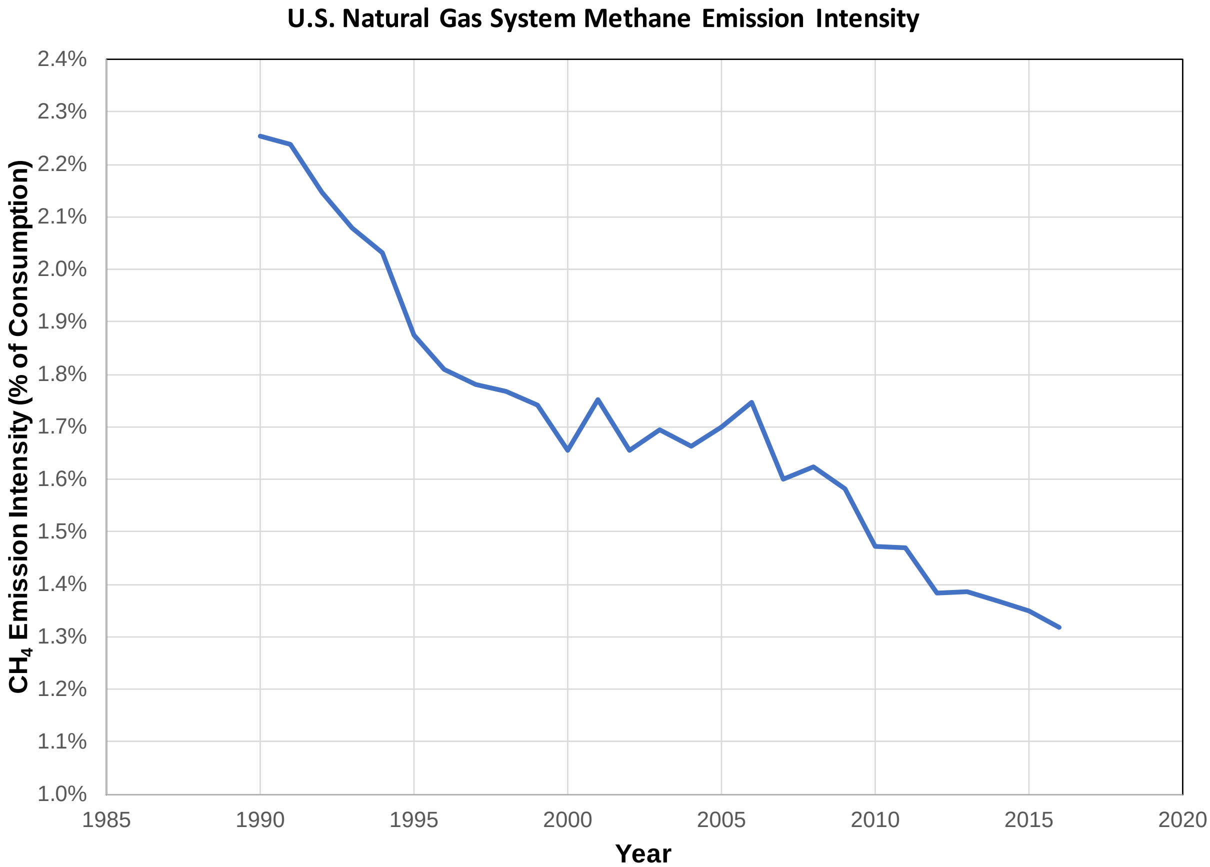

Figure 15: Natural Gas System Methane Emissions Intensity Profile 1990-2016

Source: **https://www.epa.gov/sites/production/files/2018-01/documents/2018_complete_report.pdf** (for natural gas leakage) and **https://www.eia.gov/dnav/ng/hist/n9140us2A.htm** (for natural gas consumption)

2 Analysis Framework

2.1 Public Domain Data Sources

Relevant public domain data sources listed in the references section were analyzed in preparation of this report. From this list, five sources provided most of the data compiled for this report. These sources were selected because they were in the public domain, periodically updated, and provided useful information in calculating FFC energy and emission conversion factors for electricity and fossil fuels typically used in residential and commercial buildings. The five primary sources of data include EPA, EIA, Argonne National Laboratory (ANL), National Renewable Energy Laboratory (NREL), and National Hydropower Association. Appendix B provides a more detailed description and application of information and data collected from these sources in developing the FFC energy and pollutant emission factors in this report.

2.2 FFC Boundary Condition

Analysis of the impact of building and appliance energy consumption on primary energy resource consumption and associated GHG emissions requires a definition of one or more equitable boundary conditions based on the objectives of the analysis. The definition of FFC energy used throughout this report is as follows:

> **Full-fuel-cycle energy is the energy consumed by an appliance, system, or building as measured at the building site plus the energy consumed in the extraction, processing, and transport of primary energy forms such as coal, oil, natural gas, biomass, and nuclear fuel; energy consumed in conversion to electricity in power-generation plants; and energy consumed in transmission and distribution to the building site.**

compares the “full-fuel-cycle” boundary with the site energy boundary and DOE’s “primary energy” boundary.

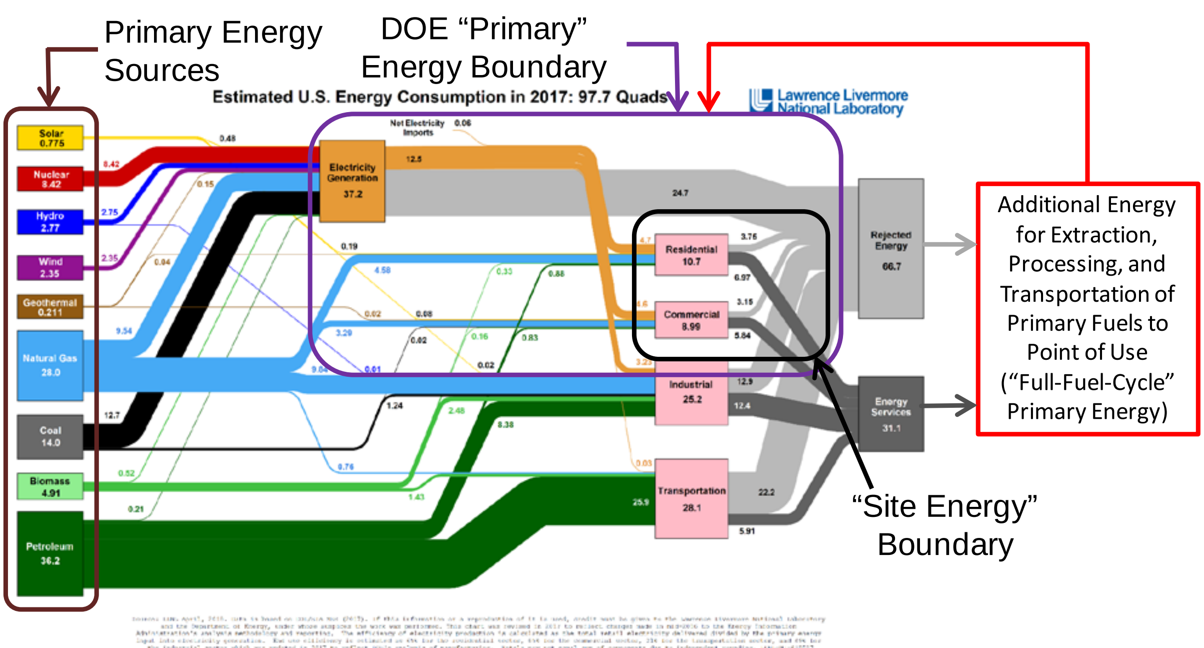

Figure 16 2017 U.S. Energy Use Profile with Different Boundary Conditions

Source: Lawrence Livermore National Laboratory 2017 Energy Flow Chart (https://flowcharts.llnl.gov/)

Other stakeholders use and define different boundary conditions for their purposes. For instance, the boundary condition for DOE appliance rulemaking is legislatively mandated at the appliance point of use, which is defined as the energy consumed to operate the appliance determined in accordance with prescribed test procedures. DOE energy factors such as the water heater uniform energy factor (UEF) are based on point-of-use energy. Of interest are situations in which the DOE energy factors do not account for all of the energy consumed by the appliance. An example is the Annual Fuel Utilization Efficiency (AFUE) for a gas furnace, or the UEF of a condensing gas water heater. These point-of-use energy factors can be misleading in that they only account for gas consumption, and do not include the electric energy consumed by the furnace or water heater. This is likely to be even more misleading when determining the performance of gas heat pumps, hybrid appliances, or combined heat and power systems.

The next level boundary condition is "building energy", which is defined by ASHRAE as the sum of all point-of-use energy used in the building, however that energy is supplied (ASHRAE Standard 105-2014). This boundary condition is misleading in mixed fuel buildings and when on-site renewable energy is supplying energy to the building appliances and back to the grid. Building energy does not distinguish among energy forms, nor does it accommodate the value of renewable energy supplied to the building from outside the building but within the boundary of the building site.

The "site energy" boundary condition aligns closely with utility metered energy. ASHRAE Standard 105-2014 defines site energy as the energy consumed by a building as measured at the building site boundary. Site energy also aligns well with the DOE definition of "delivered energy" – the amount of energy consumed at the point of sale (typically the utility meter). It would likely be less than "building energy" whenever on-site renewable energy is produced to meet the "building energy" use requirements. Site energy could also approach zero over the course of a year if there is sufficient on-site renewable energy to meet the annual building energy use requirements. However, depending on the energy form displaced by the on-site renewable production and net metering provisions, net-zero site energy consumption may not result in net zero FFC energy consumption, especially for mixed fuel buildings. This boundary condition is misleading in mixed fuel buildings because site energy does not distinguish among energy forms.

Source energy currently has different boundary conditions as defined by DOE and EPA, which can confuse the marketplace. For instance, in the EPA Portfolio Manager methodology, "source energy" incorporates transmission, delivery, and production losses, but it does not include extraction or processing losses, and is therefore not the same as FFC energy.

Three alternative boundary conditions for source energy, none of which are FFC, have been defined by DOE and EPA as follows:

"Primary" energy (DOE): Energy consumed on-site, plus energy losses that occur in the generation, transmission, and distribution of electricity, as illustrated in . Extraction, processing, and transportation energy losses are not included in the DOE primary energy definition (Federal Register /Vol. 76, No. 160 /Thursday, August 18, 2011 /Proposed Rules 51283).

"Source" energy (DOE): "The amount of fossil and renewable fuels consumed for the four end-use sectors, plus the electricity used by these end-use sectors (electricity sales). In addition, the losses associated with the production of electricity by the utility sector (i.e., losses that occur in the generation, transmission, and distribution) are also allocated to the end-use sectors. The sum of source energy for four end-use sectors (transportation, industrial, residential buildings, and commercial buildings) is equal to the sum of all primary energy consumed by the four sectors plus energy consumed by the electricity producing sector. "Source energy" is equivalent to the term "total energy" as used by EIA in the AER. For this Web site, the use of the term "source" was judged to be more precise, particularly in discussions involving subsectors and aggregations of subsectors where the term total energy may be ambiguous." https://www.energy.gov/eere/analysis/energy-intensity-indicators-overview-concepts.

"Source" energy (EPA): The total primary fuel needed to deliver heat and electricity to the building site. Generally, this means the methodology should perform the following adjustments for energy consumed on site:

- Primary Energy (e.g., natural gas, fuel oil) – Account for losses that occur in the distribution, storage, and dispensing of the primary fuel.
- Secondary Energy (e.g., electricity, district steam) – Account for conversion losses at the plant in addition to losses incurred during transmission and distribution of secondary energy to the building. https://portfoliomanager.energystar.gov/pdf/reference/Source%20Energy.pdf?3d47-8bc4

"Full-fuel-cycle" energy (DOE): Point-of-use energy, the energy losses associated with generation, transmission, and distribution of electricity, and the energy consumed in extracting, processing, and transporting or distributing primary fuels (https://www.gpo.gov/fdsys/pkg/FR-2011-08-18/pdf/2011-21078.pdf). This definition is consistent with the "full-fuel-cycle energy" definition used in this report.

2.3 FFC Energy Implementation Strategies

Reducing or avoiding building electricity consumption is an important strategy to achieve meaningful reductions in FFC (primary) energy use and GHG emissions. In this regard, strategies and programs that equitably consider the benefits of direct use of efficient natural gas technologies in buildings can provide least-cost options for major reductions in primary energy use and GHG emissions compared to electric equipment, especially electric resistance appliances. To achieve this societal benefit, it is essential to shift the focus from site energy to FFC energy methodologies when rating or benchmarking performance and when making policy or investment decisions.

As shown in Figure 17, the choice of metric, methodology, and factors depends on the objective of the analysis. Building energy loads are satisfied at the point of use based on technology and energy choices. Point-of-use energy is aggregated to site energy use by energy form. Site energy use by energy form is needed for measuring and monitoring energy consumption. Site energy is also the starting point for converting each energy form to useful metrics such as energy costs, FFC energy, and GHG or other pollutant emissions attributable to design options or building operation. Energy cost metrics are useful when the focus is on economic objectives. FFC energy is useful when the focus is on natural resources, the environment, or other societal impacts of energy use choices. Environmental impact metrics are useful when the focus is on environmental objectives such as GHG or other pollutant emissions after converting site energy to FFC energy to determine associated GHG emissions or other impacts.

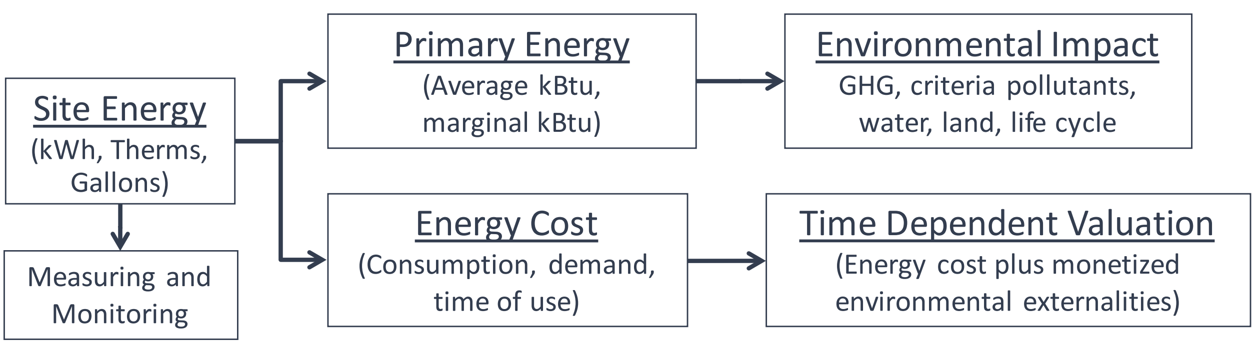

Figure 17 Different Metrics Needed Depending on Analysis Objectives

Point-of-use energy aggregated to site energy is necessary for measuring and monitoring the total amount of energy consumed within a building, and is the starting point for analysis of energy performance because it is the only thing that can be measured and verified directly at the energy-consuming appliance or meter. However, for site energy to become useful for equitable energy performance comparisons and calculations, it must always be converted into another meaningful metric such as energy cost, FFC energy, or GHG emissions. Site energy is a misleading and incomplete metric for any program, regulation, policy, or investment decision whose goal is to reduce primary energy resource consumption, energy costs, or pollutant emissions attributable to operation of the appliance, system, or building, particularly when comparing direct-use energy form options.

Site measurement methods—a calculation of the energy consumed by an appliance at the end-use point (in the building) offset by on-site renewable energy production—do not properly or equitably account for the total energy consumed when more than one energy source is used in an appliance (such as a gas furnace) or when comparing the consumption of different fuels that can be used for the same application (such as water heating or combined heat and power). In addition, site measurement does not account for the energy lost and emissions created throughout the extraction, processing, transportation, conversion, and distribution of energy to the building. On the other hand, FFC energy consumption of appliances and the overall building from the point of extraction to the point of use does account for primary energy losses and associated emissions that occur (e.g., in the processing of natural gas or in the generation of electricity).

Site energy would be a sufficient metric only if the energy at the meter were the only parameter of concern. However, the energy required for generating and delivering electricity does not originate at the meter, but at one of the primary energy sources (solar, nuclear, hydro, wind, geothermal, natural gas, coal, biomass, and petroleum). To ignore the source of the energy leads to the unsupportable argument that energy is created at the meter, and upstream energy losses are not relevant to the building. Using that argument, one Btu of electricity would be considered the same as one Btu of natural gas. However, these are not equivalent energy forms. Electricity is considered a high-value energy form because of its versatility and ability to convert directly to mechanical energy, light, and heat through devices such as motors, semiconductors, lights, and resistance heating elements. Primary energy sources such as natural gas, petroleum, nuclear, and coal, are much more limited in their direct conversion capability, typically burned or split to convert chemical or nuclear energy to heat. Electricity's versatility is valued by consumers, who are willing to pay a much higher price per Btu delivered at the meter for electricity than for other forms of energy such as natural gas.

A good example of the problem with site energy is the comparison of conventional electric and gas storage water heaters for a home. An electric resistance water heater with a site UEF of 0.95 will reduce site energy consumption by 35 percent compared to a gas storage water heater with a site UEF of 0.62. This is a misleading statistic for comparing the performance of the competing technology options because it does not account for the energy cost differences or impact on primary energy consumption or GHG emissions. Based on the 2016 national average power generation mix and residential energy prices, the gas water heater will have a much lower energy cost, FFC energy consumption, and GHG emissions than the comparable electric water heater. In this case, the natural gas water heater will reduce energy costs by 62 percent, primary energy use by 40 percent, and CO_2e emissions by 34 percent compared to the electric resistance water heater.

Given the magnitude of source-to-site FFC energy and energy cost impacts, it is important for energy efficiency and environmental initiatives to account accurately (if not precisely) for energy costs, total FFC energy use, and associated GHG (and other pollutant) emissions. Specifically, there is a need for a technically justified and easily implemented methodology for calculating building or appliance energy performance based on defensible energy prices, FFC energy factors, and GHG and other pollutant emission factors for electricity and fossil fuels like natural gas or petroleum. Fortunately, other stakeholders continue to make progress implementing FFC energy metrics in various initiatives. For instance, DOE uses FFC energy in its 2015 definition of Zero Energy Buildings (https://www.energy.gov/sites/prod/files/2015/09/f26/bto_common_definition_zero_energy_buildings_09

3015.pdf. At the state level, California recognized the need to account for FFC energy use in their building energy codes when they developed the initial Title 24 standards in 1978. California Title 24 Energy Efficiency Standards for Residential and Nonresidential Buildings incorporated FFC energy calculation methods from then until 2005, when it switched to Time Dependent Valuation (TDV), an economic metric. California now uses TDV in their Title 24 building energy budget methodology. https://www.energy.ca.gov/title24/2013standards/prerulemaking/documents/general_cec_documents/Title24_2013_TDV_Methodology_Report_23Feb2011.pdf.

Further underscoring the importance of FFC energy considerations, a 2009 report by the National Research Council (NRC)'s Board on Energy and Environmental Systems to the U.S. Department of Energy recommended shifting toward a full-fuel-cycle energy basis for appliance standards calculations. The NRC report stated "using that metric could provide the public with more comprehensive information on the impacts of energy consumption on the environment." In addition, the report notes that:

> "the current use by DOE/EERE of site energy consumption is effective for setting standards for the operational efficiency of single-fueled appliances within the same class and should be continued without change. However, DOE/EERE's current use of site energy consumption does not account for the total consumption of energy when more than one fuel is used in an appliance or when more than one fuel can be used for the same application. For these appliances, measuring full-fuel-cycle energy consumption would provide a more complete picture of energy used, allowing comparison across many different appliances as well as an improved assessment of impacts such as effects on energy security and the environment."

Those recommendations may have an impact on future federal appliance energy efficiency rulemaking and standards if DOE chooses to implement them.

2.4 Average Electricity Conversion Factors

For electricity, it is important to distinguish between conversion factors for inventory purposes and conversion factors for comparisons, compliance requirements, and investment purposes. Although average energy and emissions calculations may be suitable for inventory and benchmarking purposes, they do not necessarily provide useful information and can be misleading when comparing technologies that provide the same energy service (e.g., water heating) or when making investment decisions.

FFC energy and GHG emissions inventory and benchmarking initiatives may use national average electric power generation mix data for their calculations. National average data provides simple FFC energy and emissions conversion factors. The consistency provided by use of national average factors also sends a strong signal regarding FFC energy performance and its impact on pollutant emissions. National average factors also do not reward or penalize a building based on its location. However, a national average calculation may distort the actual FFC energy or pollutant emissions associated with electricity consumption in specific buildings in different regions.

Use of regional values has the potential to reflect more accurately the actual FFC energy use and environmental impact of the building stock for inventory or benchmarking due to the regional nature of the power grid. Some stakeholders may consider a regional average FFC methodology useful when comparing the impact of a new building or a new electrically-driven technology on two distinct geographic regions, but do not want to reward or penalize investment choices (i.e., new building design options or existing building efficiency improvement investments) compared to the existing level of performance in the building stock. Regional average factors do not reflect the impact of investment and energy consumption decisions on incremental FFC energy consumption or pollutant emissions and can be even more misleading than national average factors in some situations such as power exported or imported from one region to another. This is especially true for regions that have large fractions of hydro, wind, solar, or nuclear power.

2.5 Marginal (Non-Baseload) Electricity Conversion Factors

Understanding the limitations of average conversion factors, DOE and EPA both use marginal electricity conversion factors in selected programs and assessments. For instance, DOE uses the marginal generation displacement methodology in the appliance standard program when reporting impact assessments. As noted by EPA in chapters 3 and 4 of its evaluation of benefits of clean energy initiatives (http://www.epa.gov/statelocalclimate/resources/benefits.html), marginal impact methodologies are more useful than either national or regional average calculations for evaluating the impacts of changes in electricity consumption, such as comparing new building energy efficiency design options or evaluating competing retrofit measures. EPA's interest in marginal impact methodologies arose from its understanding that clean energy policies and energy efficiency improvements reduce emissions at the marginal (non-baseload) electric generating units. Average electricity generation emission factors can be used appropriately to determine carbon footprint or GHG inventory snapshots. However, average emission rates typically under-predict the emission reduction when used for energy savings through efficiency improvements because these averages include baseload generation, such as nuclear or hydropower, that would not be affected by the efficiency improvement.

Marginal generation represents the next generation plant used, built, or avoided with that particular fuel type and heat rate, and can be complicated to determine precisely. Marginal generation may be location specific, time-dependent, and from the local or regional power pool. Alternatively, it may involve determining the location of the ultimate power plant avoided or built within or across power pools, and may even cross international boundaries that are grid-connected. Marginal and average FFC energy and CO_2e emission results can be significantly different, especially in regions dominated by hydro, wind, solar, or nuclear power generation. Also, displacing coal plants has a higher impact on FFC energy use and CO_2e emissions than displacing natural gas plants.

Marginal generation methodologies are typically based on some form of economic dispatch model. Based on the plant's marginal generation cost, economic dispatch of electricity typically brings on plants in the following order: renewable and hydro first, then nuclear, followed by natural gas or coal, and finally oil plants. Based on economic dispatch, marginal changes in electricity (saved or consumed) would likely be from either a peaker gas plant or oil plant during peak periods. During baseload periods (evenings, weekends), the marginal plant would likely be either gas or coal. While there are exceptions associated with transmission constraints, it is unlikely that low marginal cost hydropower, wind, solar, or nuclear plants would be affected by the marginal changes in power demand. Rather, they would continue to operate and sell their power at a profit to another portion of the grid to offset more expensive coal or gas power somewhere along the interconnected grid. This key aspect of marginal generation will have a significant impact on the actual FFC energy and pollutant emissions associated with new investment decisions such as choosing an electric appliance rather than a gas appliance. It also highlights the importance of selecting the correct boundary condition, methodology, time horizon, and numerical values for a marginal analysis.

EPA recognizes several valid and established approaches to quantify emission reductions using the "non-baseload" electricity mix. Non-baseload GHG emission factors are published by the EPA to facilitate the calculation of emissions reduction attributable to energy efficiency improvements. The use of eGRID sub-region non-baseload emission factors is offered by the EPA as a simple, low-cost method to estimate emission reduction potential, to explain emission benefits to the general public, or to determine annual emission reductions or regional or national estimates. EPA's non-baseload emission rates and methodology are currently used in EPA's Greenhouse Gas Equivalencies Calculator (https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references).

EPA's non-baseload emission rate methodology also provides a convenient way to determine the FFC energy factor associated with marginal non-baseload power plants for each eGRID sub-region. The emission factors can be correlated with the associated generation mix of oil, natural gas, and coal.

Knowing the non-baseload mix, the aggregate FFC energy conversion factor can be calculated based on marginal power plant efficiency levels for each fuel type. In the absence of marginal power plant efficiency level information, average power plant efficiency levels for each energy form may provide an acceptable substitute.

GTI analysts reviewed different marginal generation mix methodologies provided by EPA to identify one or more that were considered acceptably precise and accurate for inclusion in this report. The non-baseload capacity factor methodology described in more detail in Appendix A was selected for marginal factors in this report based on its simplicity and use in the eGRID2016 non-baseload generation database.

2.6 Non-Combustible Renewable Power Generation FFC Energy Factor Options

Unlike other power generation fuels, non-combustible energy sources for renewable power generation, including hydro, wind, solar, and geothermal heat, do not "consume" fuel in the conventional sense. This fundamental difference creates a challenge when trying to determine a reasonable way to account for the FFC energy attributable to non-combustible renewable energy forms. Each of these resources is generally considered to have zero annual energy operating cost, zero depletable energy consumption, and zero GHG emissions. Accordingly, annual FFC energy use (i.e., no "embedded" energy is considered in the calculation) as the metric for comparison with other forms of energy may be inadequate for these resources. Other metrics and boundary conditions may be needed for comparative analyses and inventory calculations, but are also difficult to determine and value fairly (e.g., impacts to wildlife, excess water consumption, loss of habitat in deserts, and embedded energy in wind, hydro, geothermal, and PV components). The levelized cost of electricity for renewable power over its life cycle may be a reasonable proxy for primary energy that includes embedded energy (https://higherlogicdownload.s3.amazonaws.com/APGA/1151c1f6-49e1-4598-badd-127e33da42cd/UploadedFiles/KyQ7jphQTGK6IWtFOD95_2017--Levelized-Cost-of-Energy-Study.pdf). But that cost metric proxy could be debated as well based on one's time horizon and other factors and metrics of interest; including consideration of alternatives to electricity.

Four approaches to determining renewable power FFC energy factors include:

1. Incident Energy Efficiency
2. Fossil Fuel Equivalency
3. Captured Energy Efficiency
4. Infinite Energy Efficiency (Zero Energy Use)

Each of the four approaches yields significantly different energy factors, and each will result in a different valuation of electricity use in buildings compared with the direct use of natural gas. Some will also impact the valuation of comparisons of renewable electric power compared to other power generation options such as natural gas power generation.

Incident Energy Efficiency is the fraction of input (or incident) energy converted to electricity (thermodynamic efficiency). The Incident Energy Efficiency approach provides a common metric for FFC energy efficiency comparisons across all generation types, including among renewable options because it considers all primary energy to be equivalent. Hydropower is by far the highest FFC energy efficiency power source at ~90% efficiency. Under the Incident Energy Efficiency approach, it would be strongly incentivized compared to any other option, including other renewable power, conventional power, or direct gas use in buildings. However, increased penetration of solar (~14% efficiency) and wind (~25% efficiency) would make the average electric grid primary energy conversion factor worse, not better, thereby dis-incentivizing those forms of renewable power compared to hydropower generation, non-renewable electricity generation, and compared to direct use of gas in buildings. For this reason, the Incident Energy Efficiency approach may create inconsistent policy signals as the amount of wind and solar electricity generation grows.

Fossil Fuel Equivalency treats non-combustible renewable power generation as if it is displacing fossil fuel power generation. This is the approach used by EIA in its national annual primary energy use and losses calculations, as described in AER 2011 Appendix F (https://www.eia.gov/totalenergy/data/annual/pdf/sec17_3.pdf), and highlighted in the LLNL 2017 energy flow-chart (https://flowcharts.llnl.gov/). Fossil Fuel Equivalency is intended to value the primary energy benefit of renewable generation compared to annual average fossil fuel generation it displaces. However, it significantly overstates the contribution of hydropower energy to primary energy use in EIA national annual primary energy use calculations compared to the Incident Energy Efficiency methodology. Like the Incident Energy Efficiency approach, the Fossil Fuel Equivalency approach may create inconsistent policy signals as the amount of wind and solar electricity generation grows.

Captured Energy Efficiency treats non-combustible renewable power generation as if it is 100% efficient, irrespective of its Incident Energy Efficiency, or whether it displaces other electricity generation, or is displaced by direct use of gas in buildings. Captured energy values renewable power over direct use of gas in buildings because its energy efficiency is deemed to be 100%, but it does not differentiate among renewable energy generation options. It is effectively a point-of-use energy metric valuation of renewable power generation and incentivizes all types of non-combustible renewable power compared to other options.

Infinite Energy Efficiency (Zero Energy Use) assigns no primary energy use to non-combustible renewable power generation, essentially considering it to be infinitely efficient. Some have argued that renewable power production takes advantage of an infinitely available resource (i.e., non-depletable) and therefore should be considered free energy for FFC energy efficiency calculations. This approach provides the most incentive for renewable electricity compared to other forms of electricity or direct use of gas in buildings, but it does not distinguish among renewable electricity generation sources.

Recognizing this challenging issue, a 2016 DOE report, “Accounting Methodology for Source Energy of Non-Combustible Renewable Electricity Generation” discusses the impact of Fossil Fuel Equivalency, and Captured Energy Efficiency options for non-combustible renewable power generation: https://www.energy.gov/sites/prod/files/2016/10/f33/Source%20Energy%20Report%20-%20Final%20-%2010.21.16.pdf. The DOE report provided guidance on applications for which it considers the Captured Energy Efficiency approach to be more useful than the Fossil Fuel Equivalency approach. As noted in the DOE report:

> “neither option is considered more technically “correct” or more “accurate” than the other, as each option needs to be considered along with its intended use to determine which is appropriate. As discussed by EIA, for their purposes, fossil fuel equivalency may be more appropriate when RE generation always displaces fossil fuel generation, and captured energy may be more appropriate when RE generation never displaces fossil fuels. There are also additional confounding factors such as Renewable Portfolio Standards and priority dispatch of renewables that would make it extremely challenging to calculate a more representative conversion factor that accurately assesses what fuel source RE generation is displacing.”

European Union (EU) calculation methods https://ec.europa.eu/eurostat/statistics-explained/index.php/Calculation_methodologies_for_the_share_of_renewables_in_energy_consumption also use the Captured Energy Efficiency (physical energy content) method. The EU describes their logic for their inventory (energy statistics and energy balances) purposes as follows:

> “The choice for Eurostat's energy statistics and energy balances is to use the physical energy content method. The general principle of this method is that the primary energy form is taken as the first flow in the production process that has a practical energy use. This leads to different situations depending on the energy product:

- For directly combustible energy products (for example coal, natural gas, oil, biogas, bioliquids, solid biomass and combustible municipal/industrial waste) the primary energy is defined as the heat generated during combustion.
- For products that are not directly combustible, the application of this principle leads to:
    - the choice of heat as the primary energy form for nuclear, geothermal and solar thermal; and
    - the choice of electricity as the primary energy form for solar photovoltaic, wind, hydro, tide, wave, ocean.

In cases when the amount of heat produced in the nuclear reactor is not known, the primary energy equivalent is calculated from the electricity generation by assuming an efficiency of 33 %."

In consideration of the DOE accounting methodology guidance and EU policy decisions, tables in this report use the Captured Energy Efficiency approach (i.e., 100% generation efficiency for hydro, wind, solar, and geothermal) to determining the FFC conversion efficiency for non-combustible renewable power generation from the electric grid. While not directly addressed in these tables, excess energy to the grid from non-combustible renewable on-site power generation (e.g., for a natural gas zero energy home) can be treated differently since it establishes the incremental value to the grid of the displaced electricity as opposed to the attribution of average FFC consumption on the grid from different primary energy sources.

2.7 Renewable Natural Gas FFC Factor Options

The production of renewable natural gas (RNG) is an emerging carbon emission reduction strategy to turn organic waste or other biomass feedstock into a low carbon pipeline quality fuel for direct-use applications. A 2012 White Paper developed under the National Petroleum Council–Future Transportation Fuels Study https://www.npc.org/FTF_Topic_papers/22-RNG.pdf provides a definition of RNG along with background information on transportation applications and potential benefits of RNG. As noted in that white paper:

"Renewable Natural Gas (RNG) is pipeline quality gas that is fully interchangeable with fossil natural gas and can be used as a 100% substitute for, or blended with, conventional gas streams for use in vehicle engines. The use of RNG presents an opportunity to convert marginal and zero-value waste products into a useful transportation fuel. RNG is produced from a variety of biomass and/or biogas sources including landfill gas, solid waste, municipal wastewater, and agricultural manure via purpose-built anaerobic digesters (AD). It can also be produced from ligno-cellulosic sources such as forestry and agricultural waste via the process of thermal gasification (TG) [i.e., syngas]."

This definition can be broadened beyond the transportation sector to other applications for fully interchangeable RNG, including power plants, buildings, and industrial processes. In addition to sources identified in the above definition, RNG also includes power-to-gas from renewable electricity.

Determining reasonable FFC energy and emission factors for RNG is complicated. FFC factors for RNG pathways vary significantly depending on the pathway and underlying assumptions. A 2018 RNG market assessment for California transportation options by the National Renewable Energy Laboratory (NREL) Joint Institute for Strategic Energy Analysis includes an analysis of 14 different pathways using the California GREET model (https://afdc.energy.gov/files/u/publication/w2w_emissions_assessment-ca.pdf). Figure 18 illustrates results of that analysis for several of these options and pathways.

The multiple pathways for RNG production each have different input energy requirements and offsets depending on the alternative uses and emissions of the feedstock. For instance, RNG from agricultural waste digesters contains high levels of CO_2, moisture, and sulfur species, which take energy to remove prior to obtaining pipeline-quality RNG. If such waste were otherwise vented to the atmosphere, as in Case 3a of Figure 18, RNG derived from such sources would receive a significant methane credit by capturing and using the methane instead of venting it. RNG from landfill gas is processed in a similar fashion as agricultural waste, but requires additional energy (typically electric energy) to remove siloxanes.

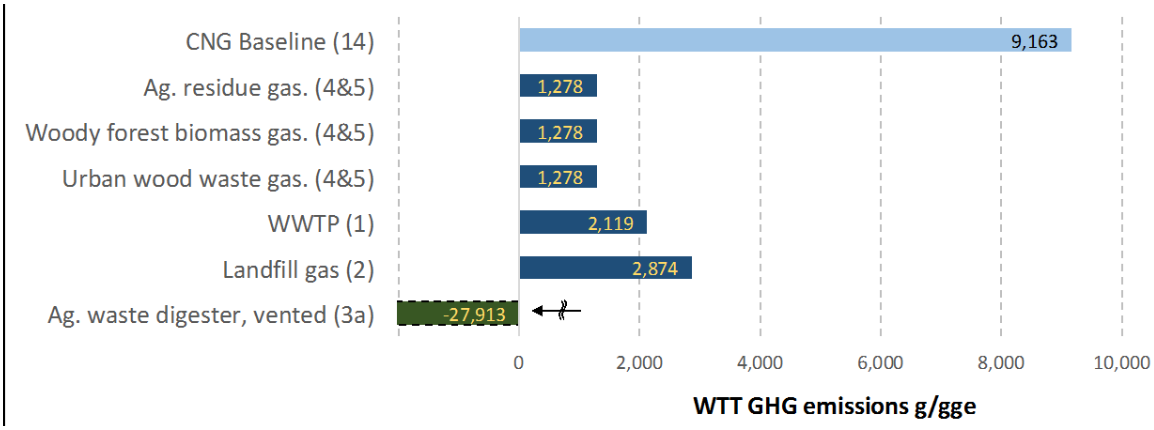

Figure 18 Well-to-Tank GHG Emissions of Conventional CNG and Selected RNG Pathways

Source: JISEA Report: Low-Carbon Natural Gas for Transportation: Well-to-Wheels Emissions and Potential Market Assessment in California (https://afdc.energy.gov/files/u/publication/w2w_emissions_assessment-ca.pdf)

The California Air Resources Board (CARB) tabulates certified carbon intensity (CI) values for transportation fuels for its low carbon fuel standard (LCFS) adjusted by their Energy Economy Ratios (https://www.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm). Figure 19 shows the November 29, 2018, CARB-certified adjusted CI ranges for 14 different fuel categories from local, national, and international fuel producers. The compressed natural gas (CNG) and "Bio-CNG" categories provide useful information on the CI values for conventional CNG and RNG.

Renewable sources of gas can lower lifecycle CO_2e emissions compared with geologic natural gas. As shown in Figure 18 and Figure 19, there is no single FFC emission factor for RNG. There is also no single FFC energy factor because the processing energy amount and form will differ among the pathways. Aggregating these disparate factors into a single average may provide a reasonable estimate of RNG impacts, especially for RNG injected into the pipeline, if the source of the RNG is not readily apparent.

The RNG scenario in the water heater sample calculations uses the "Captured Energy Efficiency" approach to be consistent with the other calculations. RNG efficiency is assumed to be 100% for the combustion phase. Upstream FFC energy and emission factors for RNG assume a 100% energy efficiency factor extraction, an 80% energy efficiency factor for "processing", and the natural gas energy efficiency factors for transportation and distribution. RNG combustion emissions are zero based on the assumption that the alternative would be to flare the gas. Upstream emissions are associated with the FFC energy consumption for the relevant pre-combustion steps (extraction, processing, and transportation for electricity, and distribution to the building in the case of direct use). RNG average price is assumed to be $3.50 per therm ($35.00 per million Btu). The winter marginal price factor of 0.89 is the same as the factor for natural gas.

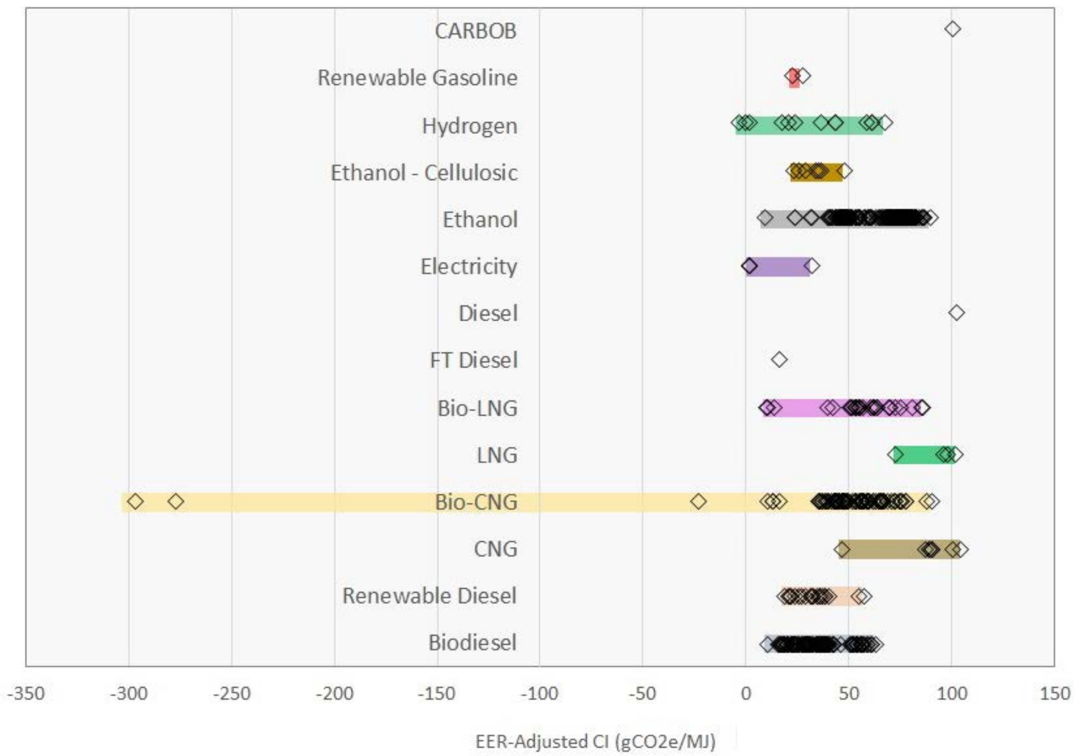

Figure 19 Carbon Intensity Values of Current CARB Certified LCFS Fuel Pathways

Source: California Air Resources Board LCFS Pathway Certified Carbon Intensities (https://www.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm)

2.8 Energy Price Options

Energy prices are required for calculation of energy cost based on site energy consumption by energy form, as well as peak electricity demand for many buildings. Energy cost is the bottom line metric for consumers and is the most easily understood metric. It is the basis of standards and certification requirements in certain minimum energy efficiency codes and standards and green building programs. Energy cost may be a useful proxy for energy consumption in hybrid and multi-fuel appliance calculations. It may also be useful for aggregations and comparisons of different energy source appliances, combined heat and power (CHP), and multi-fuel appliances for whole buildings as well as regional and national evaluations. Historically, annual energy prices for natural gas and electricity have been volatile compared FFC (primary) energy use and GHG emissions profiles, as shown in Figure 20. For this reason, price volatility can make multi-year energy cost comparisons misleading if based on a snapshot of energy prices for an individual year. In addition, subsidies can skew relative costs among fuels and for renewable energy options. Regulated utility price structures are often slow to change and respond to a variety of economic factors unrelated to use or efficiency.

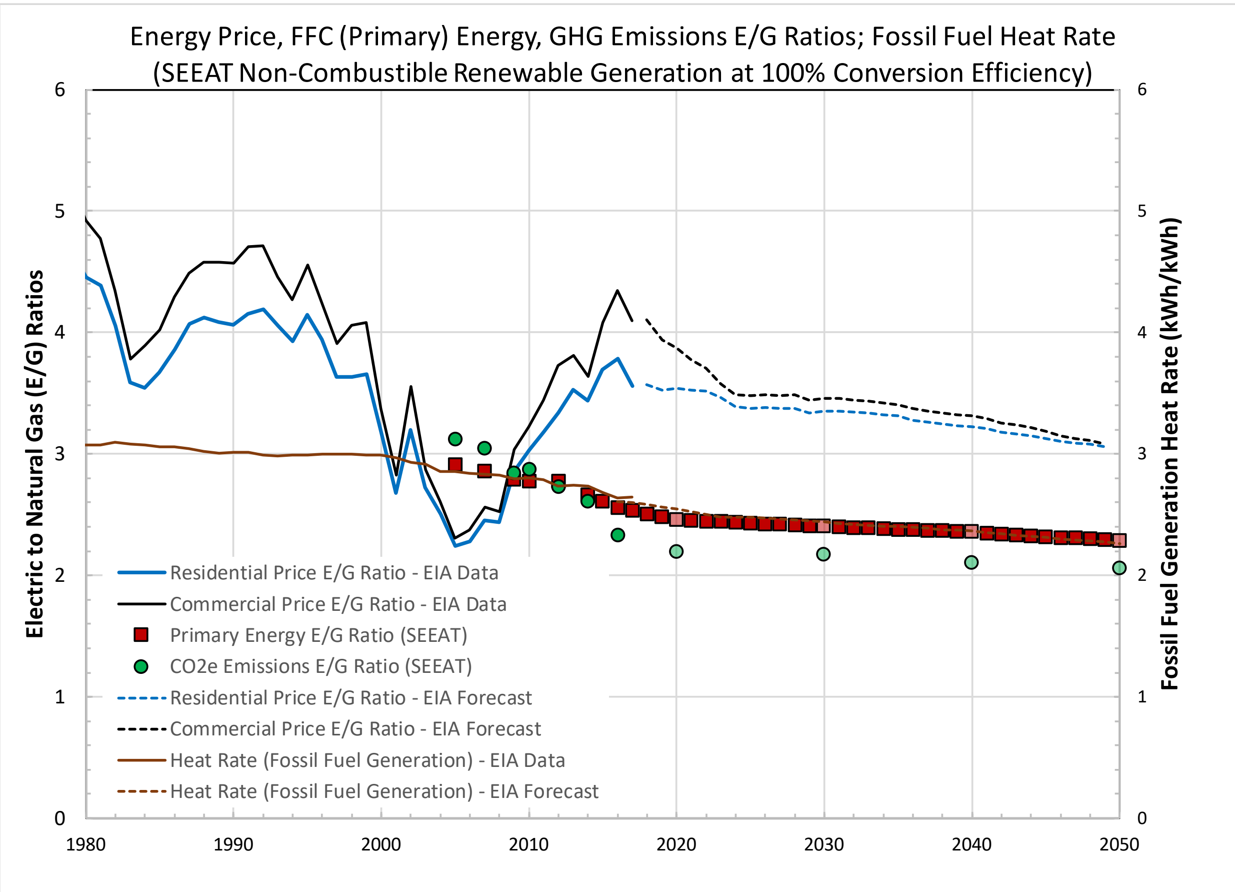

Figure 20 Energy Price, FFC Energy, and GHG Emissions E/G Ratios; Fossil Fuel Heat Rate

Source: EIA Data and Projections; SEEAT Calculations

3 FFC Energy Conversion Factors

Site energy methods are often used instead of a FFC energy-based approach due to perceived lack of reliable information on source-to-site (FFC) energy conversion factors. This is argued especially with electricity, which is generated from thousands of plants around the U.S. Fortunately, 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 simple and reasonably accurate calculation of FFC energy conversion factors for electricity and fossil fuels. Among these are information databases, reports, standards, and technical papers from the EPA, EIA, ANL, NREL, National Hydropower Association, California Energy Commission, ASHRAE, RESNET, and AGA. Protocols for mapping site to FFC energy have been developed by these and other organizations. Details differ in these protocols, but there is reasonable accuracy, precision, flexibility, and stability to permit much more rational comparisons between mixed fuel buildings and all-electric buildings than site energy methods.

In 1990, AGA published a report that included FFC energy conversion factors that formed the basis of AGA estimates of FFC energy efficiency for residential applications. Table 1 extracted from that report shows the FFC 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 FFC efficiency for residential applications, including all losses from extraction through distribution to the site. The FFC energy conversion factor is the inverse of the cumulative efficiency. Table 5 and Table 12 in this report update the 1990 factors shown in Table 1 using 2016 data.

Table 1 FFC 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 2016 data for calculations of source-to-site (FFC) energy efficiency and emission factors as well as overall FFC energy conversion factors for electricity and fossil fuels used in U.S. residential and commercial buildings. It includes detailed information on national, regional, and state-level electricity factors as well as national fossil fuel factors.

3.1 Electricity Generation Fuel Mix

The EPA eGRID2016 database (https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid) provides data for the year 2016 on U.S. electric power plant generation output and percentage of power supplied by coal, oil, natural gas, nuclear, hydro, and other renewable sources. Table 2 shows the eGRID2016 electricity generation resource mix by NERC Region shown in Figure 21 as well as the U.S. composite resource mix.

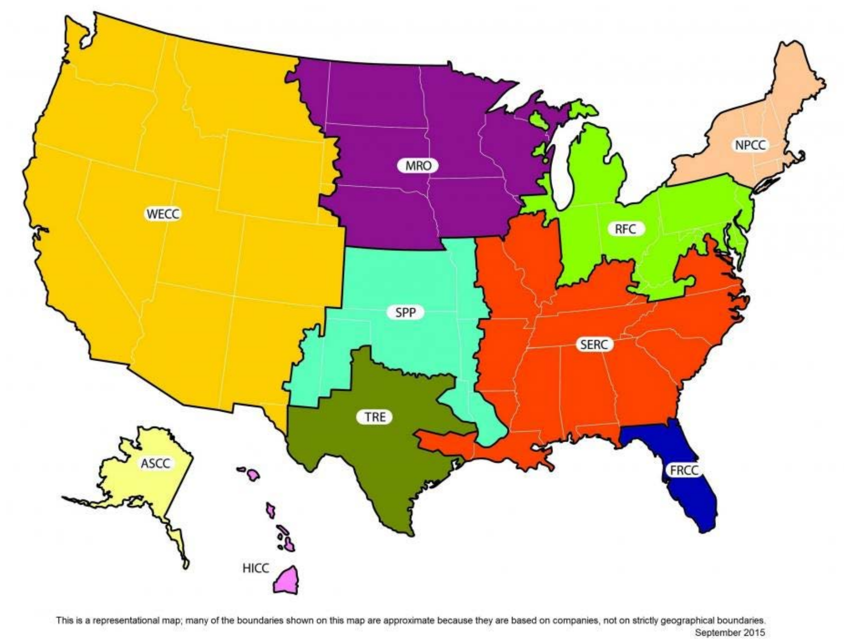

Figure 21 NERC Regions

Source: EPA eGRID2016

Table 2 Electricity Generation 2016 Resource Mix by NERC Region and U.S. (%)

NERC Region	Generation resouce mix (percent)								
	Coal	Oil	Gas	Nuclear	Hydro	Biomass	Wind	Solar	Geo-thermal
ASCC Alaska Systems Coordinating Council	9.6	13.1	48.8	-	25.1	0.7	2.6	-	-
FRCC Florida Reliability Coordinating Council	17.2	-	63.7	16.2	0.1	2.7	-	0.1	-
HICC Hawaiian Islands Coordinating Council	15.6	68.0	-	-	0.9	5.9	6.6	0.3	2.7
MRO Midwest Reliability Organization	52.1	0.1	7.9	12.6	5.3	1.8	20.2	-	-
NPCC Northeast Power Coordinating Council	1.8	0.1	45.5	30.8	13.6	5.1	2.7	0.4	-
RFC Reliability First Corporation	39.9	0.2	24.9	30.1	0.9	1.2	2.7	0.2	-
SERC SERC Reliability Corporation	32.9	-	34.3	26.6	2.9	2.4	0.4	0.4	-
SPP Southwest Power Pool	39.5	-	33.5	3.7	2.6	1.4	19.3	-	-
TRE Texas Regional Entity	27.0	-	47.4	11.1	0.3	0.3	13.7	0.2	-
WECC Western Electricity Coordinating Council	22.9	-	30.2	8.4	24.0	1.4	7.0	3.9	2.1
U.S.	**30.8**	**0.2**	**33.4**	**20.2**	**6.6**	**1.9**	**5.6**	**0.9**	**0.4**

Source: EPA eGRID2016

Table 3 shows the generation resource mix by eGRID Sub-region shown in Figure 22. Table 4 shows state-level data. The generation mix data shown in these tables is useful to calculate FFC energy conversion factors for electricity at state, regional, and national levels.

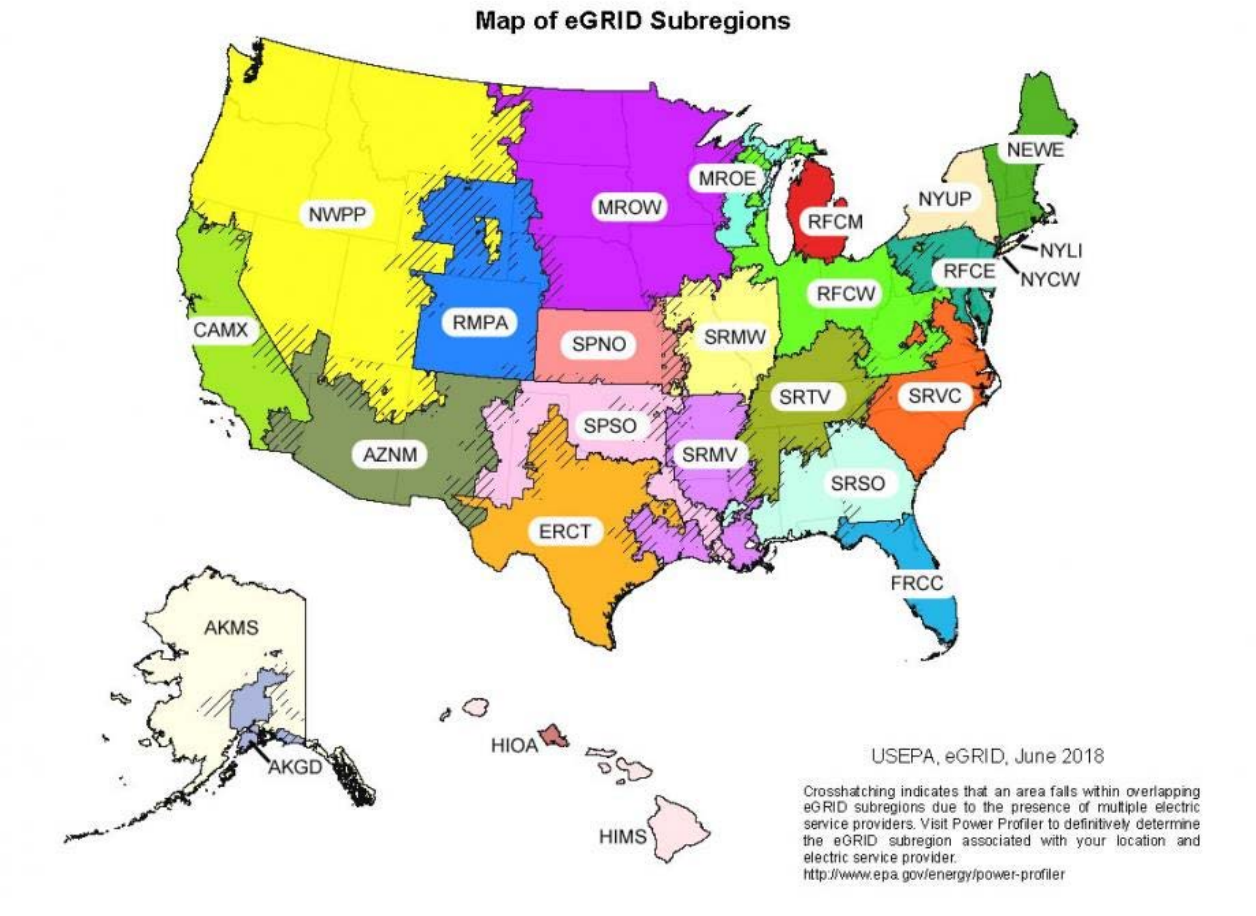

Figure 22 eGRID Sub-Regions

Source: EPA eGRID2016

Table 3 Electricity Generation 2016 Resource Mix by eGRID Sub-Region (%)

eGRID 2016 Sub-region Name	Generation Mix								
	Coal	Oil	Gas	Nuclear	Hydro	Biomass	Wind	Solar	Geo-thermal
ASCC Alaska Grid	12.8	9.0	61.8	-	12.6	0.9	2.9	-	-
ASCC Miscellaneous	-	25.9	8.5	-	63.7	-	1.9	-	-
ERCOT All	26.5	-	48.0	10.9	0.3	0.3	13.8	0.2	-
FRCC All	17.2	-	63.7	16.2	0.1	2.7	-	0.1	-
HICC Miscellaneous	-	65.7	-	-	3.5	4.9	15.8	(0.2)	10.2
HICC Oahu	21.3	68.8	-	-	-	6.2	3.3	0.4	-
MRO East	66.8	0.7	18.2	-	6.6	5.6	2.1	-	-
MRO West	53.2	-	6.4	12.8	5.0	1.3	21.2	-	-
NPCC Long Island	-	1.0	90.2	-	-	8.0	-	0.8	-
NPCC New England	2.3	0.2	49.9	30.4	5.6	8.5	2.5	0.7	-
NPCC NYC/Westchester	-	-	65.0	34.1	-	0.9	-	-	-
NPCC Upstate NY	2.2	-	27.2	31.5	32.2	2.1	4.7	0.1	-
RFC East	17.5	-	37.9	40.0	1.2	2.0	1.0	0.4	-
RFC Michigan	43.0	0.2	31.8	17.5	0.6	2.1	4.8	-	-
RFC West	50.6	0.2	16.3	27.9	0.9	0.6	3.3	0.1	-
SERC Midwest	72.0	-	7.6	15.4	1.4	0.1	3.5	-	-
SERC Mississippi Valley	15.0	-	58.5	22.4	1.5	2.5	-	-	-
SERC South	26.6	0.1	48.6	18.3	2.2	4.1	-	0.3	-
SERC Tennessee Valley	45.1	-	22.4	25.1	6.7	0.7	-	-	-
SERC Virginia/Carolina	26.0	-	27.2	40.3	2.1	3.1	0.2	1.1	-
SPP North	58.2	-	9.2	12.4	0.3	0.1	19.8	-	-
SPP South	33.3	-	42.9	-	3.8	2.1	17.8	0.1	-
WECC California	4.4	0.1	48.2	9.6	12.7	2.8	7.1	10.8	4.2
WECC Northwest	22.6	-	15.5	3.4	47.4	1.4	8.6	0.4	0.7
WECC Rockies	48.5	-	22.8	-	12.5	0.3	15.1	0.8	-
WECC Southwest	29.9	-	39.4	19.6	3.5	0.4	1.1	2.9	3.3

Source: EPA eGRID2016

Table 4 Electricity Generation 2016 Resource Mix by State (%)

State	Coal	Oil	Gas	Nuclear	Hydro	Biomass	Wind	Solar	Geo-thermal	Other unknown/ purchased fuel
AK	9.6	13.1	48.8	0.0	25.1	0.7	2.6	0.0	0.0	0.0
AL	21.1	0.0	42.5	27.9	5.2	2.8	0.0	0.0	0.0	0.4
AR	39.4	0.0	29.6	22.2	6.0	2.8	0.0	0.0	0.0	0.0
AZ	28.2	0.0	31.3	29.8	6.6	0.2	0.4	3.5	0.0	0.0
CA	0.2	0.1	48.3	9.6	15.0	3.0	6.8	9.8	5.8	1.5
CO	51.9	0.0	26.4	0.0	3.4	0.3	17.3	1.0	0.0	-0.4
CT	0.5	0.1	48.9	45.4	0.6	3.9	0.0	0.1	0.0	0.4
DC	0.0	0.0	31.0	0.0	0.0	69.0	0.0	0.0	0.0	0.0
DE	5.5	0.0	78.5	0.0	0.0	0.8	0.1	0.6	0.0	14.6
FL	17.2	0.0	61.9	15.2	0.1	2.8	0.0	0.1	0.0	2.9
GA	28.4	0.1	39.0	25.9	1.8	3.9	0.0	0.7	0.0	0.1
HI	15.2	66.1	0.0	0.0	0.9	5.7	6.4	0.3	2.6	0.0
IA	46.7	0.1	5.3	8.6	1.7	0.2	36.9	0.0	0.0	0.4
ID	0.3	0.0	20.7	0.0	57.7	3.8	16.5	0.2	0.5	0.4
IL	31.8	0.0	8.5	52.6	0.1	0.2	5.7	0.0	0.0	1.1
IN	72.3	0.2	18.3	0.0	0.4	0.4	4.8	0.2	0.0	3.3
KS	48.6	0.0	4.2	17.3	0.1	0.1	29.6	0.0	0.0	0.0
KY	86.6	0.0	8.4	0.0	4.3	0.6	0.0	0.0	0.0	0.0
LA	9.2	0.0	57.9	16.1	1.0	3.8	0.0	0.0	0.0	12.0
MA	6.1	0.0	67.2	16.9	2.2	6.5	0.7	1.9	0.0	-1.5
MD	34.9	0.0	17.0	39.7	3.7	2.7	1.4	0.6	0.0	0.0
ME	0.0	0.8	29.1	0.0	25.1	28.6	14.5	0.0	0.0	0.0
MI	37.5	0.2	26.3	28.1	1.4	2.6	4.2	0.0	0.0	-0.3
MN	38.8	0.0	14.2	23.1	1.9	3.9	17.5	0.0	0.0	0.6
MO	77.0	0.0	7.2	12.0	2.0	0.1	1.4	0.0	0.0	0.2
MS	5.2	0.0	82.6	9.4	0.0	2.8	0.0	0.0	0.0	0.0
MT	51.5	0.0	1.6	0.0	36.3	0.1	7.7	0.0	0.0	0.0
NC	28.7	0.0	24.9	32.7	3.4	1.7	0.0	2.6	0.0	6.0
ND	70.5	0.0	2.5	0.0	5.1	0.0	21.6	0.0	0.0	0.3
NE	59.1	0.0	1.5	25.1	4.1	0.2	10.2	0.0	0.0	-0.3
NH	1.9	0.1	24.6	55.8	5.9	9.5	2.2	0.0	0.0	0.0
NJ	1.7	0.0	56.3	38.5	0.0	2.0	0.0	1.0	0.0	0.5
NM	56.0	0.0	30.2	0.0	0.4	0.0	11.0	2.3	0.0	0.0
NV	5.6	0.0	71.4	0.0	4.6	0.1	0.9	6.4	8.7	0.0
NY	1.4	0.1	41.9	31.0	20.1	2.3	2.9	0.1	0.0	0.2
OH	57.9	0.8	24.2	14.1	0.4	0.7	1.0	0.1	0.0	0.6
OK	21.7	0.0	49.0	0.0	3.3	0.6	25.5	0.0	0.0	-0.1
OR	3.2	0.0	25.3	0.0	57.4	1.8	11.9	0.1	0.3	0.0
PA	25.4	0.0	31.1	38.6	1.1	1.5	1.6	0.0	0.0	0.6
RI	0.0	0.2	96.0	0.0	0.0	3.1	0.4	0.2	0.0	0.0
SC	21.3	0.0	16.9	57.6	2.3	2.9	0.0	0.0	0.0	-1.0
SD	20.3	0.0	8.9	0.0	40.2	0.0	30.6	0.0	0.0	0.0
TN	38.9	0.0	13.2	37.3	8.5	1.0	0.0	0.1	0.0	0.9
TX	27.0	0.0	48.7	9.3	0.3	0.4	12.7	0.2	0.0	1.5
UT	68.2	0.0	22.8	0.0	2.0	0.2	2.2	2.8	1.3	0.5
VA	20.6	0.2	41.2	32.1	1.2	5.4	0.0	0.0	0.0	-0.7
VT	0.0	0.2	0.0	0.0	56.4	17.0	15.2	3.1	0.0	0.0
WA	4.0	0.0	9.9	8.4	68.7	1.9	7.0	0.0	0.0	0.0
WI	51.4	0.2	23.0	15.6	4.2	2.1	2.3	0.0	0.0	1.2
WV	94.5	0.0	1.4	0.0	2.2	0.0	1.9	0.0	0.0	0.0
WY	86.1	0.0	2.2	0.0	2.1	0.0	9.4	0.0	0.0	0.0

Source: EPA eGRID2016

3.2 Electricity Generation FFC Energy Conversion Factors

GTI analysts derived FFC energy and emission factors due to electricity and fossil fuel consumption from government and public databases using GTI's Source Energy and Emissions Analysis Tool (SEEAT), available free to the public at www.cmictools.com and described in more detail in Appendix B. National, regional, and state level electricity FFC emission factors were derived based on FFC calculations.

FFC energy factors were derived only at the national level for fossil fuels. Unlike factors for electricity, average and marginal natural gas factors are expected to be very similar. Minor variations in marginal and average natural gas factors are attributable mainly to transmission distance and type of production (e.g., conventional vs. shale gas wells). Published data on such variations is limited, and the calculated impact on the results is considered to be small enough to ignore for the purposes of this report.

Table 5 through Table 8 show national, regional, and state average FFC energy factors for electricity generated with different fuel types calculated using SEEAT.

Table 9 shows aggregate average U.S. electric power generation heat rates and the corresponding plant energy conversion factors for fossil fuels and nuclear power plants. The net conversion efficiency values are very close to those provided in Table 5.

Table 10 shows marginal (non-baseload) FFC energy factors for electricity generated with different fuel types for each eGRID sub-region calculated using SEEAT. Table 11 summarizes marginal (non-baseload) and average FFC energy factors for electricity for each eGRID sub-region and the U.S.

Table 5 U.S. Average Electricity Generation FFC Energy Factors by Fuel Type

Energy Form	Process energy efficiency (percent)						
	Extraction	Processing	Transportation	Conversion	Distribution	Cumulative Efficiency	FFC Energy Conversion Factor
Electricity							
Coal	98.0	98.6	99.0	32.1	95.5	29.3	3.41
Oil	96.3	93.8	98.8	33.3	95.5	28.4	3.52
Natural Gas	96.2	97.0	99.3	44.8	95.5	39.6	2.53
Nuclear	99.0	96.2	99.9	32.6	95.5	29.6	3.38
Hydro	100.0	100.0	100.0	100.0	95.5	95.5	1.05
Biomass	99.4	95.0	97.5	31.2	95.5	27.4	3.65
Wind	100.0	100.0	100.0	100.0	95.5	95.5	1.05
Solar	100.0	100.0	100.0	100.0	95.5	95.5	1.05
Geothermal	100.0	100.0	100.0	100.0	95.5	95.5	1.05
U.S. Average	97.8	97.5	99.3	39.6	95.5	35.8	2.79

Source: SEEAT Version 8.2

Table 6 Electricity Generation Average FFC Energy Factors by NERC Region

NERC Region	NERC Region Name	Process energy efficiency (percent)						
		Extraction	Processing	Transportation	Conversion	Distribution	Cumulative Efficiency	FFC Energy Conversion Factor
ASCC	Alaska Systems Coordinating Council	97.0	97.1	99.0	43.9	94.8	38.8	2.57
FRCC	Florida Reliability Coordinating Council	97.5	97.3	99.1	39.1	95.5	35.1	2.85
HICC	Hawaiian Islands Coordinating Council	97.1	95.1	98.5	35.5	94.7	30.6	3.27
MRO	Midwest Reliability Organization	98.8	98.8	97.8	40.5	95.5	36.9	2.71
NPCC	Northeast Power Coordinating Council	97.9	96.8	99.4	41.2	95.5	37.1	2.70
RFC	Reliability First Corporation	98.5	97.9	98.9	35.6	95.5	32.4	3.08
SERC	SERC Reliability Corporation	98.3	97.7	98.9	37.1	95.5	33.7	2.97
SPP	Southwest Power Pool	98.1	98.6	98.2	41.2	95.5	37.4	2.67
TRE	Texas Regional Entity	97.7	98.0	98.3	43.0	95.1	38.5	2.60
WECC	Western Electricity Coordinating Council	98.3	98.3	98.9	48.1	95.8	44.0	2.28

Source: SEEAT Version 8.2

Table 7 Electricity Generation Average FFC Energy Factors by eGRID Sub-Region

eGRID 2016 Sub-region Acronym	eGRID 2016 Sub-region Name	Process energy efficiency (percent)						FFC Energy Conversion Factor
		Extraction	Processing	Transportation	Conversion	Distribution	Cumulative Efficiency	
AKGD	ASCC Alaska Grid	96.9	97.2	99.0	40.6	94.8	35.9	2.79
AKMS	ASCC Miscellaneous	97.6	96.7	99.4	58.4	94.8	51.9	1.93
ERCT	ERCOT All	97.7	98.0	98.3	43.1	95.1	38.6	2.59
FRCC	FRCC All	97.5	97.3	99.1	39.1	95.5	35.1	2.85
HIMS	HICC Miscellaneous	96.8	94.6	98.9	41.6	94.7	35.6	2.81
HIOA	HICC Oahu	97.3	95.3	98.4	33.3	94.7	28.7	3.48
MROE	MRO East	98.5	99.0	97.9	35.9	95.5	32.8	3.05
MROW	MRO West	98.8	98.8	97.7	40.4	95.5	36.8	2.72
NYLI	NPCC Long Island	96.7	96.7	99.0	33.8	95.5	29.9	3.35
NEWE	NPCC New England	97.9	96.6	99.2	39.4	95.5	35.3	2.83
NYCW	NPCC NYC/Westchester	97.4	96.6	99.5	38.2	95.5	34.1	2.93
NYUP	NPCC Upstate NY	98.4	97.1	99.6	48.5	95.5	44.1	2.27
RFCE	RFC East	98.2	97.1	99.2	36.4	95.5	32.9	3.04
RFCM	RFC Michigan	98.3	98.1	98.5	36.5	95.5	33.1	3.02
RFCW	RFC West	98.8	98.2	98.7	35.2	95.5	32.2	3.11
SRMW	SERC Midwest	98.8	98.9	98.0	34.7	95.5	31.7	3.15
SRMV	SERC Mississippi Valley	97.5	97.2	99.0	40.0	95.5	35.9	2.79
SRSO	SERC South	97.9	97.6	98.9	38.1	95.5	34.4	2.91
SRTV	SERC Tennessee Valley	98.7	98.2	98.8	36.4	95.5	33.3	3.00
SRVC	SERC Virginia/Carolina	98.5	97.3	99.1	36.3	95.5	32.9	3.04
SPNO	SPP North	98.8	98.9	98.0	37.5	95.5	34.3	2.92
SPSO	SPP South	97.7	98.4	98.2	42.5	95.4	38.3	2.61
CAMX	WECC California	97.6	97.5	99.3	52.0	95.8	47.1	2.12
NWPP	WECC Northwest	98.8	98.9	98.9	56.2	95.8	52.0	1.92
RMPA	WECC Rockies	98.4	99.1	98.6	41.5	95.8	38.2	2.63
AZNM	WECC Southwest	98.1	97.9	98.8	38.7	95.8	35.2	2.84

Source: SEEAT Version 8.2

Table 8 Electricity Generation FFC Energy Factors by State

State	Process energy efficiency (percent)						
	Extraction	Processing	Transportation	Conversion	Distribution	Cumulative Efficiency	FFC Energy Conversion Factor
AK	97.0	97.1	99.0	43.9	94.8	38.8	2.57
AL	98.1	97.4	99.1	38.4	95.5	34.7	2.88
AR	98.3	98.0	98.5	38.2	95.5	34.6	2.89
AZ	98.3	97.7	99.0	37.8	95.8	34.4	2.91
CA	97.6	97.3	99.4	53.6	95.8	48.4	2.06
CO	98.4	98.9	98.2	39.7	95.8	36.4	2.75
CT	97.9	96.4	99.5	37.0	95.5	33.2	3.01
DC	98.1	95.8	98.2	34.2	95.5	30.1	3.32
DE	96.5	97.2	99.2	40.6	95.5	36.0	2.78
FL	97.5	97.3	99.0	39.1	95.5	35.1	2.85
GA	98.2	97.6	98.9	37.5	95.5	34.0	2.94
HI	97.2	95.1	98.5	35.2	94.7	30.3	3.30
IA	98.9	99.1	98.3	47.2	95.5	43.5	2.30
ID	98.6	98.6	99.6	78.4	95.8	72.7	1.38
IL	98.8	97.5	99.0	34.0	95.5	31.0	3.23
IN	98.7	99.2	98.1	34.8	95.5	31.9	3.13
KS	98.9	98.8	98.2	39.1	95.5	35.9	2.79
KY	99.1	99.4	98.1	34.0	95.5	31.4	3.19
LA	97.3	97.1	99.0	42.0	95.5	37.6	2.66
MA	97.5	96.8	99.1	40.0	95.5	35.7	2.80
MD	98.6	97.6	99.0	33.8	95.5	30.8	3.25
ME	98.4	96.6	98.6	52.2	95.5	46.8	2.14
MI	98.5	97.9	98.7	36.0	95.5	32.7	3.06
MN	98.7	98.1	98.5	38.9	95.5	35.4	2.82
MO	98.8	99.0	97.9	35.2	95.5	32.2	3.11
MS	96.8	97.1	99.2	41.4	95.5	36.8	2.71
MT	99.0	99.6	97.9	43.9	95.8	40.6	2.46
NC	98.5	97.6	99.1	37.4	95.5	34.0	2.94
ND	98.5	99.6	95.2	39.3	95.5	35.0	2.86
NE	98.9	98.6	98.2	36.7	95.5	33.6	2.98
NH	98.6	96.3	99.4	35.3	95.5	31.8	3.14
NJ	97.7	96.6	99.5	38.9	95.5	34.9	2.86
NM	98.2	98.9	98.0	37.3	95.8	34.0	2.95
NV	96.9	97.5	99.2	50.3	95.8	45.1	2.22
NY	97.9	96.9	99.5	42.8	95.5	38.6	2.59
OH	98.6	98.4	98.6	35.8	95.5	32.7	3.06
OK	97.6	98.2	98.7	44.7	95.5	40.4	2.48
OR	98.3	98.5	99.4	69.3	95.8	64.0	1.56
PA	98.4	97.4	99.1	36.2	95.5	32.8	3.05
RI	96.3	96.9	99.2	44.6	95.5	39.5	2.53
SC	98.7	97.1	99.3	34.7	95.5	31.5	3.17
SD	99.0	99.4	98.8	65.5	95.5	60.8	1.64
TN	98.9	97.9	98.9	35.8	95.5	32.7	3.06
TX	97.7	98.0	98.3	42.5	95.1	38.1	2.63
UT	98.7	99.1	98.3	37.8	95.8	34.8	2.87
VA	98.1	97.2	99.1	36.9	95.5	33.3	3.00
VT	99.7	97.4	98.7	60.8	95.5	55.6	1.80
WA	99.1	98.6	99.5	70.9	95.8	66.1	1.51
WI	98.5	98.4	98.2	35.9	95.5	32.6	3.06
WV	99.3	99.6	98.0	34.9	95.5	32.3	3.10
WY	98.9	99.6	97.4	33.7	95.8	31.0	3.23

Source: SEEAT Version 8.2

Table 9 EIA Electricity Generation Heat Rates by Fuel Type

Fuel Type	Plant Heat Rate (Btu/kWh)	Net Conversion Efficiency (%)	Energy Conversion Factor
Coal	10,493	32.5%	3.08
Natural Gas	7,870	43.4%	2.31
Fuel Oil	10,811	31.6%	3.17
Nuclear	10,459	32.6%	3.07

Source: https://www.eia.gov/electricity/annual/html/epa_08_01.html

Table 10 Electricity Generation Non-Baseload FFC Energy Factors by eGRID Sub-Region

eGRID 2016 Sub-region Acronym	eGRID 2016 Sub-region Name	Process energy efficiency (percent)						FFC Energy Conversion Factor
		Extraction	Processing	Transportation	Conversion	Distribution	Cumulative Efficiency	
AKGD	ASCC Alaska Grid	96.4	96.9	99.0	33.0	94.7	28.9	3.45
AKMS	ASCC Miscellaneous	96.2	94.1	98.8	33.6	94.7	28.4	3.50
ERCT	ERCOT All	97.0	97.8	98.3	39.8	95.1	35.3	2.83
FRCC	FRCC All	97.0	97.5	99.1	39.9	95.6	35.8	2.80
HIMS	HICC Miscellaneous	96.7	94.0	98.6	28.8	94.7	24.4	4.10
HIOA	HICC Oahu	96.6	93.9	98.7	31.9	94.7	27.0	3.69
MROE	MRO East	97.7	98.1	98.3	35.6	95.5	32.0	3.11
MROW	MRO West	98.1	98.8	97.4	34.1	95.5	30.7	3.25
NYLI	NPCC Long Island	96.2	96.8	99.3	31.1	95.5	27.5	3.64
NEWE	NPCC New England	96.7	97.1	98.9	39.8	95.4	35.2	2.82
NYCW	NPCC NYC/Westchester	96.2	97.0	99.3	37.8	95.5	33.5	2.99
NYUP	NPCC Upstate NY	96.6	97.2	99.1	40.8	95.5	36.3	2.75
RFCE	RFC East	97.3	97.8	98.8	35.9	95.5	32.2	3.10
RFCM	RFC Michigan	97.9	98.4	98.1	33.0	95.4	29.8	3.34
RFCW	RFC West	98.4	98.7	98.3	33.5	95.5	30.6	3.27
SRMW	SERC Midwest	98.5	99.2	97.9	34.3	95.6	31.3	3.20
SRMV	SERC Mississippi Valley	96.7	97.3	98.9	41.2	95.5	36.6	2.73
SRSO	SERC South	97.2	97.7	98.6	37.9	95.4	33.9	2.93
SRTV	SERC Tennessee Valley	98.2	98.6	98.5	34.8	95.5	31.7	3.15
SRVC	SERC Virginia/Carolina	97.7	98.1	98.8	38.0	95.6	34.3	2.92
SPNO	SPP North	98.4	99.1	97.8	31.5	95.6	28.8	3.49
SPSO	SPP South	97.2	97.8	98.2	33.7	95.3	30.0	3.32
CAMX	WECC California	96.4	97.1	99.2	41.9	95.8	37.2	2.68
NWPP	WECC Northwest	97.9	98.3	98.5	36.2	95.9	32.9	3.04
RMPA	WECC Rockies	97.8	98.5	98.2	34.3	95.8	31.1	3.21
AZNM	WECC Southwest	97.2	97.9	98.7	37.8	95.8	34.0	2.93

Source: SEEAT Version 8.2

Table 11 Non-Baseload and Average Electricity FFC Energy Factors by eGRID Sub-Region

eGRID 2016 Sub-region Acronym	eGRID 2016 Sub-region Name	Non-Baseload FFC Energy Conversion Factor	Average FFC Energy Conversion Factor
AKGD	ASCC Alaska Grid	3.45	2.79
AKMS	ASCC Miscellaneous	3.50	1.93
ERCT	ERCOT All	2.83	2.59
FRCC	FRCC All	2.80	2.85
HIMS	HICC Miscellaneous	4.10	2.81
HIOA	HICC Oahu	3.69	3.48
MROE	MRO East	3.11	3.05
MROW	MRO West	3.25	2.72
NYLI	NPCC Long Island	3.64	3.35
NEWE	NPCC New England	2.82	2.83
NYCW	NPCC NYC/Westchester	2.99	2.93
NYUP	NPCC Upstate NY	2.75	2.27
RFCE	RFC East	3.10	3.04
RFCM	RFC Michigan	3.34	3.02
RFCW	RFC West	3.27	3.11
SRMW	SERC Midwest	3.20	3.16
SRMV	SERC Mississippi Valley	2.73	2.79
SRSO	SERC South	2.93	2.90
SRTV	SERC Tennessee Valley	3.15	3.00
SRVC	SERC Virginia/Carolina	2.92	3.04
SPNO	SPP North	3.49	2.91
SPSO	SPP South	3.32	2.61
CAMX	WECC California	2.68	2.12
NWPP	WECC Northwest	3.04	1.92
RMPA	WECC Rockies	3.21	2.63
AZNM	WECC Southwest	2.93	2.84
US Average			**2.79**

Source: SEEAT Version 8.2

3.3 Fossil Fuel FFC Energy Conversion Factors

Table 12 lists the total FFC energy conversion factor for natural gas, heating oil, and propane – the most common fossil fuels used in buildings. Process energy efficiency is included as a percentage of the energy of fuel leaving each stage to the total energy entering each stage including the energy of other fuels spent in the process. The efficiency of direct-use conversion to useful work inside the building was not included in this table as it varies depending on specific equipment efficiency.

Table 12 U.S. Average Building Fuels FFC Energy Factors by Fuel Type

Energy Type	Process energy efficiency (percent)						
	Extraction	Processing	Transportation	Conversion	Distribution	Cumulative Efficiency	FFC Energy Conversion Factor
Fossil Fuels Used in Buildings							
Natural Gas	96.2	97.0	99.0	100.0	99.0	91.5	1.09
Heating Oil	94.9	89.1	99.7	100.0	99.6	84.0	1.19
Propane/LPG	94.6	93.6	99.2	100.0	99.2	87.1	1.15

Source: SEEAT Version 8.2

4 FFC Pollutant and GHG Emission Factors

FFC emission factors due to electricity and fossil fuel consumption were derived from government and public databases using SEEAT as described in Appendix B. Emission factors include CO_2, nitrogen oxides (NO_x), sulfur dioxide (SO_2), mercury (Hg), methane (CH_4), nitrous oxide (N_2O), and CO_2e emissions based on the FFC energy consumption associated with each type of power generation. National, regional, and state level electricity emission factors were derived based on FFC calculations. Emission factors were derived only at the national level for fossil fuels based on FFC calculations. Constituent factors are tabulated below, along with the aggregated FFC emission factors associated with building energy consumption. This allows quick calculations and comparisons of the FFC emissions associated with buildings, systems, or appliances based on their point-of-use or site consumption by energy form.

4.1 Electric Power Plant Emission Factors

The eGRID2016 database provides information on pollutant emissions associated with U.S. electric power plants. The latest available eGRID data are for year 2016 and are reported for nearly all U.S. power plants and aggregated at several levels including state, eGRID sub-region, NERC region, and national level. Table 13 shows NOx, SO_2, CO_2, CH_4, and N_2O emissions in pounds of pollutant per unit of generated electricity (MWh or GWh) by NERC Region and U.S. average. eGRID no longer provides Hg emission information. Table 14 and Table 15 show similar data at the eGRID sub-region and state level. The emission factors shown in Table 13 through Table 15 are based on electricity output and include the total fuel mix used by power plants, while factors shown in Table 16 through Table 18 include power plant emissions related only to fossil fuel input.

Table 13 Power Plant Emission Rate by NERC Region and U.S. - All Fuels

NERC region	NERC name	NO_x 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/MWh)	N_2O output emission rate (lb/MWh)	Hg output emission rate (lb/MWh)*	CO_2e output emission rate (lb/MWh)
ASCC	Alaska Systems Coordinating Council	6.71	0.56	940	0.1	0.01	NA	944
FRCC	Florida Reliability Coordinating Council	0.53	0.37	1,012	0.1	0.01	NA	1,016
HICC	Hawaiian Islands Coordinating Council	4.49	7.51	1,522	0.2	0.02	NA	1,533
MRO	Midwest Reliability Organization	1.03	1.42	1,221	0.1	0.02	NA	1,229
NPCC	Northeast Power Coordinating Council	0.36	0.13	506	0.1	0.01	NA	509
RFC	Reliability First Corporation	0.83	1.05	1,104	0.1	0.02	NA	1,111
SERC	SERC Reliability Corporation	0.65	0.77	1,035	0.1	0.01	NA	1,041
SPP	Southwest Power Pool	0.82	1.26	1,271	0.1	0.02	NA	1,278
TRE	Texas Regional Entity	0.55	1.05	1,015	0.1	0.01	NA	1,020
WECC	Western Electricity Coordinating Council	0.73	0.32	799	0.1	0.01	NA	804
US		**0.72**	**0.80**	**998**	**0.1**	**0.01**	**NA**	**1,004**

* Hg emissions are no longer available in EPA eGRID2016
Source: EPA eGRID2016

Table 14 Power Plant Emission Rate by eGRID Sub-Region - All Fuels

eGRID 2016 Sub-region Acronym	eGRID 2016 Sub-region Name	NO_x 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/MWh)	N_2O output emission rate (lb/MWh)	Hg output emission rate (lb/MWh)*	CO_2e output emission rate (lb/MWh)
AKGD	ASCC Alaska Grid	6.52	0.53	1,072	0.077	0.011	NA	1,077
AKMS	ASCC Miscellaneous	6.96	0.63	503	0.023	0.004	NA	505
ERCT	ERCOT All	0.55	1.04	1,009	0.076	0.011	NA	1,014
FRCC	FRCC All	0.53	0.37	1,012	0.075	0.010	NA	1,016
HIMS	HICC Miscellaneous	7.45	4.50	1,152	0.095	0.015	NA	1,159
HIOA	HICC Oahu	3.37	8.65	1,663	0.181	0.028	NA	1,675
MROE	MRO East	1.05	1.29	1,668	0.156	0.026	NA	1,679
MROW	MRO West	1.04	1.39	1,239	0.115	0.020	NA	1,247
NYLI	NPCC Long Island	0.86	0.16	1,178	0.126	0.016	NA	1,186
NEWE	NPCC New England	0.39	0.13	558	0.090	0.012	NA	564
NYCW	NPCC NYC/Westchester	0.26	0.02	636	0.022	0.003	NA	637
NYUP	NPCC Upstate NY	0.29	0.19	295	0.021	0.003	NA	296
RFCE	RFC East	0.59	0.57	758	0.050	0.009	NA	762
RFCM	RFC Michigan	0.91	1.71	1,272	0.067	0.018	NA	1,279
RFCW	RFC West	0.95	1.20	1,243	0.108	0.019	NA	1,251
SRMW	SERC Midwest	1.14	2.44	1,613	0.082	0.026	NA	1,622
SRMV	SERC Mississippi Valley	0.80	0.71	839	0.050	0.007	NA	842
SRSO	SERC South	0.51	0.37	1,089	0.087	0.013	NA	1,095
SRTV	SERC Tennessee Valley	0.72	1.00	1,185	0.093	0.017	NA	1,193
SRVC	SERC Virginia/Carolina	0.48	0.34	805	0.067	0.011	NA	810
SPNO	SPP North	0.80	0.46	1,412	0.149	0.022	NA	1,422
SPSO	SPP South	0.85	1.66	1,248	0.095	0.015	NA	1,255
CAMX	WECC California	0.57	0.05	528	0.033	0.004	NA	530
NWPP	WECC Northwest	0.61	0.44	651	0.061	0.009	NA	655
RMPA	WECC Rockies	1.02	0.64	1,368	0.137	0.020	NA	1,377
AZNM	WECC Southwest	0.96	0.28	1,044	0.079	0.012	NA	1,049

* Hg emissions are no longer available in EPA eGRID2016
Source: EPA eGRID2016

Table 15 Power Plant Emission Rate by State - All Fuels

State abbreviation	NO_x emission rate (lb/MWh)	SO_2 emission rate (lb/MWh)	CO_2 emission rate (lb/MWh)	CH_4 emission rate (lb/MWh)	NO_2 emission rate (lb/MWh)	CO_2e emission rate (lb/MWh)	Hg emission rate (lb/MWh)*
AK	6.63	0.55	925.86	0.06	0.01	930	NA
AL	0.42	0.40	912.92	0.07	0.01	917	NA
AR	0.92	1.61	1,115.65	0.11	0.02	1,123	NA
AZ	0.63	0.24	932.23	0.07	0.01	937	NA
CA	0.48	0.04	452.54	0.03	0.00	454	NA
CO	1.12	0.71	1,468.37	0.15	0.02	1,478	NA
CT	0.32	0.04	498.47	0.06	0.01	502	NA
DC	4.58	0.10	481.79	0.02	0.00	483	NA
DE	0.40	0.12	887.42	0.03	0.00	889	NA
FL	0.55	0.37	1,024.21	0.08	0.01	1,029	NA
GA	0.45	0.36	1,001.75	0.09	0.01	1,007	NA
HI	4.49	7.51	1,522.10	0.16	0.02	1,533	NA
IA	0.77	1.05	997.86	0.05	0.02	1,004	NA
ID	0.27	0.07	188.70	0.01	0.00	189	NA
IL	0.36	0.95	811.32	0.05	0.01	816	NA
IN	1.71	1.73	1,812.70	0.19	0.03	1,825	NA
KS	0.76	0.30	1,195.55	0.13	0.02	1,204	NA
KY	1.46	1.91	1,954.30	0.19	0.03	1,968	NA
LA	0.82	0.72	878.85	0.05	0.01	882	NA
MA	0.52	0.23	821.33	0.10	0.01	828	NA
MD	0.62	0.94	1,012.68	0.08	0.02	1,019	NA
ME	0.58	0.29	336.96	0.16	0.02	348	NA
MI	0.83	1.54	1,099.85	0.06	0.02	1,106	NA
MN	0.67	0.58	1,012.67	0.12	0.02	1,020	NA
MO	1.46	2.55	1,687.74	0.12	0.03	1,699	NA
MS	0.43	0.16	940.72	0.03	0.01	943	NA
MT	1.12	1.02	1,251.02	0.14	0.02	1,260	NA
NC	0.56	0.45	867.44	0.08	0.01	873	NA
ND	1.98	2.39	1,663.75	0.13	0.03	1,675	NA
NE	1.13	2.77	1,281.15	0.14	0.02	1,291	NA
NH	0.24	0.08	310.56	0.10	0.01	317	NA
NJ	0.24	0.05	557.82	0.03	0.00	560	NA
NM	2.35	0.50	1,572.79	0.15	0.02	1,583	NA
NV	0.48	0.16	769.91	0.03	0.00	772	NA
NY	0.34	0.14	464.02	0.03	0.00	466	NA
OH	1.01	1.79	1,465.96	0.13	0.02	1,475	NA
OK	0.69	1.28	1,043.72	0.06	0.01	1,048	NA
OR	0.35	0.14	305.89	0.02	0.00	307	NA
PA	0.82	0.96	855.44	0.05	0.01	860	NA
RI	0.24	0.02	870.82	0.02	0.00	872	NA
SC	0.28	0.24	629.43	0.03	0.01	633	NA
SD	0.21	0.14	513.32	0.05	0.01	517	NA
TN	0.51	0.80	992.27	0.07	0.02	998	NA
TX	0.61	1.09	1,049.53	0.08	0.01	1,055	NA
UT	1.78	0.88	1,627.37	0.17	0.02	1,638	NA
VA	0.56	0.26	813.80	0.08	0.01	819	NA
VT	0.36	0.01	56.89	0.16	0.02	67	NA
WA	0.15	0.05	186.84	0.01	0.00	188	NA
WI	0.67	0.50	1,388.88	0.07	0.02	1,396	NA
WV	1.33	1.18	1,975.76	0.21	0.03	1,991	NA
WY	1.58	1.39	2,026.26	0.22	0.03	2,041	NA

* Hg emissions are no longer available in EPA eGRID2016
Source: EPA eGRID2016

Table 16 Power Plant Emission Rate by NERC Region and U.S. - Fossil Fuels

NERC region	NERC name	NO_x output emission rate (lb/MWh)	SO_2 output emission rate (lb/MWh)	CO_2 output emission rate (lb/MWh)	Hg output emission rate (lb/MWh)*
ASCC	Alaska Systems Coordinating Council	8.97	0.78	1,311	NA
FRCC	Florida Reliability Coordinating Council	0.56	0.43	1,184	NA
HICC	Hawaiian Islands Coordinating Council	4.81	8.91	1,722	NA
MRO	Midwest Reliability Organization	1.51	2.33	2,021	NA
NPCC	Northeast Power Coordinating Council	0.38	0.20	968	NA
RFC	Reliability First Corporation	1.09	1.58	1,688	NA
SERC	SERC Reliability Corporation	0.86	1.07	1,511	NA
SPP	Southwest Power Pool	1.10	1.66	1,714	NA
TRE	Texas Regional Entity	0.71	1.41	1,361	NA
WECC	Western Electricity Coordinating Council	1.18	0.58	1,485	NA
US		**0.97**	**1.19**	**1,524**	**NA**

* Hg emissions are no longer available in EPA eGRID2016
Source: EPA eGRID2016

Table 17 Power Plant Emission Rate by eGRID Sub-Region - Fossil Fuels

eGRID 2016 Sub-region Acronym	eGRID 2016 Sub-region Name	NO_x 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/MWh)	N_2O output emission rate (lb/MWh)	Hg output emission rate (lb/MWh)*
AKGD	ASCC Alaska Grid	7.66	0.62	1,282	0.091	0.013	NA
AKMS	ASCC Miscellaneous	21.13	1.91	1,531	0.071	0.012	NA
ERCT	ERCOT All	0.70	1.38	1,351	0.102	0.014	NA
FRCC	FRCC All	0.53	0.43	1,184	0.063	0.009	NA
HIMS	HICC Miscellaneous	10.91	6.59	1,688	0.104	0.018	NA
HIOA	HICC Oahu	3.41	9.57	1,732	0.120	0.020	NA
MROE	MRO East	0.98	1.39	1,970	0.176	0.029	NA
MROW	MRO West	1.65	2.31	2,068	0.179	0.032	NA
NYLI	NPCC Long Island	0.63	0.16	1,129	0.022	0.002	NA
NEWE	NPCC New England	0.27	0.10	934	0.028	0.003	NA
NYCW	NPCC NYC/Westchester	0.32	0.02	953	0.016	0.002	NA
NYUP	NPCC Upstate NY	0.42	0.60	947	0.035	0.004	NA
RFCE	RFC East	0.88	0.97	1,329	0.061	0.013	NA
RFCM	RFC Michigan	1.02	2.22	1,670	0.074	0.021	NA
RFCW	RFC West	1.33	1.77	1,851	0.161	0.028	NA
SRMW	SERC Midwest	1.40	3.04	2,017	0.103	0.033	NA
SRMV	SERC Mississippi Valley	1.06	0.91	1,126	0.064	0.009	NA
SRSO	SERC South	0.61	0.39	1,425	0.106	0.015	NA
SRTV	SERC Tennessee Valley	1.03	1.46	1,747	0.137	0.025	NA
SRVC	SERC Virginia/Carolina	0.72	0.52	1,444	0.099	0.017	NA
SPNO	SPP North	1.16	0.68	2,094	0.221	0.032	NA
SPSO	SPP South	1.08	2.10	1,605	0.120	0.018	NA
CAMX	WECC California	0.79	0.06	957	0.034	0.004	NA
NWPP	WECC Northwest	1.47	1.11	1,706	0.147	0.023	NA
RMPA	WECC Rockies	1.40	0.89	1,911	0.190	0.027	NA
AZNM	WECC Southwest	1.36	0.37	1,497	0.108	0.017	NA

* Hg emissions are no longer available in EPA eGRID2016
Source: EPA eGRID2016

Table 18 Power Plant Emission Rate by State - Fossil Fuels

State	NO_x output emission rate (lb/MWh)	SO_2 output emission rate (lb/MWh)	CO_2 output emission rate (lb/MWh)	Hg output emission rate (lb/MWh)*
AK	9.27	0.78	1,311	NA
AL	0.60	0.56	1,405	NA
AR	1.29	2.24	1,612	NA
AZ	1.03	0.40	1,568	NA
CA	0.65	0.01	867	NA
CO	1.40	0.90	1,874	NA
CT	0.27	0.05	880	NA
DC	4.00	0.19	1,555	NA
DE	0.33	0.14	1,040	NA
FL	0.54	0.42	1,193	NA
GA	0.58	0.41	1,464	NA
HI	5.08	8.91	1,722	NA
IA	1.39	2.00	1,904	NA
ID	0.22	0.04	886	NA
IL	0.81	2.31	1,970	NA
IN	1.76	1.89	1,966	NA
KS	1.40	0.57	2,263	NA
KY	1.51	1.99	2,056	NA
LA	1.03	0.87	1,114	NA
MA	0.28	0.15	989	NA
MD	0.98	1.71	1,902	NA
ME	0.18	0.21	850	NA
MI	1.10	2.33	1,699	NA
MN	1.03	0.99	1,854	NA
MO	1.71	2.99	1,999	NA
MS	0.47	0.13	1,060	NA
MT	2.05	1.87	2,285	NA
NC	0.84	0.61	1,463	NA
ND	2.70	3.27	2,272	NA
NE	1.80	4.59	2,123	NA
NH	0.32	0.12	965	NA
NJ	0.23	0.06	914	NA
NM	2.73	0.58	1,824	NA
NV	0.59	0.17	962	NA
NY	0.45	0.30	1,000	NA
OH	1.12	2.13	1,754	NA
OK	0.97	1.79	1,475	NA
OR	0.85	0.44	1,062	NA
PA	1.29	1.61	1,467	NA
RI	0.21	0.01	905	NA
SC	0.62	0.52	1,590	NA
SD	0.71	0.49	1,758	NA
TN	0.91	1.45	1,832	NA
TX	0.76	1.41	1,361	NA
UT	1.90	0.95	1,777	NA
VA	0.63	0.35	1,243	NA
VT	8.50	4.12	3,251	NA
WA	0.82	0.19	1,320	NA
WI	0.69	0.63	1,839	NA
WV	1.39	1.23	2,059	NA
WY	1.82	1.61	2,325	NA

* Hg emissions are no longer available in EPA eGRID2016
Source: EPA eGRID2016

4.2 Electricity Generation Pre-combustion and Plant Input Emission Factors

GREET Model v1 2012 rev2 and US EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks, draft Feb 11, 2013 were sources of information on pre-combustion air emissions associated with U.S. electric power generation. These factors are applied only to the pre-combustion energy for extraction, processing, and transportation to the power plant. Emission factors were calculated using HHV of all fuels involved in pre-combustion stages of preparing a specific fuel for combustion at the power plant. Table 19 provides U.S. average pre-combustion emission factors associated with electricity generation by fuel type. Table 20 shows similar data for power plant combustion emissions based on the consumption of each type of fuel in the power plant.

Table 19 U.S. Average Electricity Generation Pre-Combustion Emission Factors

Pre-Combustion					
Electricity Source	CO_2 (lb/MMBtu)	SO_2 (lb/MMBtu)	NOx (lb/MMBtu)	CH_4 (lb/MMBtu)	N_2O (lb/MMBtu)
Coal	70.3	0.348	0.593	7.189	0.001
Oil	169.5	0.357	0.754	2.011	0.003
Natural Gas	127.6	0.305	0.584	6.161	0.002
Nuclear	152.7	0.258	0.282	0.371	0.003
Hydro	0	0	0	0	0
Biomass	161.4	0.061	0.722	0.233	0.003
Wind	0	0	0	0	0
Solar	0	0	0	0	0
Geothermal	0	0	0	0	0

Source: GREET Model v1 2012 rev2; US EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks, draft Feb 11, 2013

Table 20 U.S. Average Power Plant Combustion Emission Factors by Fuel Type

Conversion						
Electricity Source	CO_2 (lb/MMBtu)	SO_2 (lb/MMBtu)	NOx (lb/MMBtu)	CH_4 (lb/MMBtu)	N_2O (lb/MMBtu)	CO_2e (lb/MMBtu)
Coal	207.2	0.223	0.153	0.019	0.003	208.5
Oil	178.9	0.637	0.657	0.005	0.002	179.7
Natural Gas	119.9	0.007	0.054	0.003	0	120.5
Nuclear	0	0	0	0	0	0
Hydro	0	0	0	0	0	0
Biomass	42.80	0.129	0.329	0.045	0.006	45.6
Wind	0	0	0	0	0	0
Solar	0	0	0	0	0	0
Geothermal	0	0	0	0	0	0

Source: EPA eGRID2016

4.3 Fossil Fuel Pre-combustion and Stationary Combustion Emission Factors

Table 21 lists U.S. average fossil fuel pre-combustion emissions factors, including fuel used for extraction, processing, transmission, and distribution to the building based on information provided in GREET. Emission factors were calculated using HHV of all fuels involved in pre-combustion stages of preparing a specific fuel for combustion. Table 22 lists fossil fuel stationary combustion emissions data derived from GREET. In combination with the pre-combustion emission factors provided in Table 21, the data are useful in evaluating total emissions from fossil fuel consumption in buildings. Table 23 lists LHV and HHV as well as specific density for several fossil fuels.

Table 21 Fossil Fuel Pre-Combustion Emission Factors

Fuel	CO_2 (lb/MMBtu)	SO_2 (lb/MMBtu)	NOx (lb/MMBtu)	CH_4 (lb/MMBtu)	N_2O (lb/MMBtu)
Natural Gas	127.8	0.302	0.594	6.947	0.002
Fuel Oil	166.6	0.272	0.503	1.387	0.002
Propane	166.5	0.273	0.522	1.375	0.002

Source: GREET Model v1 2012 rev2; US EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks, draft Feb 11, 2013

Table 22 Fossil Fuel Stationary Combustion Emission Factors

Conversion						
Fuel	CO_2 (lb/MMBtu)	SO_2 (lb/MMBtu)	NO_x (lb/MMBtu)	CH_4 (lb/MMBtu)	N_2O (lb/MMBtu)	CO_2e (lb/MMBtu)
Natural Gas	118.3	0.001	0.117	0.002	0.002	118.9
Fuel Oil	160.0	0.004	1.117	0.009	0.004	161.4
Propane	139.4	-	0.158	0.002	0.011	142.7

Source: GREET Model v1 2012 rev2; US EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks, draft Feb 11, 2013

Table 23 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 v1 2012 rev2

4.4 FFC Pollutant Emission Factors Associated with Building Consumption

The emission factor components shown above can be combined with the FFC energy loss factors for electricity and fossil fuels to calculate FFC emission factors associated with building energy consumption for each energy form. Table 24 shows national average FFC pollutant emission factors for electricity and fuels used in buildings. Table 25 through Table 27 show NERC region, eGRID sub-region, and state average FFC pollutant emission factors for electricity. Table 28 shows non-baseload FFC pollutant emission factors for electricity for each eGRID sub-region. Table 29 summarizes non-baseload and average FFC CO_2e emission factors for electricity for each eGRID sub-region and the U.S.

Table 24 U.S. Average FFC Electricity and Fossil Fuel Pollutant Emission Factors

Energy Form	CO_2 emission rate	SO_2 emission rate	NO_x emission rate	CH_4 emission rate	N_2O emission rate	Hg emission rate*	CO_2e emission rate
Electricity (lb/MWh)	1,101	0.97	1.02	2.55	0.013	NA	1,176
Natural Gas (lb/MMBtu)	130	0.03	0.17	0.65	0.003	NA	149
Fuel Oil (lb/MMBtu)	192	0.06	1.21	0.27	0.005	NA	201
Propane (lb/MMBtu)	163	0.06	0.23	0.13	0.011	NA	170

Source: SEEAT Version 8.2

Table 25 Average FFC Electricity Pollutant Emission Factors by NERC Region

NERC region	NERC name	CO_2 emission rate (lb/MWh)	SO_2 emission rate (lb/MWh)	NO_x emission rate (lb/MWh)	CH_4 emission rate (lb/MWh)	N_2O emission rate (lb/MWh)	CO_2e emission rate (lb/MWh)
ASCC	Alaska Systems Coordinating Council	1,067	0.77	7.41	3.05	0.009	1,155
FRCC	Florida Reliability Coordinating Council	1,090	0.54	0.86	3.01	0.010	1,177
HICC	Hawaiian Islands Coordinating Council	1,695	8.45	5.37	2.38	0.024	1,769
MRO	Midwest Reliability Organization	1,324	1.62	1.31	2.51	0.019	1,400
NPCC	Northeast Power Coordinating Council	604	0.28	0.65	1.99	0.008	662
RFC	Reliability First Corporation	1,222	1.24	1.11	2.22	0.015	1,288
SERC	SERC Reliability Corporation	1,147	0.93	0.94	2.38	0.013	1,217
SPP	Southwest Power Pool	1,349	1.44	1.10	3.01	0.015	1,437
TRE	Texas Regional Entity	1,127	1.28	0.86	3.06	0.013	1,216
WECC	Western Electricity Coordinating Council	871	0.44	0.95	1.98	0.009	929

Source: SEEAT Version 8.2

Table 26 Average FFC Electricity Pollutant Emission Factors by eGRID Sub-Region

eGRID 2016 Sub-region Acronym	eGRID 2016 Sub-region Name	CO_2 emission rate (lb/MWh)	SO_2 emission rate (lb/MWh)	NO_x emission rate (lb/MWh)	CH_4 emission rate (lb/MWh)	N_2O emission rate (lb/MWh)	CO_2e emission rate (lb/MWh)
AKGD	ASCC Alaska Grid	1,215	0.87	7.15	3.63	0.011	1,319
AKMS	ASCC Miscellaneous	618	0.83	7.86	1.25	0.006	655
ERCT	ERCOT All	1,121	1.28	0.84	3.07	0.013	1,210
FRCC	FRCC All	1,090	0.60	0.80	3.01	0.010	1,177
HIMS	HICC Miscellaneous	1,339	5.41	9.10	1.86	0.021	1,397
HIOA	HICC Oahu	1,936	9.89	4.06	2.65	0.030	2,019
MROE	MRO East	1,836	1.57	1.25	3.17	0.025	1,931
MROW	MRO West	1,339	1.64	1.27	2.54	0.019	1,415
NYLI	NPCC Long Island	1,348	0.68	1.14	4.50	0.016	1,479
NEWE	NPCC New England	669	0.46	0.54	2.12	0.013	732
NYCW	NPCC NYC/Westchester	754	0.24	0.54	2.76	0.003	832
NYUP	NPCC Upstate NY	358	0.46	0.30	1.16	0.003	391
RFCE	RFC East	871	0.82	0.80	2.08	0.009	931
RFCM	RFC Michigan	1,382	2.05	1.10	2.68	0.017	1,461
RFCW	RFC West	1,361	1.42	1.17	2.14	0.018	1,425
SRMW	SERC Midwest	1,747	2.51	1.43	2.74	0.032	1,832
SRMV	SERC Mississippi Valley	955	0.92	1.21	2.90	0.007	1,038
SRSO	SERC South	1,208	0.52	0.85	2.80	0.016	1,290
SRTV	SERC Tennessee Valley	1,289	1.19	0.96	2.14	0.016	1,354
SRVC	SERC Virginia/Carolina	904	0.51	0.70	1.88	0.011	960
SPNO	SPP North	1,519	0.63	1.05	2.64	0.020	1,599
SPSO	SPP South	1,315	1.87	1.17	3.28	0.013	1,410
CAMX	WECC California	589	0.30	0.68	1.99	0.004	646
NWPP	WECC Northwest	705	0.56	0.72	1.34	0.009	745
RMPA	WECC Rockies	1,459	0.81	1.27	2.73	0.019	1,540
AZNM	WECC Southwest	1,150	0.44	1.25	2.59	0.012	1,225

Source: SEEAT Version 8.2

Table 27 Average FFC Electricity Pollutant Emission Factors by State

State	CO_2 emission rate (lb/MWh)	SO_2 emission rate (lb/MWh)	NO_x emission rate (lb/MWh)	CH_4 emission rate (lb/MWh)	N_2O emission rate (lb/MWh)	CO_2e emission rate (lb/MWh)
AK	1,067	0.77	7.41	3.05	0.009	1,155
AL	1,026	0.58	0.70	2.37	0.013	1,096
AR	1,226	1.84	1.23	2.60	0.015	1,303
AZ	1,033	0.39	0.89	2.21	0.011	1,098
CA	508	0.13	0.73	1.92	0.003	563
CO	1,566	0.86	1.41	2.89	0.021	1,652
CT	611	0.20	0.63	2.04	0.009	670
DC	635	0.24	5.37	2.26	0.002	698
DE	1,154	0.35	0.87	4.09	0.004	1,269
FL	1,106	0.54	0.88	3.02	0.011	1,193
GA	1,107	0.53	0.73	2.45	0.013	1,179
HI	1,778	8.47	5.61	2.44	0.033	1,855
LA	1,074	1.19	0.95	1.74	0.015	1,126
ID	217	0.11	0.37	0.80	0.001	240
IL	918	1.01	0.58	1.60	0.012	966
IN	1,979	2.02	2.09	3.09	0.026	2,072
KS	1,288	0.44	0.98	2.17	0.018	1,353
KY	2,074	2.11	1.74	2.72	0.029	2,158
LA	901	0.90	1.18	2.96	0.006	986
MA	930	0.39	0.88	2.80	0.014	1,012
MD	1,126	1.13	0.89	1.95	0.017	1,185
ME	423	0.38	0.90	1.33	0.026	467
MI	1,208	1.76	1.12	2.32	0.015	1,277
MN	1,113	0.73	0.91	2.09	0.017	1,176
MO	1,809	2.80	1.78	2.91	0.033	1,899
MS	1,065	0.35	0.80	3.56	0.004	1,166
MT	1,366	1.20	1.38	2.21	0.019	1,433
NC	968	0.57	0.82	1.94	0.011	1,025
ND	1,791	2.74	2.46	4.78	0.032	1,933
NE	1,379	3.03	1.39	2.23	0.026	1,448
NH	416	0.22	0.53	1.22	0.015	454
NJ	669	0.22	0.53	2.28	0.005	734
NM	1,688	0.69	2.74	3.47	0.020	1,790
NV	869	0.29	0.78	2.94	0.004	952
NY	553	0.28	0.60	1.89	0.004	607
OH	1,589	2.02	1.30	2.57	0.026	1,668
OK	1,142	1.48	0.99	2.95	0.013	1,228
OR	345	0.20	0.49	1.16	0.003	378
PA	965	1.14	1.10	1.98	0.011	1,023
RI	994	0.21	0.63	3.76	0.001	1,100
SC	723	0.39	0.51	1.37	0.010	764
SD	552	0.20	0.31	1.11	0.007	585
TN	1,093	0.88	0.71	1.72	0.015	1,145
TX	1,166	1.33	0.93	3.20	0.010	1,258
UT	1,738	1.02	2.07	2.72	0.022	1,820
VA	922	0.42	0.87	2.29	0.012	989
VT	106	0.03	0.58	0.25	0.024	120
WA	213	0.09	0.23	0.55	0.003	230
WI	1,519	0.65	0.97	2.76	0.020	1,601
WV	2,091	1.35	1.59	2.56	0.040	2,173
WY	2,151	1.62	1.91	3.43	0.030	2,255

Source: SEEAT Version 8.2

Table 28 Non-Baseload FFC Electricity Pollutant Emission Factors by eGRID Sub-Region

eGRID 2016 Sub-region Acronym	eGRID 2016 Sub-region Name	CO_2 emission rate (lb/MWh)	SO_2 emission rate (lb/MWh)	NO_x emission rate (lb/MWh)	CH_4 emission rate (lb/MWh)	N_2O emission rate (lb/MWh)	CO_2e emission rate (lb/MWh)
AKGD	ASCC Alaska Grid	1,499	0.72	7.10	5.00	0.009	1,642
AKMS	ASCC Miscellaneous	1,875	2.84	27.42	3.09	0.013	1,965
ERCT	ERCOT All	1,503	1.56	1.20	4.18	0.016	1,625
FRCC	FRCC All	1,343	0.62	1.08	3.70	0.010	1,450
HIMS	HICC Miscellaneous	2,281	14.77	13.08	2.91	0.031	2,371
HIOA	HICC Oahu	1,878	8.38	5.70	2.46	0.027	1,954
MROE	MRO East	1,738	1.46	1.32	3.79	0.019	1,849
MROW	MRO West	1,984	2.30	2.07	4.15	0.029	2,108
NYLI	NPCC Long Island	1,525	0.70	1.46	5.38	0.004	1,676
NEWE	NPCC New England	1,227	0.52	1.09	3.58	0.015	1,331
NYCW	NPCC NYC/Westchester	1,222	0.26	1.02	4.58	0.002	1,351
NYUP	NPCC Upstate NY	1,207	1.02	1.28	3.78	0.009	1,316
RFCE	RFC East	1,583	1.53	1.63	3.73	0.015	1,692
RFCM	RFC Michigan	1,983	2.71	1.71	3.80	0.023	2,096
RFCW	RFC West	2,038	2.48	1.82	3.36	0.024	2,138
SRMW	SERC Midwest	2,068	3.22	1.68	3.51	0.035	2,176
SRMV	SERC Mississippi Valley	1,285	1.18	1.69	3.94	0.008	1,398
SRSO	SERC South	1,559	0.87	1.19	3.66	0.019	1,667
SRTV	SERC Tennessee Valley	1,899	2.02	1.51	3.26	0.026	1,997
SRVC	SERC Virginia/Carolina	1,560	0.83	1.19	3.35	0.017	1,659
SPNO	SPP North	2,217	1.60	2.17	4.15	0.028	2,341
SPSO	SPP South	1,797	2.64	1.87	4.58	0.016	1,930
CAMX	WECC California	1,124	0.24	1.23	3.90	0.005	1,235
NWPP	WECC Northwest	1,694	1.21	2.07	3.53	0.019	1,798
RMPA	WECC Rockies	1,890	1.04	1.71	3.93	0.024	2,007
AZNM	WECC Southwest	1,575	0.54	1.69	3.78	0.014	1,685

Source: SEEAT Version 8.2

Table 29 Non-Baseload & Average FFC Electricity CO_2e Emission Factors by eGRID Sub-Region

eGRID 2016 Sub-region Acronym	eGRID 2016 Sub-region Name	Non-Baseload CO_2e Emission Factor (lb/MWH)	Average CO_2e Emission Factor (lb/MWH)
AKGD	ASCC Alaska Grid	1,642	1,319
AKMS	ASCC Miscellaneous	1,965	655
ERCT	ERCOT All	1,625	1,210
FRCC	FRCC All	1,450	1,177
HIMS	HICC Miscellaneous	2,371	1,397
HIOA	HICC Oahu	1,954	2,019
MROE	MRO East	1,849	1,931
MROW	MRO West	2,108	1,415
NYLI	NPCC Long Island	1,676	1,479
NEWE	NPCC New England	1,331	732
NYCW	NPCC NYC/Westchester	1,351	832
NYUP	NPCC Upstate NY	1,316	391
RFCE	RFC East	1,692	931
RFCM	RFC Michigan	2,096	1,461
RFCW	RFC West	2,138	1,425
SRMW	SERC Midwest	2,176	1,832
SRMV	SERC Mississippi Valley	1,398	1,038
SRSO	SERC South	1,667	1,290
SRTV	SERC Tennessee Valley	1,997	1,354
SRVC	SERC Virginia/Carolina	1,659	960
SPNO	SPP North	2,341	1,599
SPSO	SPP South	1,930	1,410
CAMX	WECC California	1,235	646
NWPP	WECC Northwest	1,798	745
RMPA	WECC Rockies	2,007	1,540
AZNM	WECC Southwest	1,685	1,225
US Average			**1,176**

Source: SEEAT Version 8.2

5 Generation Mix Forecasts and Alternatives for Analysis

The electricity grid is undergoing a long-term shift away from coal power generation toward natural gas and renewable power generation. Building energy performance analysis based on historical power generation mix such as the 2016 average mix can provide a potentially misleading result if the shift continues or accelerates. The use of a marginal generation mix methodology largely avoids this issue as the marginal grid mix is unlikley to change substantially until renewable energy or other zero-carbon sources are utilized for electricity consumption at the margin. The eGRID2016 non-baseload generation mix is typically dominated by natural gas power plants, but some coal power plants are also included as part of the marginal generation mix in many eGRID sub-regions.

To understand the impact of alternative analytical assumptions about the makeup of the electric grid, two options for alternative FFC energy and emission factors are derived for use in the sample calculations in this report that could also be applied to other building energy performance analysis scenarios:

- EIA Annual Energy Outlook 2018 Reference Case projected generation mix at current generation efficiencies by energy form; and
- 85% natural gas @ 50% power plant HHV efficiency coupled with 15% renewable power.

5.1 AEO 2018 Projected Generation Mix

As shown previously in Figure 3, the EIA AEO 2018 reference case projection shows a modest decline in total coal and nuclear power generation compared to 2016, with steady natural gas generation and a modest increase in renewable power generation. AEO 2018 also includes several other cases to allow consideration of alternative future scenarios. Table 30 lists the 2016 and the projected generation mix for coal, natural gas, nuclear, and renewable sources generation mix for the reference case and the clean power plan case, along with the resulting FFC energy and CO_2e emission factors for each scenario.

Table 30 AEO 2018 Reference Case Projected Generation Mix Through 2050

Year	AEO 2018 Reference Case					
	Generation Mix (%)				FFC Factor	
	Coal	Natural Gas	Nuclear	Renewable Sources	Energy	CO_2e (lb/MWh)
2016	30.8	33.4	20.2	15.4	2.79	1,176
2020	30.4	28.9	20.0	21.0	2.68	1,107
2030	29.0	30.9	17.3	23.1	2.62	1,092
2040	26.7	31.7	15.6	26.2	2.53	1,043
2050	25.1	33.3	14.0	26.0	2.48	1,021
	AEO 2018 Clean Power Plan Scenario					
2020	30.4	28.9	20.0	21.1	2.68	1,106
2030	23.9	33.5	18.0	24.8	2.55	998
2040	22.0	33.7	16.3	28.1	2.47	952
2050	19.8	36.0	14.7	27.9	2.41	923

Source: eGRID2016, EIA AEO 2018, SEEAT Analysis

5.2 Natural Gas Combined Cycle + Renewable Power Generation FFC Factors

The AEO 2018 forecast includes a substantial fraction of coal power generation, even in the clean power plan case. As shown in Table 30, the 2016 natural gas generation fraction already exceeds the 2050 AEO reference case projection. Future incremental (marginal) power plants may be predominantly natural gas or renewable (wind or solar). To examine the impact of a scenario in which combinations of natural gas and renewable power generation on marginal or future FFC energy and CO_2e emission factors, a state-of-the-art combined cycle power plant at a net generation annual efficiency of 50% is paired with different fractions of renewable power using the incident energy efficiency approach (100% generation efficiency). Table 31 shows the assumed generation mix and resulting FFC energy and CO_2e emission factors for each scenario.

Table 31 Natural Gas Combined Cycle + Renewable Power Generation Mix FFC Factors

Generation Mix (%)		FFC Factor	
Natural Gas	Renewable Sources	Energy	CO_2e (lb/MWh)
100	0	2.26	1,027
85	15	2.08	873
70	30	1.90	720
55	45	1.71	566
40	60	1.53	409
25	75	1.35	257
10	90	1.17	102
0	100	1.05	0

Source: SEEAT Analysis

6 Energy Price Factors

FFC energy and emission factors in this report use aggregated annual average and marginal values for those metrics. For equivalent economic analyses and comparisons, annual average and marginal energy prices are of interest. Annual values enable a consistent approach to comparisons as well as comparable values for determination of the EEE impacts of baseline and alternative scenarios. Table 32 and Table 33 list the aggregated annual average residential and commercial energy prices for 2016 by state and for the U.S. along with summer and winter aggregated marginal energy prices.

Average energy prices are state-level EIA 2016 annual average data for electricity and natural gas. (https://www.eia.gov/electricity/data/state/) (https://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_a.htm). Marginal prices for natural gas are derived from marginal adjustment factors for summer and winter based on the DOE average data. The marginal price methodology was developed by AGA based on a member company survey of utility rate structures (https://www.aga.org/research/reports/aga-marginal-pricing-methodology-furnace-efficiency-rule/). Marginal pricing factors for electricity were developed by the U.S. Department of Energy. (https://www.regulations.gov/document?D=EERE-2014-BT-STD-0048-0030 with methodology described in https://www.regulations.gov/document?D=EERE-2014-BT-STD-0048-0098).

Table 32 Average and Marginal 2016 Residential Energy Price Factors by State

State	Electricity ($/MMBtu) Average	Electricity ($/MMBtu) Marginal Summer	Electricity ($/MMBtu) Marginal Winter	Natural Gas ($/MMBtu) Average	Natural Gas ($/MMBtu) Marginal Summer	Natural Gas ($/MMBtu) Marginal Winter	Oil ($/MMBtu) Average	Propane ($/MMBtu) Average
AL	35.1	31.2	29.4	13.7	13.2	13.6	16.4	27.6
AK	59.5	61.3	59.0	9.8	7.7	8.9	16.4	22.4
AZ	35.6	35.5	33.1	14.7	8.1	12.2	16.4	22.4
AR	29.1	28.2	26.2	11.0	6.7	9.8	16.4	21.4
CA	51.0	66.3	67.3	11.4	10.2	10.9	16.4	22.4
CO	35.4	34.9	33.1	6.9	4.3	5.9	16.4	20.8
CT	58.6	59.0	57.6	12.6	8.0	11.3	17.2	28.8
DE	39.3	38.0	35.4	11.4	7.3	10.4	16.9	30.5
DC	36.0	34.8	32.5	10.4	7.8	9.7	16.9	22.4
FL	32.2	29.6	29.3	19.8	14.3	16.3	15.7	51.7
GA	33.7	32.7	30.1	14.1	13.8	14.0	15.6	22.0
HI	80.5	88.6	87.7	37.2	33.2	33.5	16.4	22.4
ID	29.2	28.9	27.1	7.8	5.3	7.2	16.4	24.0
IL	36.7	34.8	33.7	7.6	5.0	6.7	14.0	15.1
IN	34.6	33.0	32.0	7.6	4.9	6.8	14.3	19.3
IA	35.0	33.1	31.0	7.7	4.7	6.7	12.5	11.3
KS	38.3	35.6	32.9	9.5	5.4	8.1	14.0	13.0
KY	30.7	27.3	25.7	9.8	4.8	8.3	13.7	20.0
LA	27.4	26.5	24.6	11.1	6.2	8.9	16.4	22.4
ME	46.4	46.7	45.6	13.5	3.7	10.9	14.1	24.7
MD	41.7	40.3	37.6	11.0	7.2	9.9	17.1	29.6
MA	55.7	54.7	53.3	12.1	10.7	11.7	16.6	31.8
MI	44.6	43.2	41.9	7.9	5.5	7.2	14.1	19.2
MN	37.1	35.2	32.9	7.7	5.5	7.1	13.3	14.3
MS	30.7	27.2	25.7	9.8	6.8	8.8	16.4	21.8
MO	32.9	30.4	27.9	10.7	4.5	8.6	14.0	15.0
MT	32.1	31.7	29.8	7.0	5.4	6.4	16.4	18.3
NE	31.8	29.5	27.3	7.6	4.7	6.6	12.8	11.4
NV	33.4	33.9	31.7	9.8	5.0	8.0	16.4	22.4
NH	53.9	54.2	52.9	13.8	7.0	11.4	15.3	33.8
NJ	46.1	46.2	44.4	8.0	6.4	7.6	17.1	36.0
NM	35.3	35.7	33.4	7.7	4.6	6.6	16.4	22.4
NY	51.5	50.5	49.2	10.5	5.4	8.7	18.5	28.1
NC	32.3	31.3	29.0	10.9	6.5	9.8	15.6	26.4
ND	29.8	28.2	26.4	6.7	2.8	5.3	14.0	11.5
OH	36.5	34.9	33.8	8.4	3.0	6.6	13.9	24.1
OK	29.9	29.0	26.9	10.1	6.2	8.3	14.0	16.8
OR	31.2	31.4	30.9	11.0	8.3	10.1	16.4	22.4
PA	40.6	40.7	39.2	9.8	6.7	8.9	14.4	30.1
RI	54.6	54.9	53.6	13.4	9.7	12.2	16.7	37.2
SC	37.1	35.9	33.2	12.3	7.3	10.9	15.7	22.4
SD	33.6	31.8	29.8	7.2	4.9	6.5	14.0	12.2
TN	30.5	26.8	25.4	8.9	5.5	8.0	14.0	33.8
TX	32.2	30.8	30.1	11.4	5.6	8.9	16.4	23.5
UT	32.3	32.0	30.0	8.8	6.4	8.2	16.4	26.4
VT	50.9	51.2	50.0	13.8	8.7	12.1	14.5	35.5
VA	33.3	31.9	29.5	10.3	6.6	9.2	15.7	30.1
WA	27.8	27.9	27.4	10.0	7.7	9.2	16.4	22.4
WV	33.5	34.1	32.2	8.4	5.7	7.7	15.7	22.4
WI	41.2	39.3	37.9	7.8	4.6	6.9	14.0	13.8
WY	32.6	32.3	30.3	7.9	5.6	7.0	16.4	22.4
U.S.	**36.8**	**36.0**	**34.2**	**9.7**	**6.5**	**8.6**	**16.4**	**22.5**

Source: EIA, DOE EERE, AGA

Table 33 Average and Marginal 2016 Commercial Energy Price Factors by State

State	Electricity ($/MMBtu)			Natural Gas ($/MMBtu)			Oil ($/MMBtu)	Propane ($/MMBtu)
	Average	Marginal		Average	Marginal			
		Summer	Winter		Summer	Winter	Average	Average
AL	32.6	28.9	27.2	10.3	9.9	10.2	14.7	24.9
AK	51.5	53.1	51.0	8.3	6.5	7.6	14.7	20.3
AZ	30.5	30.4	28.3	8.5	4.7	7.1	14.7	20.3
AR	24.1	23.4	21.7	7.0	4.3	6.2	14.7	19.3
CA	44.2	57.5	58.3	8.1	7.2	7.7	14.7	20.3
CO	28.1	27.8	26.3	6.0	3.7	5.1	14.7	18.7
CT	46.2	46.4	45.3	8.6	5.4	7.7	15.4	25.9
DE	29.5	28.5	26.6	9.2	5.9	8.4	15.3	27.5
DC	34.3	33.2	30.9	9.5	7.1	8.9	15.2	20.3
FL	26.1	24.0	23.8	10.2	7.3	8.4	14.1	46.5
GA	28.7	27.9	25.7	7.7	7.6	7.6	14.1	19.8
HI	72.2	79.5	78.7	27.5	24.5	24.8	14.7	20.3
ID	22.7	22.5	21.1	6.9	4.7	6.3	14.7	21.6
IL	26.4	25.0	24.2	6.9	4.6	6.1	12.6	13.6
IN	29.3	28.0	27.1	6.3	4.0	5.6	12.9	17.3
IA	26.9	25.4	23.8	5.7	3.5	5.0	11.3	10.1
KS	38.3	35.6	32.9	8.1	4.6	6.9	12.6	11.7
KY	28.0	24.9	23.4	7.7	3.8	6.5	12.3	18.0
LA	25.2	24.4	22.7	7.7	4.3	6.2	14.7	20.3
ME	35.4	35.6	34.8	10.4	2.9	8.4	12.7	22.2
MD	32.2	31.1	29.0	8.5	5.6	7.7	15.4	26.6
MA	45.7	44.9	43.8	9.2	8.1	8.9	14.9	28.6
MI	31.2	30.2	29.3	6.6	4.6	6.0	12.7	17.3
MN	28.9	27.4	25.6	6.2	4.4	5.7	12.0	12.9
MS	28.0	24.9	23.4	7.6	5.3	6.8	14.7	19.6
MO	27.1	25.1	23.0	7.7	3.2	6.2	12.6	13.5
MT	29.9	29.6	27.7	6.9	5.3	6.3	14.7	16.4
NE	25.8	24.0	22.2	5.1	3.2	4.4	11.5	10.3
NV	23.2	23.6	22.0	6.6	3.4	5.4	14.7	20.3
NH	42.3	42.5	41.5	11.0	5.6	9.1	13.8	30.4
NJ	35.9	36.0	34.6	7.6	6.1	7.2	15.4	32.4
NM	28.6	29.0	27.1	5.4	3.2	4.6	14.7	20.3
NY	13.0	12.8	12.5	6.0	3.1	4.9	16.6	25.4
NC	25.3	24.5	22.6	7.4	4.4	6.7	14.1	23.8
ND	26.8	25.4	23.8	5.0	2.1	4.0	12.6	10.4
OH	36.5	34.9	33.8	5.4	2.0	4.2	12.5	21.7
OK	22.4	21.8	20.2	7.4	4.6	6.0	12.6	15.1
OR	26.1	26.3	25.8	8.8	6.7	8.1	14.7	20.3
PA	27.0	27.0	26.0	7.8	5.3	7.1	13.0	27.2
RI	43.6	43.9	42.8	10.8	7.8	9.8	15.1	33.5
SC	30.1	29.2	27.0	8.2	4.8	7.3	14.1	20.3
SD	28.1	26.6	24.9	5.3	3.6	4.8	12.6	10.9
TN	29.9	26.3	24.9	7.6	4.7	6.8	12.6	30.4
TX	24.2	23.1	22.7	6.7	3.3	5.2	14.7	21.2
UT	25.6	25.4	23.8	7.1	5.2	6.6	14.7	23.8
VT	42.6	42.9	41.8	6.5	4.1	5.7	13.1	32.0
VA	23.2	22.3	20.6	6.9	4.4	6.2	14.1	27.2
WA	24.7	24.9	24.4	7.9	6.1	7.2	14.7	20.3
WV	27.4	27.9	26.3	7.1	4.8	6.5	14.1	20.3
WI	31.6	30.0	29.0	6.1	3.6	5.4	12.6	12.4
WY	27.5	27.3	25.6	6.1	4.3	5.4	14.7	20.3
U.S.	**30.6**	**29.9**	**28.5**	**7.0**	**4.7**	**6.2**	**14.7**	**20.3**

Source: EIA, DOE EERE, AGA

7 Energy, Emissions, and Economic Impacts

7.1 Balancing Metrics to Meet Multiple Objectives

Measuring and comparing technology and building energy performance equitably with minimum unintended consequences has been challenging for decades. In order to provide economic and societal benefits with minimum unintended consequences, energy performance indicators and related energy management initiatives would benefit from metrics, methods, and values that are technically defensible, useable, easy to adopt, and enforceable. Balancing metrics, methodologies, and values for determining and comparing energy performance is a key issue for providing equitable comparisons of different energy forms that can be used for the same energy services. With an increased focus on environmental impacts, a single performance metric that may be suitable for one economic or societal objective may be unsuitable or misleading when trying to achieve another economic or societal objective.

Building energy performance comparisons can include economics, resources, and environmental impacts associated with the time and location of the energy delivery. Each of these impacts can give rise to metrics that are complicated and can give contradictory advice for building applications, which will be increasingly important as the electric grid decarbonizes and if natural gas prices remain low, as is currently projected in the U.S. If possible, comparative metrics, methodologies, and values should allow the user a choice of perspectives in discussions with other stakeholders and ultimately in making energy management and policy decisions.

Energy cost is likely to be the metric of most interest to consumers and other stakeholders concerning energy tradeoffs. Energy cost calculations have often led to similar results compared to FFC energy, although results are starting to diverge as natural gas prices have declined while its FFC energy and GHG emission profiles have been stable. Electricity is becoming more expensive relative to natural gas even as electricity's FFC energy use and GHG emissions profiles have been improving for the past decade. Energy cost may not correlate well with GHG emissions profiles in the future. Annual energy cost also does not deal adequately with renewable power options such as on-site photovoltaics, whose installed cost is relatively high but whose annual energy cost, primary energy use, and GHG emissions are either very low or zero. Life cycle cost calculations may be helpful in that case, but economic parameters, in general, are not sufficient to address the societal and environmental benefits of renewable technologies. As a result, annual energy costs can be misleading or inadequate to address environmental issues and other life cycle factors.

FFC energy addresses the resource impacts of building energy consumption. FFC energy use is gaining recognition because it is relatively stable and historically has been well-aligned with GHG emissions and energy costs. But not all primary energy forms are equivalent. Primary energy use of nuclear power is not the same as coal, natural gas, solar, wind or hydropower. Because of these inherent differences, FFC energy use may be incomplete or misleading if it is the sole measure of building energy performance. Additional metrics such as energy cost, GHG emissions, or life cycle parameters are likely to be needed to address economic and environmental impacts of FFC energy use depending on the objectives of the standard or initiative.

The GHG emissions metric aligns with climate change goals, but is insensitive to FFC energy use, installed costs, and energy costs. Reliance solely on a GHG emissions metric would significantly skew decisions as well. Technology options with high initial costs such as solar panels that have zero GHG emissions would be strongly incentivized over lower cost alternatives that reduce GHG emissions but don't eliminate them, such as replacing a less efficient gas furnace with a higher efficiency option. Technologies with no GHG emissions but relatively low FFC energy efficiency such as nuclear power would be strongly incentivized over highly efficient combined cycle natural gas power plants. A balanced approach to evaluating energy performance would help address these limitations.

7.2 EEE Impacts of Building Energy Performance

A 2019 ASHRAE Conference Paper entitled "Energy, Emissions and Economics (EEE) Impact Derivation and Applications for Energy Performance Calculations and Comparisons" (AT-2019-C053) provides background information and elements of the EEE impacts concept. The EEE impacts methodology provides a framework for the equitable treatment of all technologies that provide the same energy service (e.g., electric, gas, or solar water heaters) based on their weighted and aggregated impact on the metrics of choice to determine overall performance for decisions and comparisons. The EEE framework includes four key elements:

- Metrics,
- Equivalency Factors,
- Weighting Factors, and
- Baseline.

Each of these elements involves options and a set of decisions by the agency promulgating the energy code, standard, or another initiative to help it achieve its primary intent equitably with minimum unintended consequences. The EEE Impacts framework provides a comparison of the EEE Index Score for the alternative scenario relative to the baseline which, by definition in the framework, has an EEE Index Score of 100. A higher score indicates worse performance; a lower score indicates better performance compared to the baseline.

Conceptually, a wide range of metrics can be included in the EEE Impacts framework as long as reasonable equivalency factors compared to the baseline can be determined for each metric. A single baseline for comparisons and policy choices for weighting factors among metrics are critical elements for application of the EEE impacts framework. To illustrate the EEE framework, the sample calculations in this report uses FFC energy use, CO_2e emissions, and average or marginal energy price per unit of site energy consumption.

8 FFC Energy, Emissions, and Economics Sample Calculations

Site energy consumption by energy form for each energy consuming device and for the whole building forms the basis of the FFC energy and emissions calculation methodology in SEEAT 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 FFC energy and emission calculations as well as marginal analysis of incremental changes in consumption by fuel type.

The following sample calculations illustrate the application of the SEEAT methodology to compare the annual FFC energy, pollutant emissions, and energy costs of electric and gas technology options. The average, marginal and forecast calculations compare an electric water heater with an energy factor (EF) of 0.95 and a natural gas water heater with an EF of 0.62 for a fixed annual domestic hot water service load of 12.4 MMBtu. Resulting site energy consumption for these calculations is 3,828 kWh (13.05 MMBtu) for the electric water heater, and 200 therms (20.0 MMBtu) for the gas water heater. Based on these values for site energy consumption, FFC energy consumption and associated emissions are presented for eGRID sub-regions and the U.S. using average and non-baseload factors for electricity and average factors for natural gas. Forecasted electricity grid mix and renewable natural gas scenarios are provided based on U.S. average energy and price factors and U.S. marginal price factors. EEE Impacts scenarios are provided for a whole house energy use comparison with an electric heat pump and resistance water heating, cooking, and clothes drying compared to a gas furnace, storage water heater, cooking, and clothes drying, based on California average FFC energy, CO_2e emissions, and energy price factors.

The sample calculations illustrate the economic and societal benefit of optimizing the use of the nation's primary energy sources associated with building operation. While there is no single best choice for all situations, 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 GHG and other pollutant emissions, along with consumer energy costs.

8.1 Average and Marginal (Non-Baseload) FFC Energy Calculations

Table 34 shows the FFC energy consumption comparison based on electricity and natural gas site energy consumption, calculated using eGRID sub- region and U.S. average FFC energy factors for all power plants. Table 35 shows similar calculations for non-baseload power plants

The results of the regional and national comparison indicate that the FFC energy consumption of the gas water heater was always less than the electric water heater, but the savings varied significantly depending on the electricity generation mix in the eGRID sub-region, and whether the analysis used average generation mix or non-baseload (marginal) generation data.

Based on all power plants (average overall generation mix), the savings from the gas water heater ranged from 13 to 52 percent in the eGRID sub-regions, while for the U.S. average generation mix, the difference was 40 percent. The variability in regional average savings is primarily due to the impact of hydropower and other non-combustible renewable power generation, which is assumed to have 100% conversion efficiency in these calculations.

Based on non-baseload power plants (marginal generation mix), the FFC energy savings from the gas water heater were always significant, ranging from 38 to 59 percent across the eGRID sub-regions. The variability in savings was much less than the average generation mix case because the non-baseload power will nearly always be fossil fuel.

8.2 Average and Marginal (Non-Baseload) Pollutant Emission Calculations

Table 36 compares corresponding pollutant emissions using eGRID sub- region and U.S. average FFC energy factors for all power plants. Table 37 shows similar calculations for non-baseload power plants. Table 38 summarizes the pollutant emission savings of the natural gas water heater compared to the electric water heater using eGRID sub- region and U.S. average FFC energy factors for all power plants. Table 39 shows similar savings calculations for non-baseload power plants.

Based on all power plants (average overall generation mix), CO_2e emissions from the gas water heater were also lower than the electric water heater for the U.S. average and in all but five eGRID sub-regions that are dominated by renewable or nuclear power generation. The variability was wider than the FFC energy consumption, ranging from a 99 percent increase to 61 percent reduction across eGRID sub-regions, with the U.S. average reduction of 34 percent. SO_2 and NOx emission reductions varied from 37 percent to 98 percent reduction for SO_2 and an 200 percent increase to 90 percent reduction for NOx across eGRID sub-regions. The U.S. average reduction was 84 percent for SO_2 and 12 percent for NOx. The variability in regional average CO_2e savings is primarily due to the impact of hydropower and nuclear power, both of which have essentially no pollutant emissions. The variability in average NOx emissions illustrates the impact of electric regional criteria pollutant emission reduction initiatives.

Based on marginal (non-baseload) power plants, pollutant emissions from the gas water heater were significantly lower than the electric water heater in all 26 eGRID sub-regions. CO_2e emissions savings ranged from 37 percent to 67 percent across the eGRID sub-regions. The variability in savings was much less than the average generation mix case because the non-baseload power will nearly always be fossil fuel. Corresponding SO_2 and NOx emission reductions ranged from 37 to 99 percent for SO_2 and 12 to 97 percent for NOx across eGRID sub-regions.

Table 34 FFC Energy Comparison, eGRID Sub-Regions and U.S., All Power Plants

eGRID 2016 Sub-region Acronym	eGRID 2016 Sub-region Name	FFC Energy		FFC Energy Savings	
		Electric WH (MMBtu)	Gas WH (MMBtu)	Gas WH savings (MMBtu)	Gas WH savings (%)
AKGD	ASCC Alaska Grid	36.4	21.8	14.6	40%
AKMS	ASCC Miscellaneous	25.2	21.8	3.4	13%
ERCT	ERCOT All	33.8	21.8	12.0	36%
FRCC	FRCC All	37.2	21.8	15.4	41%
HIMS	HICC Miscellaneous	36.7	21.8	14.9	41%
HIOA	HICC Oahu	45.4	21.8	23.6	52%
MROE	MRO East	39.8	21.8	18.0	45%
MROW	MRO West	35.5	21.8	13.7	39%
NYLI	NPCC Long Island	43.7	21.8	21.9	50%
NEWE	NPCC New England	36.9	21.8	15.1	41%
NYCW	NPCC NYC/Westchester	38.2	21.8	16.4	43%
NYUP	NPCC Upstate NY	29.6	21.8	7.8	26%
RFCE	RFC East	39.7	21.8	17.9	45%
RFCM	RFC Michigan	39.4	21.8	17.6	45%
RFCW	RFC West	40.6	21.8	18.8	46%
SRMW	SERC Midwest	41.2	21.8	19.4	47%
SRMV	SERC Mississippi Valley	36.4	21.8	14.6	40%
SRSO	SERC South	37.9	21.8	16.1	42%
SRTV	SERC Tennessee Valley	39.2	21.8	17.4	44%
SRVC	SERC Virginia/Carolina	39.7	21.8	17.9	45%
SPNO	SPP North	38.0	21.8	16.2	43%
SPSO	SPP South	34.1	21.8	12.3	36%
CAMX	WECC California	27.7	21.8	5.9	21%
NWPP	WECC Northwest	25.1	21.8	3.3	13%
RMPA	WECC Rockies	34.3	21.8	12.5	36%
AZNM	WECC Southwest	37.1	21.8	15.3	41%
US Average		**36.4**	**21.8**	**14.6**	**40%**

Source: SEEAT Version 8.2

Table 35 FFC Energy Comparison, eGRID Sub-Regions, Non-Baseload Power Plants

eGRID 2016 Sub-region Acronym	eGRID 2016 Sub-region Name	FFC Energy		FFC Energy Savings	
		Electric WH (MMBtu)	Gas WH (MMBtu)	Gas WH savings (MMBtu)	Gas WH savings (%)
AKGD	ASCC Alaska Grid	45.0	21.8	23.2	52%
AKMS	ASCC Miscellaneous	45.7	21.8	23.9	52%
ERCT	ERCOT All	36.9	21.8	15.1	41%
FRCC	FRCC All	36.5	21.8	14.7	40%
HIMS	HICC Miscellaneous	53.5	21.8	31.7	59%
HIOA	HICC Oahu	48.2	21.8	26.4	55%
MROE	MRO East	40.6	21.8	18.8	46%
MROW	MRO West	42.4	21.8	20.6	49%
NYLI	NPCC Long Island	47.5	21.8	25.7	54%
NEWE	NPCC New England	36.8	21.8	15.0	41%
NYCW	NPCC NYC/Westchester	39.0	21.8	17.2	44%
NYUP	NPCC Upstate NY	35.9	21.8	14.1	39%
RFCE	RFC East	40.5	21.8	18.7	46%
RFCM	RFC Michigan	43.6	21.8	21.8	50%
RFCW	RFC West	42.7	21.8	20.9	49%
SRMW	SERC Midwest	41.8	21.8	20.0	48%
SRMV	SERC Mississippi Valley	35.6	21.8	13.8	39%
SRSO	SERC South	38.2	21.8	16.4	43%
SRTV	SERC Tennessee Valley	41.1	21.8	19.3	47%
SRVC	SERC Virginia/Carolina	38.1	21.8	16.3	43%
SPNO	SPP North	45.6	21.8	23.8	52%
SPSO	SPP South	43.3	21.8	21.5	50%
CAMX	WECC California	35.0	21.8	13.2	38%
NWPP	WECC Northwest	39.7	21.8	17.9	45%
RMPA	WECC Rockies	41.9	21.8	20.1	48%
AZNM	WECC Southwest	38.2	21.8	16.4	43%

Source: SEEAT Version 8.2

Table 36 Pollutant Emissions Comparison, eGRID Sub-Regions and U.S., All Power Plants

	eGRID 2016 Sub-region Acronym	eGRID 2016 Sub-region Name	CO_2 emissions (lbs)	SO_2 emissions (lbs)	NO_x emissions (lbs)	CH_4 emissions (lbs)	NO_2 emissions (lbs)	CO_2e emissions (lbs)
Electric Water Heater	AKGD	ASCC Alaska Grid	4,649	3.3	27.4	13.9	0.04	5,050
	AKMS	ASCC Miscellaneous	2,367	3.2	30.1	4.8	0.02	2,508
	ERCT	ERCOT All	4,290	4.9	3.2	11.7	0.05	4,632
	FRCC	FRCC All	4,172	2.3	3.1	11.5	0.04	4,505
	HIMS	HICC Miscellaneous	5,127	20.7	34.8	7.1	0.08	5,348
	HIOA	HICC Oahu	7,412	37.9	15.5	10.2	0.11	7,727
	MROE	MRO East	7,027	6.0	4.8	12.1	0.10	7,392
	MROW	MRO West	5,126	6.3	4.9	9.7	0.07	5,418
	NYLI	NPCC Long Island	5,162	2.6	4.4	17.2	0.06	5,660
	NEWE	NPCC New England	2,560	1.8	2.1	8.1	0.05	2,801
	NYCW	NPCC NYC/Westchester	2,887	0.9	2.1	10.6	0.01	3,186
	NYUP	NPCC Upstate NY	1,370	1.8	1.1	4.5	0.01	1,498
	RFCE	RFC East	3,332	3.1	3.1	8.0	0.03	3,565
	RFCM	RFC Michigan	5,289	7.8	4.2	10.3	0.07	5,593
	RFCW	RFC West	5,209	5.4	4.5	8.2	0.07	5,456
	SRMW	SERC Midwest	6,687	9.6	5.5	10.5	0.12	7,013
	SRMV	SERC Mississippi Valley	3,657	3.5	4.6	11.1	0.03	3,975
	SRSO	SERC South	4,623	2.0	3.3	10.7	0.06	4,939
	SRTV	SERC Tennessee Valley	4,936	4.6	3.7	8.2	0.06	5,181
	SRVC	SERC Virginia/Carolina	3,460	2.0	2.7	7.2	0.04	3,673
	SPNO	SPP North	5,815	2.4	4.0	10.1	0.08	6,119
	SPSO	SPP South	5,033	7.2	4.5	12.5	0.05	5,397
	CAMX	WECC California	2,253	1.1	2.6	7.6	0.02	2,471
	NWPP	WECC Northwest	2,698	2.1	2.8	5.1	0.03	2,850
	RMPA	WECC Rockies	5,583	3.1	4.9	10.5	0.07	5,895
	AZNM	WECC Southwest	4,400	1.7	4.8	9.9	0.05	4,690
	US Average		**4,216**	**3.7**	**3.9**	**9.8**	**0.05**	**4,502**
Gas Water Heater			**2,605**	**0.6**	**3.4**	**13.0**	**0.06**	**2,983**

Source: SEEAT Version 8.2

Table 37 Pollutant Emissions Comparison, eGRID Sub-Regions, Non-Baseload Power Plants

	eGRID 2012 Sub-region Acronym	eGRID 2012 Sub-region Name	CO_2 emissions (lbs)	SO_2 emissions (lbs)	NO_x emissions (lbs)	CH_4 emissions (lbs)	N_2O emissions (lbs)	CO_2e emissions (lbs)
Electric Water Heater	AKGD	ASCC Alaska Grid	5,739	3	27	19	0.03	6,284
	AKMS	ASCC Miscellaneous	7,179	11	105	12	0.05	7,523
	ERCT	ERCOT All	5,754	6	5	16	0.06	6,218
	FRCC	FRCC All	5,142	2	4	14	0.04	5,549
	HIMS	HICC Miscellaneous	8,733	57	50	11	0.12	9,076
	HIOA	HICC Oahu	7,188	32	22	9	0.10	7,479
	MROE	MRO East	6,651	6	5	14	0.07	7,076
	MROW	MRO West	7,595	9	8	16	0.11	8,069
	NYLI	NPCC Long Island	5,837	3	6	21	0.02	6,417
	NEWE	NPCC New England	4,695	2	4	14	0.06	5,095
	NYCW	NPCC NYC/Westchester	4,679	1	4	18	0.01	5,172
	NYUP	NPCC Upstate NY	4,621	4	5	14	0.03	5,036
	RFCE	RFC East	6,061	6	6	14	0.06	6,476
	RFCM	RFC Michigan	7,591	10	7	15	0.09	8,022
	RFCW	RFC West	7,801	9	7	13	0.09	8,185
	SRMW	SERC Midwest	7,917	12	6	13	0.13	8,329
	SRMV	SERC Mississippi Valley	4,919	5	6	15	0.03	5,349
	SRSO	SERC South	5,968	3	5	14	0.07	6,379
	SRTV	SERC Tennessee Valley	7,267	8	6	12	0.10	7,642
	SRVC	SERC Virginia/Carolina	5,973	3	5	13	0.07	6,350
	SPNO	SPP North	8,486	6	8	16	0.11	8,959
	SPSO	SPP South	6,879	10	7	18	0.06	7,386
	CAMX	WECC California	4,303	1	5	15	0.02	4,726
	NWPP	WECC Northwest	6,486	5	8	14	0.07	6,884
	RMPA	WECC Rockies	7,236	4	7	15	0.09	7,681
	AZNM	WECC Southwest	6,029	2	6	14	0.05	6,448
Gas Water Heater			**2,605**	**0.6**	**3.4**	**13.0**	**0.06**	**2,983**

Source: SEEAT Version 8.2

Table 38 Gas Water Heater Emissions Savings, eGRID Sub-Regions and U.S., All Power Plants

eGRID 2016 Sub-region Acronym	eGRID 2016 Sub-region Name	CO_2 emissions reduction		SO_2 emissions reduction		NO_x emissions reduction		CH_4 emissions reduction		NO_2 emissions reduction		CO_2e emissions reduction	
		lbs	%	lbs	%	lbs	%	lbs	%	lbs	%	lbs	%
AKGD	ASCC Alaska Grid	2,045	44%	2.8	83%	23.9	87%	0.9	6%	-0.018	-42%	2,067	41%
AKMS	ASCC Miscellaneous	-238	-10%	2.6	82%	26.6	89%	-8.2	-171%	-0.037	-161%	-475	-19%
ERCT	ERCOT All	1,686	39%	4.3	88%	-0.2	-7%	-1.3	-11%	-0.010	-21%	1,649	36%
FRCC	FRCC All	1,567	38%	1.7	75%	-0.4	-12%	-1.5	-13%	-0.022	-57%	1,521	34%
HIMS	HICC Miscellaneous	2,522	49%	20.1	97%	31.4	90%	-5.9	-82%	0.020	25%	2,364	44%
HIOA	HICC Oahu	4,807	65%	37.3	98%	12.1	78%	-2.9	-28%	0.055	48%	4,744	61%
MROE	MRO East	4,422	63%	5.4	90%	1.3	28%	-0.9	-7%	0.036	37%	4,409	60%
MROW	MRO West	2,521	49%	5.7	91%	1.4	29%	-3.3	-34%	0.013	18%	2,434	45%
NYLI	NPCC Long Island	2,557	50%	2.0	78%	0.9	21%	4.2	24%	0.001	2%	2,676	47%
NEWE	NPCC New England	-44	-2%	1.2	67%	-1.4	-66%	-4.9	-60%	-0.010	-21%	-182	-7%
NYCW	NPCC NYC/Westchester	282	10%	0.3	37%	-1.4	-66%	-2.5	-23%	-0.049	-422%	202	6%
NYUP	NPCC Upstate NY	-1,235	-90%	1.2	67%	-2.3	-200%	-8.6	-192%	-0.049	-422%	-1,485	-99%
RFCE	RFC East	727	22%	2.6	82%	-0.4	-12%	-5.1	-64%	-0.026	-74%	581	16%
RFCM	RFC Michigan	2,684	51%	7.3	93%	0.8	18%	-2.8	-27%	0.005	8%	2,610	47%
RFCW	RFC West	2,604	50%	4.9	89%	1.0	23%	-4.8	-59%	0.009	13%	2,473	45%
SRMW	SERC Midwest	4,083	61%	9.0	94%	2.0	37%	-2.5	-24%	0.062	51%	4,030	57%
SRMV	SERC Mississippi Valley	1,052	29%	2.9	84%	1.2	26%	-1.9	-17%	-0.033	-124%	991	25%
SRSO	SERC South	2,018	44%	1.4	71%	-0.2	-6%	-2.3	-21%	0.001	2%	1,956	40%
SRTV	SERC Tennessee Valley	2,331	47%	4.0	87%	0.2	6%	-4.8	-59%	0.001	2%	2,198	42%
SRVC	SERC Virginia/Carolina	856	25%	1.4	70%	-0.8	-28%	-5.8	-81%	-0.018	-42%	690	19%
SPNO	SPP North	3,211	55%	1.8	76%	0.6	14%	-2.9	-29%	0.017	22%	3,136	51%
SPSO	SPP South	2,428	48%	6.6	92%	1.0	23%	-0.5	-4%	-0.010	-21%	2,413	45%
CAMX	WECC California	-352	-16%	0.6	49%	-0.8	-32%	-5.4	-71%	-0.045	-292%	-512	-21%
NWPP	WECC Northwest	93	3%	1.6	73%	-0.7	-25%	-7.9	-153%	-0.026	-74%	-133	-5%
RMPA	WECC Rockies	2,978	53%	2.5	81%	1.4	29%	-2.6	-25%	0.013	18%	2,912	49%
AZNM	WECC Southwest	1,795	41%	1.1	66%	1.3	28%	-3.1	-31%	-0.014	-31%	1,706	36%
US Average		**1,611**	**38%**	**3.1**	**84%**	**0.5**	**12%**	**-3.3**	**-33%**	**-0.010**	**-21%**	**1,519**	**34%**

Source: SEEAT Version 8.2

Table 39 Gas Water Heater Emissions Savings, eGRID Sub-Regions, Non-Baseload Power Plants

eGRID 2016 Sub-region Acronym	eGRID 2016 Sub-region Name	CO_2 emissions reduction		SO_2 emissions reduction		NO_x emissions reduction		CH_4 emissions reduction		NO_2 emissions reduction		CO_2e emissions reduction	
		lbs	%	lbs	%	lbs	%	lbs	%	lbs	%	lbs	%
AKGD	ASCC Alaska Grid	3,134	55%	2.2	79%	23.7	87%	6.1	32%	-0.026	-74%	3,301	53%
AKMS	ASCC Miscellaneous	4,574	64%	10.3	95%	101.5	97%	-1.2	-10%	0.050	100%	4,539	60%
ERCT	ERCOT All	3,149	55%	5.4	90%	1.2	25%	3.0	19%	0.061	100%	3,235	52%
FRCC	FRCC All	2,537	49%	1.8	76%	0.7	17%	1.1	8%	0.038	100%	2,565	46%
HIMS	HICC Miscellaneous	6,128	70%	56.0	99%	46.6	93%	-1.9	-17%	0.119	100%	6,093	67%
HIOA	HICC Oahu	4,583	64%	31.5	98%	18.4	84%	-3.6	-38%	0.103	100%	4,496	60%
MROE	MRO East	4,047	61%	5.0	90%	1.6	32%	1.5	10%	0.073	100%	4,093	58%
MROW	MRO West	4,990	66%	8.2	93%	4.5	57%	2.9	18%	0.111	100%	5,086	63%
NYLI	NPCC Long Island	3,232	55%	2.1	78%	2.1	38%	7.6	37%	0.015	100%	3,434	54%
NEWE	NPCC New England	2,090	45%	1.4	71%	0.7	18%	0.7	5%	0.057	100%	2,111	41%
NYCW	NPCC NYC/Westchester	2,074	44%	0.4	42%	0.5	12%	4.5	26%	0.008	100%	2,189	42%
NYUP	NPCC Upstate NY	2,017	44%	3.3	85%	1.5	30%	1.5	10%	0.034	100%	2,053	41%
RFCE	RFC East	3,456	57%	5.3	90%	2.8	45%	1.3	9%	0.057	100%	3,493	54%
RFCM	RFC Michigan	4,986	66%	9.8	94%	3.1	47%	1.5	10%	0.088	100%	5,039	63%
RFCW	RFC West	5,196	67%	8.9	94%	3.5	51%	-0.2	-1%	0.092	100%	5,202	64%
SRMW	SERC Midwest	5,312	67%	11.7	95%	3.0	47%	0.4	3%	0.134	100%	5,346	64%
SRMV	SERC Mississippi Valley	2,314	47%	3.9	87%	3.0	47%	2.1	14%	0.031	100%	2,366	44%
SRSO	SERC South	3,363	56%	2.8	83%	1.1	24%	1.0	7%	0.073	100%	3,396	53%
SRTV	SERC Tennessee Valley	4,662	64%	7.2	92%	2.3	40%	-0.6	-4%	0.100	100%	4,659	61%
SRVC	SERC Virginia/Carolina	3,368	56%	2.6	82%	1.1	24%	-0.2	-1%	0.065	100%	3,367	53%
SPNO	SPP North	5,881	69%	5.5	91%	4.9	59%	2.9	18%	0.107	100%	5,976	67%
SPSO	SPP South	4,274	62%	9.5	94%	3.7	52%	4.5	26%	0.061	100%	4,403	60%
CAMX	WECC California	1,699	39%	0.3	37%	1.3	27%	1.9	13%	0.019	100%	1,742	37%
NWPP	WECC Northwest	3,881	60%	4.1	87%	4.5	57%	0.5	4%	0.073	100%	3,901	57%
RMPA	WECC Rockies	4,631	64%	3.4	85%	3.1	47%	2.0	13%	0.092	100%	4,698	61%
AZNM	WECC Southwest	3,424	57%	1.5	72%	3.0	47%	1.5	10%	0.054	100%	3,465	54%

Source: SEEAT Version 8.2

8.3 Forecast and RNG Scenario Sample Calculations

Table 40 and Table 41 provide results for the water heater comparison under several forecast scenarios using average and marginal price factors:

- AEO 2018 Reference Case for year 2030,
- AEO 2018 Clean Power Plan scenario for year 2030,
- Natural gas combined cycle power plant (85% of mix) coupled with renewable power generation (15% of mix) for year 2016, and
- 10% Renewable Natural Gas for power generation and building use for year 2016.

Table 40 2030 Projected and RNG Scenarios Water Heater Comparison

U.S. Average Scenario	Electric Water Heater (3,828 kWh)				Gas Water Heater (200 therms)			
	FFC Energy (MMBtu)	CO_2e emissions (lbs)	Average Cost ($)	Marginal Cost ($)	FFC Energy (MMBtu)	CO_2e emissions (lbs)	Average Cost ($)	Marginal Cost ($)
eGRID2016	36.4	4,502	480	447	21.8	2,983	194	172
2030 Ref. Case	34.2	4,177	511	476	21.8	2,983	221	196
2030 CPP	33.3	3,818	537	500	21.8	2,983	246	218
85% NGCC	27.1	3,341	480	447	21.8	2,983	256	227
10% RNG	35.9	4,384	523	486	22.3	2,760	245	217

Source: SEEAT Version 8.2

Table 41 2030 Projected and RNG Scenarios Gas Water Heater Savings

U.S. Average Scenario	Gas Water Heater Savings							
	FFC Energy		CO_2e emissions		Average Cost		Marginal Cost	
	MMBtu	%	lb	%	$	%	$	%
eGRID2016	14.6	40.1	1,519	33.7	286	59.6	275	61.5
2030 Ref. Case	12.4	36.3	1,194	28.6	290	56.7	280	58.8
2030 CPP	11.5	34.5	835	21.9	292	54.3	282	56.4
85% NGCC	5.3	19.7	358	10.7	224	46.7	220	49.2
10% RNG	13.6	37.9	1,624	37.0	278	53.2	270	55.4

Source: SEEAT Version 8.2

As shown in these scenarios, the underlying assumptions about each parameter can change the result significantly. Also of note is the difference in the amount and percent savings across metrics for the same scenario. This combined influence on results is expected to increase in the future as additional renewable resources are added to the electric grid, the natural gas supply, and the building.

8.4 EEE Impact Sample Calculations

California's electric power generation mix and energy prices provide a good data set to illustrate the impact of the EEE framework on building energy performance results. California has a relatively energy efficient, low emission electric grid compared to the rest of the U.S. due to renewable power and natural gas generation. In contrast, California's electricity prices are high compared to national average prices. In this example, an efficient all-electric home in Sacramento, CA is compared to a similar home with natural gas appliances for heating, water heating, range, and clothes dryer. In this scenario, total annual site energy use is assumed to be 15,345 kWh for the electric home, and 7,311 kWh electricity and 54.2 MBtu (15,885 kWh) natural gas use for the gas home. FFC energy, GHG emissions, and energy price factors for electricity and natural gas use California average data for 2016.

This sample calculation highlights the significant impact the choice of metrics and weighting factors has on relative energy performance calculations compared to results using a single metric. The EEE Index (EEEI) provides an indicator of the relative performance of the electric and gas homes. In this example, the electric home is the baseline and has an EEEI of 100 by definition. The gas home will have an EEEI that is either lower (better) or higher (worse) than the electric home based on its EEEI calculated in accordance with equations 1 through 4 below.

$$PEI_{Bldg} = \frac{\Sigma(PEFef * TEUef)}{\Sigma(PEFef * RTEUef)} * 100 \qquad (1)$$

$$EMI_{Bldg} = \frac{\Sigma(EMFef * TEUef)}{\Sigma(EMFef * RTEUef)} * 100 \qquad (2)$$

$$ECI_{Bldg} = \frac{\Sigma(ECFef * TEUef)}{\Sigma(ECFef * RTEUef)} * 100 \qquad (3)$$

$$EEEI_{Bldg} = WFpe * PEI_{Bldg} + WF_{em} * EMI_{Bldg} + WF_{ec} * ECI_{Bldg} \qquad (4))$$

where:

PEI_{Bldg} = Building FFC (Primary) Energy Index
PEF_{ef} = FFC Energy Factor for each energy form
TEU_{ef} = Total site energy use for each energy form in the building
$RTEU_{ef}$ = Total site energy use for each energy form in the baseline building
EMI_{Bldg} = Building GHG Emissions Index
EMF_{ef} = GHG Emissions Factor for each energy form
ECI_{Bldg} = Building Energy Cost Index
ECF_{ef} = Annual Energy Cost Factor for each energy form
WF_{pe} = FFC Energy Weighting Factor
WF_{em} = GHG Emissions Weighting Factor
WF_{ec} = Energy Cost Weighting Factor

Table 42 shows the three sets of weighting factors (WFs) used in this sample calculation. WF1 focuses more on economic impacts, WF2 focuses more on environmental impacts, while WF3 provides a balanced focus among the three metrics.

Table 42 Weighting Factors for EEE Impact Sample Calculations

Parameter	Economics Focus (WF1)	Environmental Focus (WF2)	Balanced Focus (WF3)
Primary Energy (WF_{pe})	30%	30%	33%
GHG Emissions(WF_{em})	10%	60%	33%
Energy Cost(WF_{ec})	60%	10%	34%

Table 43 provides the results of the sample calculations. The EEEI for the gas home ranges from 86 to 115 depending on the weighting factor focus. This is in contrast to an Energy Cost Index (ECI) of 71 using energy cost as the single metric and an Emissions Index (EMI) of 129 using only GHG emissions as the single metric. In this example, the Primary Energy Index (PEI) is virtually the same as the balanced focus EEEI. For decision-making purposes, it is clear that the metrics, methods, and values all matter. An economics focus would drive decisions toward a natural gas home whereas an environmental focus would drive decisions toward an all-electric home in California. A balanced focus would be indifferent, allowing other factors to influence the decision.

Table 43 EEE Impact Sample Calculation Results

Parameter	All-Electric Baseline	Mixed Fuel Building	Electricity	Natural Gas
Site Energy Use (kWh/Year)				
Electricity	15,345	7,311		
Natural Gas	0	15,885		
Total	15,345	23,196		
FFC Energy Factor			2.12	1.09
FFC Energy Use (kWh/Year)	32,531	32,813		
GHG Emissions Factor (kg/kWh)			0.292	0.228
GHG Emissions (kg/Year)	4,481	5,756		
Energy Price ($/kWh)			0.174	0.033
Energy Cost ($/Year)	2,668	1,889		
PEI	100	101		
EMI	100	129		
ECI	100	71		
WF1 EEEI	100	86		
WF2 EEEI	100	115		
WF3 EEEI	100	100		

9 Summary

Within this report, an extensive set of data were compiled using publicly available sources to support the calculation of the FFC energy consumption and associated GHG and other pollutant emissions for electricity generation and fossil fuel energy use. The factors for calculating FFC energy consumption and related emissions for the full-fuel-cycle of extraction, processing, transportation, conversion, distribution, and consumption of energy were developed at the state, eGRID sub-region, NERC region, and U.S. average level for electricity for all power plants. Factors for non-baseload power plants were developed at the eGRID sub-region level. Factors for fossil fuels were developed at the U.S. average level.

Comparison of the U.S. average FFC energy factors in the AGA report published in 2013 with the corresponding new datasets shows modest FFC energy efficiency changes. The fossil fuels FFC emission factors compiled in this report are similar to those provided in the 2013 AGA report. CO_2e emission factors are provided for calculation of total GHG emissions.

The sample calculations of residential electric and natural gas water heaters provide examples of the application of the tabulated FFC energy and emissions factors to evaluate impacts of energy choice on FFC energy consumption and pollutant emissions, including CO_2e emissions. The sample calculations illustrate the importance of selecting the appropriate energy and fuel type as well as geographical conversion factors when evaluating the benefits of optimizing energy use in buildings.

As shown in these scenarios, the underlying assumptions about each parameter can change the result significantly. To provide societal benefits with minimum unintended consequences, energy performance indicators and related energy management initiatives would benefit from using metrics that are technically defensible, useable, easy to adopt, and enforceable. One metric may be inadequate to address multiple objectives fairly with minimum unintended consequences. A balanced approach to evaluating energy performance, such as the EEE Impacts framework, may be of interest to address these limitations.

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Appendix A FFC Energy and Emissions Factors Algorithms

A-1. Average FFC Energy Factors

The FFC energy factor for electric power generation is given by:

$$s_t = \begin{bmatrix} m_1 \\ m_2 \\ \dots \\ m_n \end{bmatrix} \cdot \begin{bmatrix} s_1 \\ s_2 \\ \dots \\ s_n \end{bmatrix} \quad (1)$$

where, m_i is the fraction of the power generation from each type of fuel and s_i is the FFC energy factor of each type of fuel. The subscripts 1 through n for both the generation mix and the FFC energy factors specifically represent:

1	Coal
2	Oil
3	Natural Gas
4	Nuclear
5	Hydro
6	Biomass
7	Wind
8	Solar
9	Geothermal
10	Other

The mix fractions m_i are determined by analysis of the eGRID2016 database. In the case of coal based generation, the fraction of lignite, bituminous, and sub-bituminous coals used are given by NREL/TP-550-38617.

For example, in the SPSO sub-region the aggregate average FFC energy factor is given by:

$$s_t = \begin{bmatrix} 0.3333 \\ 0.0000 \\ 0.4290 \\ 0.0000 \\ 0.0380 \\ 0.0210 \\ 0.1780 \\ 0.0100 \\ 0.0000 \\ 0.0000 \end{bmatrix} \cdot \begin{bmatrix} 3.52 \\ 4.33 \\ 2.74 \\ 3.38 \\ 1.05 \\ 1.89 \\ 1.05 \\ 1.05 \\ 1.05 \\ 5.15 \end{bmatrix} = 2.61 \quad (2)$$

The FFC energy factors s_i are calculated according to:

$$s_i = \frac{1}{e_1 \cdot e_2 \cdot \dots \cdot e_n} \quad (3)$$

where, e_n is the efficiency of each of the processes contributing to power generation. The subscripts 1 through n specifically represent:

1 Extraction
2 Processing
3 Transportation
4 Conversion
5 Distribution

In the SPSO sub-region for coal based generation this yields:

$$s_{coal} = \frac{1}{0.988 \cdot 0.996 \cdot 0.968 \cdot 0.313 \cdot 0.954} = 3.52 \qquad (4)$$

which is the first FFC energy value used in Equation 2.

Using this procedure for each type of generation fuel gives the values shown in Table 44 below. The values that populate Table 44 cells use database information from published sources as shown in Table 45.

Table 44 FFC Energy Factors for SPSO Sub-region, All Plants

Fuel Type	Extraction	Processing	Transportation	Conversion	Distribution	Cumulative Efficiency	Generation Mix (%)	FFC Factor
Coal	98.8	99.6	96.8	31.3	95.4	28.4	33.3	3.52
Oil	96.3	93.8	98.8	27.1	95.4	23.1	0	4.33
Natural Gas	96.2	97	99.3	41.3	95.4	36.5	42.9	2.74
Nuclear	99	96.2	99.9	32.6	95.4	29.6	0	3.38
Hydro	100	100	100	100	95.4	95.4	3.8	1.05
Biomass	99.4	95	97.5	60.3	95.4	53.0	2.1	1.89
Wind	100	100	100	100	95.4	95.4	17.8	1.05
Solar	100	100	100	100	95.4	95.4	0.1	1.05
Geothermal	100	100	100	100	95.4	95.4	0	1.05
Other	100	100	100	20.3	95.4	19.4	0	5.15
Total	**97.9**	**98.5**	**98.6**	**42.5**	**95.4**	**38.5**	**100**	**2.61**

Table 45 Sources for FFC Energy Factors

	Extraction	Processing	Transportation	Conversion	Distribution	Mix	Source
Coal	a	a	a	d	from eGRID 2012 V1.0 Database	Calculated from eGRID 2012 V1.0 Database	Calculated from Equation 3
Oil	b	b	b	d			
Natural Gas	b	b	b	d			
Nuclear	b	b	b	e			
Hydro	c	c	c	f			
Biomass	b	b	b	d			
Wind	c	c	c	g			
Solar	c	c	c	h			
Geothermal	c	c	c	i			
Other	c	c	c	d			
Total	k						j

a. Coal mix from NREL/TP-550-38617, efficiencies from NREL LCI database

b. From NREL LCI database

c. Assumed to be 100%

d. Calculated from eGRID 2012 V1.0 Database

e. DOE EIA Table 8.4a Consumption for Electricity Generation by Energy Souce: Total (All Sectors), http://www.eia.doe.gov/emeu/aer/txt/ptb0804a.html

f. Based on published estimates for the efficiency of larg-scale hydroelectric plants. See http://www.usbr.gov/power/edu/pamphlet.pdf.

g. Based on the average rated efficiency at rated wind speed for a sample of commercially available wind turbines. The rated wind speed is the minimum wind speed at which a turbine achieves its nameplate rated output under standard atmospheric conditions. Efficiency is calculated by dividing the nameplate rated power by the power available from the wind stream intercepted by the rotor disc at the rated wind speed.

h. Based on the average rated efficiency for a sample of commercially available modules. Rated efficiency is the conversion efficiency under standard test conditions which represents a fixed, controlled operating point for the equipment, efficiency can vary with temperature and the strength of incident sunlight. Rated efficiencies are based on the direct current output of the module; since grid-tied applications require alternating current output, efficiencies are adjusted to account for a 20% reduction in output when converting from DC to AC.

i. Estimated by EIA on the basis of an informal survey of relevant plants

j. Calculated from Equation 1

k. Total weighted average efficiencies for each process can be calculated according to, for example in the case of overall extraction efficiency $e_1^T = \frac{1}{\frac{m_1}{e_1}+\frac{m_2}{e_1}+\cdots+\frac{m_n}{e_1}}$

A-2. Marginal FFC Energy and Emission Factors

A public domain marginal analysis methodology is available from EPA to quantify the emission reduction due to energy efficiency measures or clean energy policies. EPA's interest in this methodology arose from its understanding that clean energy policies and energy efficiency improvements reduce emissions at the marginal or non-baseload electric generating units. Analysts and EPA staff have noted that emission reductions must be quantified using non-baseload emission factors rather than average emission factors[1 2 3] Average electricity generation emission factors can be used appropriately to determine carbon footprint or GHG inventory. However, average emission rates typically under-predict the emission reduction when used for energy savings through efficiency improvements because these averages include baseload generation such as nuclear or hydro power, which would not be affected by the efficiency improvement.[4]

EPA recognizes several valid and established approaches to quantify emission reductions using the non-baseload electricity mix.[5] Non-baseload CO_2 emission factors are published by the EPA to facilitate the calculation of emissions reduction due to energy efficiency improvements. The use of eGRID sub-region non-baseload emission factors is recommended by the EPA as a simple, low-cost method to estimate emission reduction potential, to explain emission benefits to the general public, or to determine annual emission reductions or regional / national estimates.[6] EPA's non-baseload emission rates and methodology are currently used in several tools, including EPA's Greenhouse Gas Equivalencies Calculator (http://epa.gov/cleanenergy/energy-resources/calculator.html) and Green Power Partnership's Green Power Equivalency Calculator (http://www.epa.gov/greenpower/pubs/calculator.htm).[7]

EPA's non-baseload emission rate methodology also provides a convenient way to determine the primary energy factor associated with marginal non-baseload power plants for each eGRID sub-region. The emission factors can be correlated with the associated generation mix of oil, natural gas, and coal. Knowing this mix, the aggregate primary energy conversion factor can be calculated based on marginal power plant efficiency levels for each fuel type. In the absence of marginal power plant efficiency level information, average power plant efficiency levels may provide an acceptable substitute.

Keith and Biewald developed a methodology implemented by the EPA for calculating marginal (or non-baseload) power plant emission rates based on the capacity factor of each plant8. The capacity factor methodology allows the user to determine marginal energy consumption and GHG emissions at any level of desired aggregation using historical or projected power plant values for any time period. It provides a simplified and reasonably accurate methodology compared to marginal dispatch models or hourly

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1 Jacobson, D. and High, C. , *U.S. Policy Action Necessary to Ensure Accurate Assessment of the Air Emission Reduction Benefits of Increased Use of Energy Efficiency and Renewable Energy Technology*, Journal of Energy and Environmental Law, Vol. 1:1, 2010. (http://www.rsginc.com/assets/Reports--Publications/RSG-Modeling-of-Air-Emission-Reduction-in-the-Electricity-Sector.pdf)
2 DeYoung, R., *Deciding an Approach for Quantifying Emission Impacts of Clean Energy Policies and Programs*, U.S. Environmental Protection Agency, State Climate and Energy Program, January 30, 2012. (http://www.epa.gov/statelocalclimate/documents/pdf/DeYoung_presentation_1-30-2012.pdf)
3 Rothschild, S. and Diam, A., *Total, Non-baseload, eGRID Sub-region, State? Guidance on the Use of eGRID Output Emission Rates*, Prepared for the U.S. Environmental Protection Agency, Climate Protection Partnership Division, Washington, DC, 2008. (http://www.epa.gov/ttn/chief/conference/ei18/session5/rothschild.pdf)
4 Jacobson, D., Flawed Methodologies in Calculating Avoided Emissions from Renewable Energy , The GW Solar Institute, October 24, 2009. (http://solar.gwu.edu/index_files/Resources_files/DJ_REILPresentation.pdf)
5 DeYoung, R., *Deciding an Approach for Quantifying Emission Impacts of Clean Energy Policies and Programs*, U.S. Environmental Protection Agency, State Climate and Energy Program, January 30, 2012. (http://www.epa.gov/statelocalclimate/documents/pdf/DeYoung_presentation_1-30-2012.pdf)
6 DeYoung, R., *Quantification Methods using eGRID State and Local Examples*, U.S. Environmental Protection Agency, State Climate and Energy Program, March 31, 2011. (http://www.epa.gov/statelocalclimate/documents/pdf/DeYoung_presentation_3-31-11.pdf)
7 Collison, B., *Green Power 101*, US EPA Green Power Partnership, Renewable Energy Markets Conference, Atlanta, GA, September 13, 2009 (http://www.renewableenergymarkets.com/docs/presentations/2010/Wed_RE%20101_Blaine%20Collison.pdf)
8 Keith, G. and Bruce Biewald. *Methods for Estimating Emissions Avoided by Renewable Energy and Energy Efficiency*, Prepared for the U.S. Environmental Protection Agency, Washington, DC, July 8, 2005. (http://www.synapse-energy.com/sites/default/files/SynapseReport.2005-07.PQA-EPA.Displaced-Emissions-Renewables-and-Efficiency-EPA.04-55.pdf)

generation databases. The EPA implemented this methodology in the eGRID database to list the emissions of "non-baseload" power plants for application in marginal generation scenarios and analyses. Using this approach, all plants with generation capacity factors less than 0.2 are considered non-baseload generation in the eGRID non-baseload generation database, and those with capacity factors greater than 0.8 are considered baseload generation as shown in Figure 23. For the SPSO sub-region this yields the results shown in Table 46. Note that the pre-combustion efficiencies remain the same but the conversion efficiencies and the generation mix change.

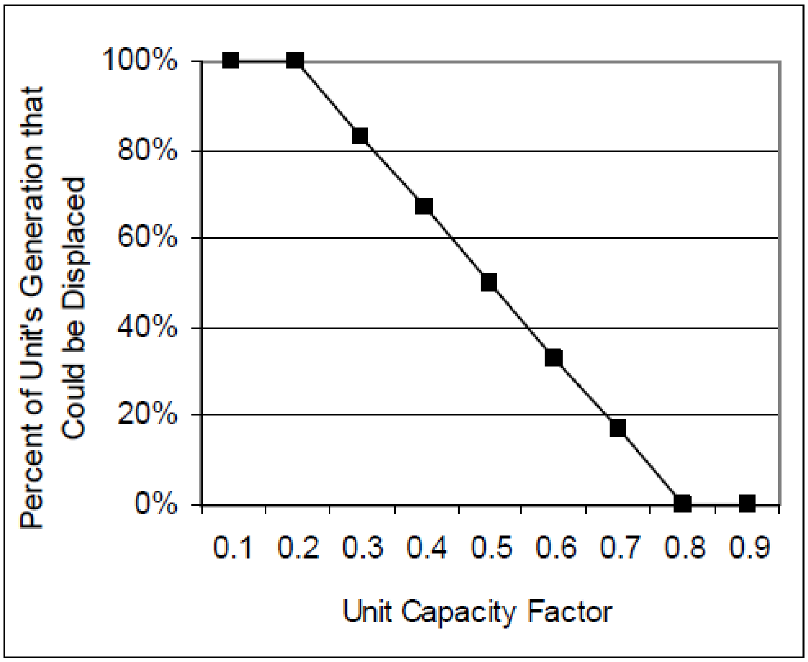

Figure 23 Keith and Biewald Capacity Factor Displacement Methodology

Table 46 FFC Energy Factors for SPSO Sub-region, Non-baseload.

Fuel Type	Extraction	Processing	Transportation	Conversion	Distribution	Cumulative Efficiency	Generation Mix (%)	FFC Factor
Coal	98.8	99.6	96.8	30.1	95.4	27.4	40.1	3.65
Oil	96.3	93.8	98.8	29.5	95.4	25.1	2.2	3.98
Natural Gas	96.2	97	99.3	36.8	95.4	32.5	56.8	3.08
Nuclear	99	96.2	99.9	32.6	95.4	29.6	0	3.38
Hydro	100	100	100	100	95.4	95.4	0	1.05
Biomass	99.4	95	97.5	60.2	95.4	52.9	1.0	1.89
Wind	100	100	100	100	95.4	95.4	0	1.05
Solar	100	100	100	100	95.4	95.4	0	1.05
Geothermal	100	100	100	100	95.4	95.4	0	1.05
Other	100	100	100	20.3	95.4	19.4	0	5.15
Total	**97.4**	**98.1**	**98.1**	**33.7**	**95.4**	**30.1**	**100.00**	**3.32**

A-3. Pollutant Emission Factors

Emissions factors used in the calculation of FFC emissions come from several sources. Fossil fuels pre-combustion emissions factors are calculated using data from the GREET Model v1 2012 rev. 2 with natural gas CH_4 pre-combustion emissions adjusted to comply with latest U.S. EPA Inventory of U.S. Greenhouse Gas Emissions and Sinks" draft document released February 11, 2013. (http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2011.pdf). The combustion emissions for conversion to electricity are calculated using eGRID2012 V1.0. Table 47 gives baseload conversion emissions factors and Table 50 gives non-baseload conversion emissions factors for the SPSO sub-region. The emissions factors used for the SPSO sub-region for pre-combustion are given in Table 48. Note that in the case of pre-combustion processes the emissions factors apply to the energy consumed during the pre-combustion processes, not the energy used in electric generation.

The emissions factors, F_i, are used to calculate total emissions using the following procedure. The FFC energy required in units of MMBtu of FFC energy per MWh of electric generation is calculated according to:

$$E_{required}\left(\frac{MMBtu}{MWh}\right) = \frac{3.4121\frac{MMBtu}{MWh}}{e_{conversion} \cdot e_{distribution}} \qquad (5)$$

where, $e_{conversion}$ and $e_{distribution}$ are the efficiencies of conversion and distribution given in Table 44. For coal in the SPSO baseload case this yields:

$$E_{required} = \frac{3.4121\frac{MMBtu}{MWh}}{0.313 \cdot 0.954} = 11.43\frac{MMBtu}{MWh} \qquad (6)$$

Table 47 Emissions Factors for Conversion Processes in the SPSO Sub-region (Baseload)

	Conversion					
Fuel Type	**CO_2 (lb/MMBtu)**	**SO_2 (lb/MMBtu)**	**NO_x (lb/MMBtu)**	**CH_4 (lb/MMBtu)**	**N_2O (lb/MMBtu)**	**CO_2e (lb/MMBtu)**
Coal	210.4	0.428	0.151	0.022	0.003	211.8
Oil	161.4	0.282	2.024	0.007	0.001	161.9
Natural Gas	123.1	0.016	0.07	0.003	0	123.2
Nuclear	0	0	0	0	0	0.0
Hydro	0	0	0	0	0	0.0
Biomass	33.8	0.192	0.343	0.019	0.004	35.4
Wind	0	0	0	0	0	0.0
Solar	0	0	0	0	0	0.0
Geothermal	0	0	0	0	0	0.0
Other	123.1	0.016	0.07	0.003	0	123.2

Table 48 Emissions Factors for Pre-Combustion Processes in the SPSO Sub-region (Baseload)

	Pre-Combustion				
Fuel Type	**CO_2 (lb/MMBtu)**	**SO_2 (lb/MMBtu)**	**NO_x (lb/MMBtu)**	**CH_4 (lb/MMBtu)**	**N_2O (lb/MMBtu)**
Coal	70.3	0.348	0.593	7.189	0.001
Oil	169.5	0.357	0.754	2.011	0.003
Natural Gas	127.6	0.305	0.584	6.161	0.002
Nuclear	152.7	0.258	0.282	0.371	0.003
Hydro	0	0	0	0	0
Biomass	161.4	0.061	0.722	0.233	0.003
Wind	0	0	0	0	0
Solar	0	0	0	0	0
Geothermal	0	0	0	0	0
Other	0	0	0	0	0

Emissions due to conversion for each fuel type are then calculated using:

$$Emissions_{conversion} = E_{required} \cdot F_{conversion} \tag{7}$$

where, for the SPSO baseload case, the emissions factors are given in Table 47. For CO_2e from coal in the SPSO baseload case this gives:

$$Emissions_{conversion} = 11.43\frac{MMBtu}{MWh} \cdot 211.81\frac{lb}{MMBtu} = 2420.35\frac{lb\ CO_2e}{MWh} \tag{8}$$

Pre-conversion emissions are calculated according to equation 9,

$$Emissions_{pre} = (1 - e_1 \cdot e_2 \cdot e_3)E_{required} e_1 \cdot e_2 \cdot e_3 F_{pre} \tag{9}$$

where, e_1, e_2, and e_3 are the efficiencies of extraction processing and transportation given in Table 44, $E_{required}$ is given by Equation 6, and the emissions factor is given in Table 48. For CO_2e from coal in the SPSO baseload case this gives:

$$Emissions_{pre} = \frac{(1-0.988\cdot 0.996\cdot 0.968)\cdot 11.43\frac{MMBtu}{MWh}}{0.989\cdot 0.996\cdot 0.969} 271.85\frac{lb\ CO_2e}{MMBtu} = 154.72\frac{lb\ CO_2e}{MWh} \tag{10}$$

Emissions pre-conversion and conversion are then added to determine total emissions for each type of fuel. These are then summed using the generation mix ratios to determine the overall emissions according to:

$$Emissions_{total} = \begin{bmatrix} m_1 \\ m_2 \\ \dots \\ m_n \end{bmatrix} \cdot \begin{bmatrix} Emissions_1 \\ Emissions_2 \\ \dots \\ Emissions_n \end{bmatrix} \tag{11}$$

where , m_i is the fraction of the power generation from each type of fuel and the subscripts are the same as those given for Equation 1. For CO_2e emissions in the baseload generation case for the SPSO sub-region this procedure gives the results displayed in Table 49.

The same process is repeated for the case of non-baseload emissions but in this case emissions factors for energy conversion are updated as are the generation mix and FFC energy efficiencies. For the SPSO sub-region the emissions factors for conversion processes are given in Table 50. This yields the energy requirements and pre-conversion and conversion process emissions shown in Table 51.

Table 49 CO_2e Emissions for Each Fuel Type and Overall in the SPSO Sub-Region (Baseload)

Fuel Type	Required MMBtu/MWh	Pre-Conversion	Conversion	Total FFC CO_2e (lb/MWh)	Generation Mix (%)	CO_2e Fraction
Coal	11.43	154.7	2420.3	2575.1	33.3	469.5
Oil	13.20	360.4	2136.2	2496.6	0	0
Natural Gas	8.66	206.2	1066.8	1273.0	42.9	604.8
Nuclear	10.97	91.8	0	91.8	0	0
Hydro	3.58	0	0	0	3.8	53.6
Biomass	5.93	86.2	209.9	296.1	2.1	29.6
Wind	3.58	0	0	0	17.8	250.9
Solar	3.58	0	0	0	0.1	1.4
Geothermal	3.58	0	0	0	0	0
Other	17.62	0.0	2170.4	2170.4	0	0
Total						**1409.8**

Table 50 Factors for Conversion Processes in the SPSO Sub-region (non-Baseload)

	Conversion					
Fuel Type	CO_2 (lb/MMBtu)	SO_2 (lb/MMBtu)	NO_x (lb/MMBtu)	CH_4 (lb/MMBtu)	N_2O (lb/MMBtu)	CO_2e (lb/MMBtu)
Coal	207.3	0.48	0.155	0.019	0.003	208.6
Oil	202.6	0.167	0.101	0.012	0.002	203.5
Natural Gas	122.2	0.011	0.121	0.003	0	122.3
Nuclear	0	0	0	0	0	0.0
Hydro	0	0	0	0	0	0.0
Biomass	33.8	0.394	0.198	0.02	0.005	35.7
Wind	0	0	0	0	0	0.0
Solar	0	0	0	0	0	0.0
Geothermal	0	0	0	0	0	0.0
Other	0	0	0	0	0	0.0

Table 51 CO_2e Emissions by Fuel Type and Overall in SPSO Sub-Region (non-Baseload)

Fuel Type	Required MMBtu/MWh	Pre-Conversion	Conversion	Total/Source (lb/MWh)	Generation Mix (%)	CO_2e Fraction
Coal	11.88	154.7	2479.0	2633.7	40.1	773.8
Oil	12.12	360.4	2466.9	2827.2	2.2	42.5
Natural Gas	9.72	206.2	1188.5	1394.7	56.8	1096.0
Nuclear	10.97	91.8	0	91.8	0	0
Hydro	3.58	0	0	0	0	0
Biomass	5.94	86.2	212.0	298.2	1	19.3
Wind	3.58	0	0	0	0	0
Solar	3.58	0	0	0	0	0
Geothermal	3.58	0	0	0	0	0
Other	17.62	0	0	0	0	0
Total						**1929.6**

Appendix B Source Energy and Emissions Analysis Tool Description

B-1. Overview

GTI's Carbon Management Information Center (CMIC) Source Energy and Emissions Analysis Tool (SEEAT), available free to the public at www.cmictools.com, determines source energy consumption and related greenhouse gas (GHG) and criteria pollutant emissions for selected fossil fuels and electricity based on point-of-use energy consumed by an appliance, building, industrial application, or vehicle. SEEAT is a flexible and simple tool for comparisons within and across energy forms. SEEAT uses government data and models and other publicly available data sources as the basis of its default energy and emission factors and calculations. The user can choose default input data for numerous parameters necessary for the analysis. SEEAT also offers user-specified input options for most energy and emission parameters to allow users to tailor the analysis as needed.

B-2. User Inputs

SEEAT uses six steps in its buildings and transportation modules to determine the source energy and emissions associated with point-of-use energy consumption for baseline and alternative configurations. In the industrial module, four steps are used to determine the source energy and emissions per million dollars of manufactured goods.

In **Step 1**, the user selects the market segment for analysis (e.g., residential buildings), then the geographical region for electricity generation mix and typical point-of-use energy consumption if desired. Region options include State; EPA Emissions & Generation Resources Integrated Database (eGRID) Sub-regions; National Electric Reliability Council (NERC) Regions; and U.S. Average.

In **Step 2**, the user inputs the annual point-of- use or site energy consumption associated with the baseline and alternative configurations for one or more of the following energy forms: Electricity, natural gas, fuel oil, or propane. Point-of-use energy estimation modules can be used to enter annual site energy consumption automatically for user selected options.

In **Step 3**, the user chooses the source energy conversion factors desired for the analysis. The user can choose either default values or enter user-specified efficiency factors for each energy form. Several additional options for determining electricity factors are available in SEEAT. The user selects the eGRID electric power plant database year from seven historical eGRID databases in SEEAT, ranging from 2016 data (eGRID2016) to 2005 data (eGRID2007). eGRID provides plant level and aggregate data on annual electric power plant generation and emissions for the selected year. Users also have the option of choosing the eGRID aggregated databases or the eGRID plant level database for regional or national analysis. The plant level database was screened by CMIC to verify and align fuel plant classification more closely with primary input fuel. The plant level database option is intended to address inconsistencies identified in the eGRID aggregated regional and national databases.

Users can evaluate electricity consumption using average or non-baseload (marginal) source energy and GHG emission factors. Selecting the non-baseload (marginal) calculation option for electricity option limits user geographical area selection to eGRID Sub-regions and data source selection to 2016, 2014, 2012, 2010, or 2009 eGRID plant level data. The marginal generation factors impact results most significantly when evaluating source energy and emissions in regions dominated by non-combustion electric generation, such as the NWPP or CAMX Sub-regions, whose marginal or avoided generation will likely be from natural gas or coal power generation.

The user also chooses the desired electricity generation mix and characteristics, either using the eGRID defaults for the selected region or user-specified generation mix, and either default or user-specified efficiency factors. Check box options for non-combustible renewable power allow the user to choose either incident energy efficiency (thermodynamic efficiency), captured energy efficiency (100%

efficiency), or infinite energy efficiency (i.e., zero source energy consumption) for hydro, wind, solar, and geothermal power generation. Thermodynamic efficiency permits comparisons within the renewable generation mix, but may not align well with renewable energy policy objectives. The captured energy efficiency may be of interest when the focus is alignment with other policy objectives, but does not capture the efficiency or cost differences among renewable power options. Infinite energy efficiency may be of interest when the focus is alignment with the non-depletable attributes of non-combustible renewables, irrespective of their relative costs or other comparison parameters.

In **Step 4**, the user can choose either default GHG and pollutant emission factors or enter user-specified values for each energy form. Options for determining CO_2e factors include Global Warming Potential (GWP) or Global Temperature Potential (GTP) of emissions from consumed fuels during their pre-combustion and combustion/conversion processes.

In **Step 5**, the user selects the state (when the NERC Region or eGRID Sub-region comprises more than one state) and chooses default marginal or average energy prices or enters user-specified values.

In **Step 6**, the user chooses either default values for Energy, Emissions, and Economics (EEE) Impacts or enters user-specified factors. EEE Impact factors are used to compare the performance of baseline and alternative technologies based on their weighted and aggregated impact on primary energy resources, GHG emissions, and consumer economics. Weighting factors for these three metrics add up to 100% and are used to determine the EEE Index Score for the alternative scenario relative to the baseline which, by definition, has an EEE Index Score of 100.

B-3. Source Energy and Emissions Calculations

Based on user-specified and default inputs, SEEAT calculates source energy and emissions factors and values for the analysis. Based on annual electricity consumption, SEEAT calculates location-specific:

- Electric distribution efficiency and resulting power plant generation requirement,
- Power plant fuel mix,
- Conversion efficiency and corresponding source energy and GHG and criteria pollutant emissions by fuel type at the power plant,
- Source energy required and corresponding GHG and criteria pollutant emissions by generation fuel type for extraction, processing, and transportation to the power plant
- Source energy and composite GHG and criteria pollutant emission factors
- Total source energy required and corresponding GHG and criteria pollutant emissions
- Annual energy cost
- EEE Impacts compared to baseline

The aggregated source energy factor (s_t) for location-specific electric power generation is calculated as follows:

$$s_t = \begin{bmatrix} m_1 \\ m_2 \\ \dots \\ m_n \end{bmatrix} \cdot \begin{bmatrix} s_1 \\ s_2 \\ \dots \\ s_n \end{bmatrix} \qquad (1)$$

where, m_i is the fraction of the power generation from each type of fuel and s_i is the source energy factor of each type of fuel. The subscripts 1 through n for both the generation mix and the source energy factors specifically represent:

1	Coal
2	Oil
3	Natural Gas
4	Nuclear
5	Hydro

6	Biomass
7	Wind
8	Solar
9	Geothermal
10	Other

The mix fractions m_i are from the applicable eGRID2016 database.

The source energy factors s_i are calculated as follows:

$$s_i = \frac{1}{e_1 \cdot e_2 \cdot \ldots \cdot e_n} \quad (3)$$

where, e_n is the efficiency of each of the processes contributing to each type of power generation. The subscripts 1 through n specifically represent:

1	Extraction
2	Processing
3	Transportation
4	Conversion
5	Distribution

Based on annual natural gas, oil, or propane site consumption, SEEAT calculates location-specific:

- Source energy required and corresponding GHG and criteria pollutant emissions for extraction, processing, transmission, and distribution to the building. Combustion occurs at the point of use, so an upstream "conversion efficiency" factor is not applicable for these energy forms.
- Source energy and composite GHG and criteria pollutant emission factors
- Total source energy required and corresponding GHG and criteria pollutant emissions
- Annual energy cost
- EEE Impacts compared to baseline

Non-Baseload (Marginal) Source Energy and Emission Factors

A public domain marginal analysis methodology is available from EPA to quantify the emission reduction due to energy efficiency measures or clean energy policies. EPA's interest in this methodology arose from its understanding that clean energy policies and energy efficiency improvements reduce emissions at the marginal or non-baseload electric generating units. Analysts and EPA staff have noted that emission reductions must be quantified using non-baseload emission factors rather than average emission factors[9] [10] [11] Average electricity generation emission factors can be used appropriately to determine carbon footprint or GHG inventory. However, average emission rates typically under-predict the emission reduction when used for energy savings through efficiency improvements because these averages include baseload generation such as nuclear or hydro power, which would not be affected by the efficiency improvement.[12]

9 Jacobson, D. and High, C. , *U.S. Policy Action Necessary to Ensure Accurate Assessment of the Air Emission Reduction Benefits of Increased Use of Energy Efficiency and Renewable Energy Technology*, Journal of Energy and Environmental Law, Vol. 1:1, 2010. (http://www.rsginc.com/assets/Reports--Publications/RSG-Modeling-of-Air-Emission-Reduction-in-the-Electricity-Sector.pdf)
10 DeYoung, R., *Deciding an Approach for Quantifying Emission Impacts of Clean Energy Policies and Programs*, U.S. Environmental Protection Agency, State Climate and Energy Program, January 30, 2012. (http://www.epa.gov/statelocalclimate/documents/pdf/DeYoung_presentation_1-30-2012.pdf)
11 Rothschild, S. and Diam, A., *Total, Non-baseload, eGRID Sub-region, State? Guidance on the Use of eGRID Output Emission Rates*, Prepared for the U.S. Environmental Protection Agency, Climate Protection Partnership Division, Washington, DC, 2008. (http://www.epa.gov/ttn/chief/conference/ei18/session5/rothschild.pdf)
12 Jacobson, D., Flawed Methodologies in Calculating Avoided Emissions from Renewable Energy , The GW Solar Institute, October 24, 2009. (http://solar.gwu.edu/index_files/Resources_files/DJ_REILPresentation.pdf)

EPA recognizes several valid and established approaches to quantify emission reductions using the non-baseload electricity mix.[13] Non-baseload CO_2emission factors are published by the EPA to facilitate the calculation of emissions reduction due to energy efficiency improvements. The use of eGRID sub-region non-baseload emission factors is recommended by the EPA as a simple, low-cost method to estimate emission reduction potential, to explain emission benefits to the general public, or to determine annual emission reductions or regional / national estimates.[14] EPA's non-baseload emission rates and methodology are currently used in several tools, including EPA's Greenhouse Gas Equivalencies Calculator (http://epa.gov/cleanenergy/energy-resources/calculator.html) and Green Power Partnership's Green Power Equivalency Calculator (http://www.epa.gov/greenpower/pubs/calculator.htm).[15]

EPA's non-baseload emission rate methodology also provides a convenient way to determine the primary energy factor associated with marginal non-baseload power plants for each eGRID sub-region. The emission factors can be correlated with the associated generation mix of oil, natural gas, and coal. Knowing this mix, the aggregate primary energy conversion factor can be calculated based on marginal power plant efficiency levels for each fuel type. In the absence of marginal power plant efficiency level information, average power plant efficiency levels may provide an acceptable substitute.

Keith and Biewald developed a methodology implemented by the EPA for calculating marginal (or non-baseload) power plant emission rates based on the capacity factor of each plant. The capacity factor methodology allows the user to determine marginal energy consumption and GHG emissions at any level of desired aggregation using historical or projected power plant values for any time period. It provides a simplified and reasonably accurate methodology compared to marginal dispatch models or hourly generation databases. The EPA implemented this methodology in the eGRID database to list the emissions of "non-baseload" power plants for application in marginal generation scenarios and analyses. Using this approach, all plants with generation capacity factors less than 0.2 are considered non-baseload generation in the eGRID non-baseload generation database, and those with capacity factors greater than 0.8 are considered baseload generation, with prorated fractions for capacity factors between 0.2 and 0.8.

B-4. Reports

SEEAT output reports include tabular and graphic results for the baseline and alternative configurations as well as a comparison of baseline versus alternative for the following:

- **Annual Site Energy Consumption** by energy form in units delivered to the site
- **Annual Site Energy Cost** by energy form and total in dollars for residential and commercial sites
- **Annual Source Energy Consumption** by energy form and total in units delivered to the site converted to source Btu's
- **Source Energy Factors** for each energy form and composite factor
- **Annual Greenhouse Gas Emissions** (CO_2 and CO_2e) by energy form and total in units delivered to the site converted to source energy emissions in thousand pounds.
- **Annual Emissions - Other Pollutants**, including SO_2 and NO_x by energy form and total in pounds.
- **Efficiency Factors for Energy Delivered to Building**, including electricity and other energy forms

13 DeYoung, R., *Deciding an Approach for Quantifying Emission Impacts of Clean Energy Policies and Programs*, U.S. Environmental Protection Agency, State Climate and Energy Program, January 30, 2012. (http://www.epa.gov/statelocalclimate/documents/pdf/DeYoung_presentation_1-30-2012.pdf)

14 DeYoung, R., *Quantification Methods using eGRID State and Local Examples*, U.S. Environmental Protection Agency, State Climate and Energy Program, March 31, 2011. (http://www.epa.gov/statelocalclimate/documents/pdf/DeYoung_presentation_3-31-11.pdf)

15 Collison, B., *Green Power 101*, US EPA Green Power Partnership, Renewable Energy Markets Conference, Atlanta, GA, September 13, 2009 (http://www.renewableenergymarkets.com/docs/presentations/2010/Wed_RE%20101_Blaine%20Collison.pdf)

- **Emission Factors for Energy Delivered to Building**, including electricity and other energy forms
- **Electric Generation Resource Mix** for the region selected for analysis
- **Energy, Emissions, and Economics Impact** compares the EEE Index Score for the alternative scenario relative to the baseline which, by definition, has an EEE Index Score of 100. A higher score indicates worse performance, and a lower score indicates better performance compared to the baseline.

B-5. Point-of-Use and Site Energy Consumption Estimation Modules

SEEAT includes point-of-use and site energy consumption estimation modules to aid users in screening and comparing total annual energy consumption by energy form for baseline and alternative configurations. This information can be submitted to automatically fill in the data input cells for the annual site energy consumption by energy form in Step 2 for use in source energy and emissions calculations. Current modules provide location-specific consumption estimates for residential buildings and several types of commercial buildings, normalized energy consumption estimates for certain industrial applications, and comparative consumption estimates for various types of passenger vehicles.

The **Residential Buildings Module** includes Detached Single-Story, Detached Two-Story, Townhouse, and Multi-family configurations. Energy consumption is calculated for each appliance and the entire building based on modeled energy loads of relatively energy efficient building envelope configurations using GTI's Building Energy Analyzer (BEA). The user selects the desired location, size, number of occupants, and appliances to include in the building, and the module provides an estimate of associated site energy consumption for each appliance and the whole building to meet the associated loads.

Range, refrigerator, dishwasher, washing machine, and dryer site energy consumption estimates are derived from ANSI/RESNET/ICC 301-2014 Standard for the Calculation and Labeling of the Energy Performance of Low-Rise Residential Buildings using an Energy Rating Index (http://www.resnet.us/blog/wp-content/uploads/2016/01/ANSI-RESNET-ICC_301-2014-Second-Edition-Publish-Version.pdf), with adjustments for number of occupants, building location, and building type and size.

Residential domestic hot water (DHW) usage is calculated based on an Florida Solar Energy Center study by D.S. Parker, *Estimating Daily DHW Use in North American Homes* (FSEC-PF-464-15), which developed DHW formulas based on occupancy from measured and modeled data.

HWgpd = 22 × (Occ × Fmix) + CWgpd + DWgpd (Equation 11)

Where:

HWgpd = total residential hot water usage, gallons per day (gpd)
Occ = Occupants in the household
Fmix = variable based on average mains water temperature and DHW temperature set point
CWgpd = clothes washer hot water usage, gallons per day
DWgpd = dishwasher hot water usage, gallons per day

To calculate fixture water usage (sink, showers, etc.), Fmix parameter averaged 0.68 for the measured usage [Parker 2015]. Based on three occupants with an Fmix = 0.68, this model estimates the daily water usage for a standard clothes washer and dishwasher to be 7.4 gallons (28 liters) per day.

Using these models, SEEAT calculates the average total water consumption as a function of occupancy:

HWgpd = (22 × Occ × 0.68) + 7.4

This equation calculates an average 52.3 gpd (198 L/d) for a household of three. This estimate aligns well with measured data from several studies, including the average 46 gpd reported by 2015 study by Ecotope, Inc. for Northwest Energy Efficiency Alliance (NEEA #E15-306) and the average 56 gpd reported by a 2012 GTI study for the California Energy Commission (CEC-500-2013-060). In addition, the current ASHRAE method of test for residential water heaters is based on 55 gpd as a "medium usage" household. DHW energy consumption is then calculated based on HWgpd and adjusted for regional temperature impacts. The regional factor is based on normalized DHW energy use calculated by BEA models for each location listed.

The **Commercial Buildings Module** includes Fast Food, Nursing Home, Retail Store, School, Small Office, and Supermarket configurations. Energy consumption calculations are similar to the residential buildings module.

The **Industrial Applications Module** includes annual industrial energy consumption data collected by the U.S. Energy Information Administration and by the U.S. Census Bureau linked to value-based measures of industrial output (Btu/$ produced) for 12 different major industrial classifications. This data is used by the tool to calculate the FFC energy and emissions per million dollars produced.

The **Passenger Vehicle Module** includes both conventional and low emission vehicles. All modeled vehicles are passenger cars with a Gross Vehicle Weight Rating (GVWR) less than 6,000 lbs. MPG (per GREET 2017 gasoline equivalent gallon) is based on a gallon of 38/62% mix of conventional and reformulated gasoline with Higher Heating Value of 114,142 Btu. The module includes the following vehicle types:

- **Gasoline - 50/50 Conv. & Ref. Fuel**; Spark ignition gasoline vehicle fueled with 50/50% mix of conventional and reformulated gasoline with a default fuel efficiency of 23.4 MPG
- **Compressed Natural Gas - Dedicated Vehicle**; Dedicated compressed natural gas vehicle with a default fuel efficiency of 22.2 MPG (per gasoline equivalent gallon)
- **Liquid Petroleum Gas - Dedicated Vehicle**; Dedicated liquid petroleum gas (propane) vehicle with a default fuel efficiency of 23.4 MPG (per gasoline equivalent gallon)
- **Diesel - Direct Injection Compression Ignition**; Diesel vehicle fueled with conventional diesel with a default fuel efficiency of 28.1 MPG (per gasoline equivalent gallon)
- **Electric Vehicle**; Electric vehicle with 85% efficient grid to battery charger efficiency with a default fuel efficiency of 84.5 MPG (per gasoline equivalent gallon)
- **Hybrid Electric - 50/50 Conv. & Ref. Gasoline**; Hybrid electric / spark ignition gasoline vehicle fueled with 50/50% mix of conventional and reformulated gasoline with a default fuel efficiency of 32.7 MPG (per gasoline equivalent gallon)
- **Plug-in Hybrid Electric - 50/50 Conv. & Ref. Gasoline**; Plug-in hybrid electric / spark ignition gasoline vehicle fueled with 50/50% mix of conventional and reformulated gasoline with a default fuel efficiency of 48.9 MPGe (per gasoline equivalent gallon). Fully charged vehicle Operational All Electric Range (OAER) is 11.2 miles; percentage of miles driven in Charge Depletion (CD) mode is 25.6%; balance of 74.4% is driven in Charge Sustaining (CS) mode. Grid to battery charger efficiency is assumed to be 85%.

B-6. Renewable Power Generation FFC Energy Conversion Options

SEEAT uses thermodynamic efficiency in its default calculations for all power generation energy forms. For example, wind power generation efficiency is determined by calculating how much of the available wind energy reaching the turbine is converted to electricity. Using thermodynamic efficiency allows a direct comparison with other renewable options such as solar thermal and photovoltaics, but does not value a renewable Btu differently than a conventional Btu such as nuclear energy or fossil fuels.

GHG emission factors account for the environmental benefits of renewable energy. However, renewable energy poses unique analytical challenges from a full-fuel-cycle energy efficiency perspective. The thermodynamic efficiency methodology compares all FFC energy efficiency equally irrespective of the energy form, including renewable energy. When comparing fuel types used to generate electricity, the energy consumption of renewable energy such as hydropower and wind power is not the same as depletable resource consumption (nuclear or fossil fuels) because the energy "consumed" is renewable and free when available. Full-fuel-cycle methodologies cannot address this issue except by substituting a policy-based conversion factor (e.g., 100% generation efficiency, or zero consumption for the power generated) that biases the energy efficiency analysis in favor of renewable energy based on its "non-depletable" benefit. SEEAT can accommodate that approach through user inputs, but the thermodynamic efficiency was selected as the basis of the default efficiency factor based on simple physics rather than nature of the energy form. Hydropower production in the US is not likely to increase much in the future. However, as wind power and solar thermal systems become more prevalent, this issue will need to be addressed equitably based on policy goals.

For full-fuel-cycle analysis based on current and projected power generation mix, renewable power does not impact the results meaningfully. Using 100% efficiency for all renewables (hydro, biomass, wind, solar, geothermal), the national average electricity FFC energy factor using eGRID 2012 data goes from 3.15 to 3.00. Using "zero energy" for non-combusted renewables (i.e., the energy from hydro, wind, solar, and geothermal is considered inexhaustible and should not be included in FFC energy consumption calculations for electricity), the FFC energy factor goes to 2.86.

Full-fuel-cycle pollutant emission factors attributable to site electricity consumption are not affected by changes in assumed renewable power efficiency since renewable energy emission factors are already zero.

Renewable power factors are irrelevant for marginal analysis because renewable power (a non-depletable intermittent power source) will never be displaced when available due to its low marginal cost of operation.

B-7. Government and Published Sources for Default Values

Default values for emission and FFC energy factors in SEEAT were derived from the following sources:

- **Source Energy Factors**
  - Source energy factors for pre-combustion energy consumption are calculated using the Argonne National Laboratory Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET 2017) model (http://www.transportation.anl.gov/modeling_simulation/GREET).
  - Source energy factors for nuclear fuel mining, enrichment, and transportation are estimated based on information from the world nuclear organization based on natural uranium (0.7% U_{235}) mining, 5% U_{235} enrichment processes http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/conversion-enrichment-and-fabrication/uranium-enrichment.aspx,and rail transportation of 5% U_{235} enriched fuel.
  - Source energy factors for on-site fuel combustion are assumed to be 100% (i.e., essentially complete combustion).
  - Source energy factors for power plant fuel combustion for conversion to electricity are calculated using the eGRID2016 database (http://www.epa.gov/cleanenergy/energy-resources/egrid/) which provides detailed and aggregated data on 2016 power plant generation and emissions. eGRID power generation data is available for nearly all U.S. power plants and aggregated at eGRID sub-region, NERC region, state, or national levels. 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 used 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 eGRID2016. SEEAT also includes an option to use data from previous versions of eGRID for the years 2014, 2012, 2010, 2009, 2007 and 2005.
  - The "incident energy efficiency" option for non-combustible renewable power generation assumes:
    - Hydroelectric plant 90% conversion efficiency. [1a]
    - Solar power 12% conversion efficiency. [1b]
    - Wind power 26% conversion efficiency. [1c]
    - Geothermal power 16% conversion efficiency. [1d]
  - The "captured energy efficiency" option for non-combustible renewable power generation assumes 100% conversion efficiency for hydroelectric, solar, wind, and geothermal power.
  - The "zero source energy" option for non-combustible renewable power generation assumes infinite conversion efficiency (zero source energy use) for hydroelectric, solar, wind, and geothermal power.
  - Nuclear power generation conversion efficiency is a national average value based on DOE EIA data. [2]
  - Biomass power generation conversion efficiency is calculated using eGRID2016 data.

- **Greenhouse Gas and Criteria Pollutant Emission Factors**
  - Emission factors for fossil fuels pre-combustion emissions are calculated using GREET 2017 data.
  - Emission factors for fossil fuels on-site combustion emissions are calculated using GREET 2017 data.
  - Emission factors for fossil fuels combustion emissions for conversion to electricity are calculated using the eGRID2016 database. The tool also includes an option to use data from previous versions of eGRID for the years 2014, 2012, 2010, 2009, 2007 and 2005. eGRID emissions data includes CO_2, NO_x, SO_2, CH_4, and N_2O emissions for all plants, as ewell as for non-baseload plants at the eGRID sub-region level.
  - CO_2e emissions calculation options include Global Warming Potential (GWP) or Global Temperature Potential (GTP) of pre-combustion and combustion energy and associated greenhouse gas emissions from fuels. Default calculations are based on:
    1) GWP values, 100 year time horizon, from 2013 Intergovernmental Panel on Climate Change (AR5 pg. 714): CO_2 GWP = 1; CH_4 GWP = 28 ; N_2O GWP = 265
    2) GTP values, 100 year time horizon, from 2013 Intergovernmental Panel on Climate Change (AR5 pg. 714): CO_2 GTP = 1; CH_4 GTP = 4 ; N_2O GWP = 234
- **Energy Prices**
  - Default electric and natural gas residential and commercial prices are based on state-level EIA 2016 annual average data (https://www.eia.gov).
  - Default oil and propane residential prices are based on state-level EIA 2016 weekly data, average over one year (https://www.eia.gov).
  - Default oil and propane commercial prices are estimated as 10% lower than residential state-level EIA 2016 annual average data.
  - U.S. average oil or propane price is used as the default for states with unavailable data.
  - Marginal pricing factors for natural gas were developed by AGA based on a member company survey.

(https://www.gti.energy/wp-content/uploads/2018/11/Technical-Analysis-of-DOE-Supplemental-Notice-of-Proposed-Rulemaking-on-Residential-Furnace-Minimum-Efficiencies.pdf)
- Marginal pricing factors for electricity were developed by the U.S. Department of Energy. (https://www.regulations.gov/document?D=EERE-2014-BT-STD-0048-0030 with methodology described in https://www.regulations.gov/document?D=EERE-2014-BT-STD-0048-0098)

EIA Citations:

[1] U.S. Energy Information Administration - Annual Energy Review 2011, Appendix F
Alternatives for Estimating Energy Consumption, Table F1. Conversion Efficiencies of Noncombustible Renewable Energy Sources. http://www.eia.gov/totalenergy/data/annual/pdf/sec17.pdf

Sources cited by U.S. EIA:

[1a] Conventional Hydroelectric: Based on published estimates for the efficiency of large-scale hydroelectric plants. http://www.usbr.gov/power/edu/pamphlet.pdf.

[1b] Solar Photovoltaic: Based on the average rated efficiency for a sample of commercially available modules. Rated efficiency is the conversion efficiency under standard test conditions, which represents a fixed, controlled operating point for the equipment; efficiency can vary with temperature and the strength of incident sunlight. Rated efficiencies are based on the direct current (DC) output of the module; since grid-tied applications require alternating current (AC) output, efficiencies are adjusted to account for a 20 percent reduction in output when converting from DC to AC.

[1c] Wind: Based on the average efficiency at rated wind speed for a sample of commercially available wind turbines. The rated wind speed is the minimum wind speed at which a turbine achieves its nameplate rated output under standard atmospheric conditions. Efficiency is calculated by dividing the nameplate rated power by the power available from the wind stream intercepted by the rotor disc at the rated wind speed.

[1d] Geothermal: Estimated by EIA on the basis of an informal survey of relevant plants.

[2] The nuclear average heat rate is the weighted average tested heat rate for nuclear units as reported on the Form EIA-860; https://www.eia.gov/electricity/annual/html/epa_08_01.html