Public Review Draft

Proposed Addendum h to Standard 189.1-2023

Standard for the Design of High-Performance Green Buildings

Except Low-Rise Residential Buildings

First Public Review (September, 2024)
(Draft Shows Proposed Changes to Current Standard)

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Foreword

The performance approach to energy efficiency compliance in Standard 189.1 currently requires compliance with each of three different metrics: cost, source energy, and CO2e. Requiring compliance with three metrics has the effect of increasing the overall stringency of the standard, perhaps beyond the stringency expected by the SSPC.

In recent years, the focus of the building industry has increasingly shifted to CO2e emissions.

This addendum deletes the use of energy cost and source energy metrics as requirements of the performance approach to energy efficiency. It leaves CO2e as the sole performance approach metric, although the current option of using either annual average emission factors or time varying factors is retained. However, the 90.1 backstop for energy efficiency is retained and the language has been moved from the previous Section 7.6.1.1 to new Section 7.6.1. This change will greatly simplify Section 7.6 for users and will simplify the process of updating the section each cycle.

[Note to Reviewers: This addendum makes proposed changes to the current standard. These changes are indicated in the text by <u>underlining</u> (for additions) and ~~strikethrough~~ (for deletions) except where the reviewer instructions specifically describe some other means of showing the changes. Only these changes to the current standard are open for review and comment at this time. Additional material is provided for context only and is not open for comment except as it relates to the proposed changes.]

Addendum h to 189.1-2023

Modify Section 7.6 as follows:

7.6 Performance Option. Buildings shall comply with Sections 7.6.1, <u>and with Section</u> 7.6.2~~, and 7.6.3~~ using the baseline building definition and modeling procedures as defined in Standard 90.1, Appendix G, and modified by Normative Appendix B of this standard.

On-site renewable energy systems in the *proposed design* shall be calculated using the procedures in Normative Appendix B. For mixed-use buildings, the building performance factor (BPF) shall be determined by weighting each building type by floor area. A *building project* served in whole or in part by a *district energy plant* shall follow the modeling requirements contained in Normative

Appendix B, Section B1.4, in order to comply with this section.

Delete Section 7.6.1 and renumber Section 7.6.1.1 as 7.6.1. Delete Table 7.6.1. Delete the "Source Energy Conversion Factors" column from Table 7.6.2.1.

~~**7.6.1 Annual Energy Cost.** The *proposed building performance* cost index (PCI) shall be calculated in accordance with ANSI/ASHRAE/IES Standard 90.1, Normative Appendix G, and be equal to or less than the target PCI, as determined from the following equation:~~

$$PCI_{target} = \frac{[EC_{UBB} + (EC_{RBB} \times BPF_c)] \times (1 - RF_c)}{EC_{UBB} + EC_{RBB}}$$

~~where~~
~~PCI_{target} = target PCI required for achieving compliance with Section 7.6.1 of the standard, unitless~~
~~EC_{UBB} = annual energy cost of the baseline building resulting from *unregulated energy use*, \$~~
~~EC_{RBB} = annual energy cost of the baseline building resulting from *regulated energy use*, \$~~
~~BPF_c = building performance factor for cost taken from Table 7.6.1, unitless~~
~~RF_c = renewable energy production fraction for cost from Table 7.6.1, unitless~~

~~**Table 7.6.1. Building Performance Factors for Cost (BPF_c) and Renewable Fraction (RF_c)**~~

		Building Type								
	Climate Zone	**Multifamily**	**Healthcare/ Hospital**	**Hotel/ Motel**	**Office**	**Restaurant**	**Retail**	**School**	**Warehouse**	**All Others**
Building Performance Factor for Cost	0A	0.69	0.62	0.64	0.51	0.63	0.46	0.51	0.25	0.55
	0B	0.68	0.60	0.63	0.52	0.61	0.44	0.54	0.27	0.55
	1A	0.72	0.63	0.66	0.50	0.61	0.42	0.55	0.21	0.61
	1B	0.69	0.60	0.61	0.51	0.60	0.42	0.54	0.24	0.54
	2A	0.73	0.60	0.61	0.46	0.60	0.38	0.51	0.20	0.58
	2B	0.73	0.56	0.61	0.47	0.60	0.36	0.52	0.21	0.59
	3A	0.74	0.57	0.60	0.45	0.62	0.36	0.50	0.21	0.57
	3B	0.76	0.57	0.62	0.48	0.62	0.37	0.50	0.20	0.60
	3C	0.68	0.54	0.59	0.40	0.62	0.35	0.52	0.17	0.48
	4A	0.74	0.58	0.62	0.45	0.64	0.37	0.47	0.27	0.56
	4B	0.75	0.56	0.59	0.46	0.64	0.37	0.47	0.21	0.56
	4C	0.74	0.53	0.60	0.43	0.65	0.38	0.50	0.23	0.54
	5A	0.73	0.57	0.63	0.48	0.66	0.37	0.49	0.32	0.59
	5B	0.76	0.54	0.62	0.48	0.65	0.37	0.48	0.26	0.57
	5C	0.75	0.55	0.60	0.46	0.67	0.40	0.47	0.23	0.54
	6A	0.72	0.58	0.65	0.49	0.67	0.37	0.48	0.35	0.57
	6B	0.73	0.57	0.62	0.49	0.65	0.39	0.45	0.30	0.53
	7	0.71	0.59	0.64	0.48	0.67	0.38	0.47	0.32	0.56
	8	0.73	0.60	0.66	0.52	0.69	0.40	0.48	0.34	0.61
Renewable Fraction		0.50	0.35	0.50	0.50	0.10	0.50	0.50	0.50	0.50

Table 7.6.2. Building Performance Factors for Emissions (BPF_e) and Renewable Fraction (RF_e)

	Climate Zone	Building Type								
		Multifamily	Healthcare / Hospital	Hotel/ Motel	Office	Restaurant	Retail	Schoo l	Warehouse	All Others
Building Performance Factor for Cost	0A	0.68	0.63	0.67	0.51	0.65	0.46	0.52	0.25	0.56
	0B	0.67	0.61	0.66	0.53	0.63	0.44	0.55	0.27	0.56
	1A	0.71	0.63	0.68	0.51	0.62	0.43	0.56	0.21	0.61
	1B	0.69	0.60	0.63	0.51	0.62	0.43	0.55	0.24	0.55
	2A	0.71	0.60	0.64	0.46	0.63	0.39	0.53	0.20	0.58
	2B	0.71	0.57	0.65	0.48	0.63	0.37	0.53	0.21	0.59
	3A	0.74	0.58	0.65	0.46	0.66	0.39	0.54	0.24	0.59
	3B	0.72	0.58	0.66	0.48	0.65	0.38	0.52	0.20	0.59
	3C	0.66	0.56	0.64	0.41	0.65	0.36	0.55	0.16	0.49
	4A	0.68	0.59	0.65	0.43	0.68	0.40	0.47	0.32	0.54
	4B	0.70	0.57	0.61	0.46	0.67	0.39	0.49	0.24	0.56
	4C	0.67	0.55	0.65	0.43	0.68	0.41	0.54	0.26	0.53
	5A	0.65	0.58	0.65	0.46	0.69	0.41	0.50	0.39	0.57
	5B	0.68	0.56	0.65	0.48	0.68	0.40	0.50	0.31	0.56
	5C	0.67	0.58	0.64	0.47	0.69	0.43	0.49	0.26	0.55
	6A	0.64	0.60	0.66	0.47	0.69	0.41	0.49	0.43	0.56
	6B	0.65	0.60	0.65	0.49	0.69	0.43	0.46	0.36	0.54
	7	0.62	0.61	0.66	0.46	0.70	0.42	0.46	0.38	0.54
	8	0.64	0.63	0.66	0.49	0.71	0.44	0.48	0.40	0.60
Renewable Fraction		0.50	0.35	0.50	0.50	0.10	0.50	0.50	0.50	0.50

Delete the "Source Energy Conversion Factors" column from Table 7.6.2.1.

Table 7.6.2.1 ~~Source Energy Conversion Factors and~~ CO2e Emission Factors

		CO_2e Emissions, kg/MWh		
	~~Source Energy Conversion Factor~~	Combustion	Precombustion	Total
Fossil fuels delivered to buildings				
Natural gas	~~1.092~~	184	93	277
Liquefied petroleum gas or propane	~~1.151~~	229	66	295
Fuel oil (residual)	~~1.191~~	265	70	334
Fuel oil (distillate)	~~1.158~~	255	69	324
Coal	~~1.048~~	332	51	382
Gasoline	~~1.187~~	255	82	337
Other fuels not specified in this table	~~1.048~~	332	51	382
	Electricity			
AKGD–ASCC Alaska Grid	~~2.47~~	514	159	673
AKMS–ASCC miscellaneous	~~1.35~~	289	93	383

AZNM –WECC Southwest	~~2.57~~	444	121	565
CAMX–WECC California	~~1.66~~	255	88	343
ERCT–ERCOT all	~~2.32~~	431	126	558
FRCC–FRCC all	~~2.78~~	442	155	596
HIMS–HICC miscellaneous	~~3.15~~	681	211	892
HIOA–HICC Oahu	~~3.87~~	895	233	1128
MROE–MRO East	~~2.92~~	770	150	920
MROW–MRO West	~~2.21~~	534	94	628
NEWE–NPCC New England	~~2.66~~	287	96	383
NWPP–WECC Northwest	~~1.48~~	349	76	426
NYCW–NPCC NYC/Westchester	~~2.89~~	269	110	379
NYLI–NPCC Long Island	~~2.84~~	481	169	650
NYUP–NPCC Upstate NY	~~1.81~~	132	48	180
PRMS–Puerto Rico Miscellaneous	~~3.27~~	731	214	944
RFCE–RFC East	~~2.90~~	350	106	456
RFCM–RFC Michigan	~~2.93~~	594	133	727
RFCW–RFC West	~~2.97~~	532	113	645
RMPA–WECC Rockies	~~2.16~~	580	120	699
SPNO–SPP North	~~2.21~~	515	93	608
SPSO–SPP South	~~2.05~~	460	123	583
SRMV–SERC Mississippi Valley	~~2.84~~	418	137	555
SRMW–SERC Midwest	~~3.09~~	779	134	913
SRSO–SERC South	~~2.89~~	496	133	629
SRTV–SERC Tennessee Valley	~~2.82~~	473	104	577
SRVC–SERC Virginia/Carolina	~~2.91~~	360	97	456
All other electricity	~~2.51~~	436	111	547
Thermal Energy				
Chilled water	~~0.60~~	104	26	131
Steam	~~1.84~~	309	157	466
Hot water	~~1.73~~	292	148	440

Informative Note: The CO_2e emission factors presented in this table are based on U.S. data and a 20-year time horizon for methane (CH_4) and nitrous oxide (N_2O). When comparing or combining CO_2e values, care should be taken to ensure that a consistent time horizon is used for all estimates of CO_2e. Informative Appendix I, Table I-10, has emission rates based on a 100-year time horizon for use when the use of 100-year time horizons is necessary.

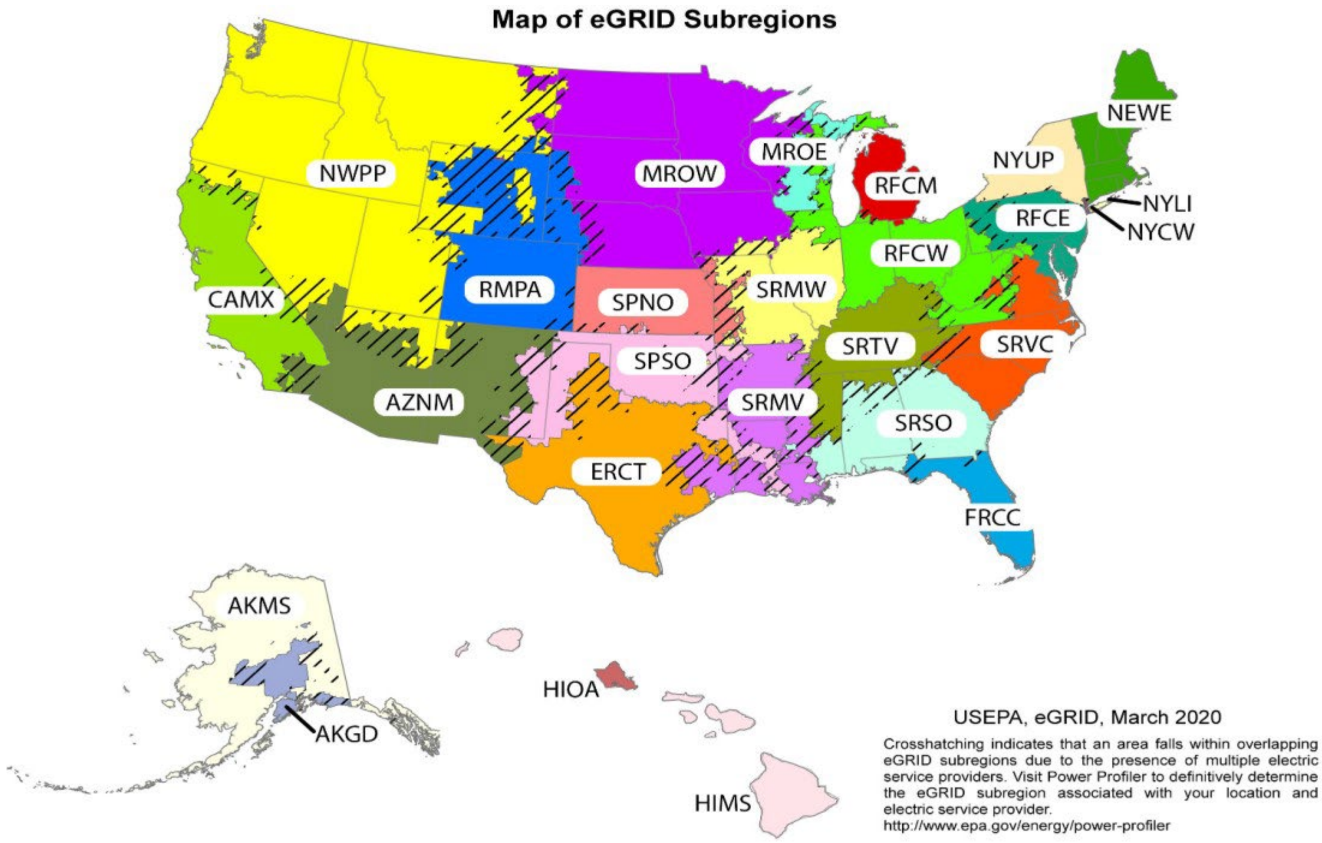

Figure 7.6.2.1 Map of eGRID subregions.
Crosshatching indicates that an area falls within overlapping eGRID subregions due to the presence of multiple electric service providers. Power Profiler can be used to definitively determine the eGRID subregion associated with a specific location and electric service provider (www.epa.gov/energy/power-profiler).

Table 7.6.2.2.1 Building Performance Factors for Emissions (BPF_e) and Renewable Fraction (RF_e) for Use with LRMER

	Climate Zone	Building Type								
		Multifamily	Healthcare/ Hospital	Hotel/ Motel	Office	Restaurant	Retail	School	Warehouse	All Others
Building Performance Factor for Greenhouse Gas Emissions	0A	0.70	0.63	0.67	0.51	0.63	0.43	0.55	0.22	0.54
	0B	0.70	0.63	0.67	0.51	0.63	0.43	0.55	0.22	0.54
	1A	0.70	0.63	0.67	0.51	0.63	0.43	0.55	0.22	0.54
	1B	0.70	0.63	0.67	0.51	0.63	0.43	0.55	0.22	0.54
	2A	0.70	0.60	0.64	0.47	0.64	0.39	0.53	0.21	0.52
	2B	0.68	0.59	0.73	0.49	0.67	0.39	0.57	0.22	0.54
	3A	0.72	0.58	0.66	0.47	0.69	0.42	0.56	0.28	0.55
	3B	0.64	0.60	0.73	0.49	0.70	0.43	0.56	0.22	0.55
	3C	0.57	0.63	0.78	0.44	0.73	0.41	0.70	0.17	0.55
	4A	0.63	0.58	0.65	0.43	0.69	0.44	0.45	0.37	0.53
	4B	0.59	0.59	0.66	0.47	0.73	0.45	0.53	0.31	0.54
	4C	0.51	0.60	0.76	0.43	0.75	0.57	0.65	0.41	0.59
	5A	0.60	0.59	0.65	0.45	0.71	0.45	0.50	0.47	0.55
	5B	0.54	0.59	0.70	0.47	0.74	0.51	0.54	0.43	0.57
	5C	0.49	0.68	0.73	0.49	0.76	0.57	0.55	0.39	0.58
	6A	0.57	0.61	0.66	0.46	0.72	0.47	0.48	0.52	0.56
	6B	0.52	0.65	0.69	0.47	0.75	0.56	0.46	0.50	0.58
	7	0.53	0.64	0.66	0.43	0.73	0.49	0.45	0.46	0.55
	8	0.62	0.63	0.66	0.49	0.71	0.45	0.47	0.43	0.56
Renewable Fraction		0.50	0.35	0.50	0.50	0.10	0.50	0.50	0.50	0.50

~~7.6.1.1~~ 7.6.1 Compliance with ANSI/ASHRAE/IES Standard 90.1 without Renewables. The proposed building PCI shall comply with the requirements of ANSI/ASHRAE/IES Standard 90.1, Section 4.2.1.1. The energy cost credits from on-site renewable energy production shall not be subtracted from the *proposed design* energy costs for the purposes of this section.

7.6.2 Zero Carbon Emissions Factor (zCEF). The *proposed design zCEF* shall be equal to or less than the target *zCEF* as follows:

$$zCEF_{PROPOSED} \leq zCEF_{TARGET}$$

Where:

$$zCEF_{TARGET} = \frac{[GHG_{UBB} + (GHG_{RBB} \times BPF_E)] \times (1 - RF_E)}{GHG_{UBB} + GHG_{RBB}}$$

and

$$zCEF_{PROPOSED} = \frac{GHG_P - AE}{GHG_{UBB} + GHG_{RBB}}$$

and

$zCEF_{target}$ = target *zCEF* required for achieving compliance with the standard, unitless

$zCEF_{proposed}$ = proposed building *zCEF*, unitless

GHG_{UBB} = baseline building annual CO_2e emissions resulting from unregulated energy (see Section 7.6.2.1), CO_2e

GHG_{RBB} = baseline building annual CO_2e emissions resulting from regulated energy (see Section 7.6.2.1), CO_2e

BPF_e = building performance factor for emissions taken from Table 7.6.2, unitless

RF_e = renewable energy production fraction for emissions from Table 7.6.2, unitless

$GHG_{proposed}$ = proposed building annual CO_2e emissions resulting from regulated and unregulated energy (see Section 7.6.2.1), CO_2e

AE = avoided CO_2e emissions resulting from the purchase of off-site renewable energy (see Section 7.6.2.1)

7.6.2.1 Annual Average GHG Emissions. To determine the annual CO_2e for each energy source in the baseline building and *proposed design* (GHG_{UBB} , GHG_{RBB}, $GHG_{proposed}$), the energy consumption for each fuel shall be multiplied by the CO_2e emission factors from Table 7.6.2.1. U.S. locations shall use values for eGRID subregions from Table 7.6.2.1 and Figure 7.6.2.1 for electricity. Locations outside the U.S. shall use the value for "All other electricity" or locally derived values.

(***Informative Note:*** The values in Table 7.6.2.1 are based on eGRID subregions and delivery of fossil fuels for U.S. locations. Some jurisdictions use locally derived values based on procedures in Informative Appendix I.)

$$GHG_x = \sum_i [Q_i \times e_i]$$

where

GHG_x = annual CO_2e emissions for GHG_{UBB}, GHG_{RBB}, and $GHG_{proposed}$ from Section 7.6.2, kg

Q_i = annual energy consumption, MWh

e_i = CO_2e emissions rate taken from Table 7.6.2.1 for fuel type *i*; eGRID values shall be used for electricity when applicable, kg/MWh

i = index for fuel used at the baseline or proposed building

The avoided emissions from off-site renewable energy procurement shall be calculated as follows:

$$\mathrm{AE} = \sum_k [Q_k \times \mathrm{REPF}_k \times e_e]$$

where

Q_k = annual renewable energy (electricity) purchased through procurement method *k*, MWh

REPF_k = renewable energy procurement factor from Table 7.4.1.2 for renewable energy procurement method *k*, unitless

e_e = CO_2e emissions rate for electricity taken from Table 7.6.2.1. eGRID values shall be used when applicable.

k = index for off-site renewable energy procurement method

7.6.2.2 [JO] Long-Run Marginal Emission Rates (LRMER). Section 7.6.2.2 replaces Section 7.6.2.1 for electricity emissions calculations. Electricity *carbon dioxide equivalent (CO_2e)* emissions for the *baseline building design* and *proposed design* shall be calculated using the long-run marginal emission rates from Normative Appendix D for each time period. The calculation shall be made using month-hour or annual-hour values and shall be *approved*. For fossil fuels and thermal energy, the CO_2e emissions shall be calculated by multiplying by the CO_2e emission factors from Table 7.6.2.1 times the annual consumption.

$$GHG_x = \sum_t [q_{e,t} \times e_{e,t}] + \sum_i [Q_i \times e_i]$$

where

GHG_x = annual long-run marginal CO_2e emissions for GHG_{UBB}, GHG_{RBB}, and GHG_P, units CO_2e for a specified GWP time horizon

$q_{e,t}$ = annual electricity consumption for time period t, MWh

$e_{e,t}$ = long-run marginal CO_2e emissions rate for electricity in time period t from Normative Appendix D, Tables D-1 through D-20 units kg/MWh

t = index for time period of electricity consumption

Q_i = annual energy consumption for fossil fuels or thermal energy, MWh

e_i = CO_2e emissions rate taken from Table 7.6.2.1 for fossil fuel or thermal energy type i

i = index for fossil fuel or thermal energy type

Informative Note: The CO_2e time-horizon is independent of the index for the time period of electricity consumption (t).

The avoided emissions from off-site renewable energy procurement shall be calculated as shown in the following equation and meet the requirements of Section 7.4.1.3.

$$\mathrm{AE} = \sum\nolimits_g [Q_g \times \mathrm{REPF} \times AE_g]$$

where

Q_g = annual renewable electricity procured for renewable energy generator type g, MWh

g = index for generator type

AE_g = annual avoided CO_2e emissions rate for renewable energy generator type g from Normative Appendix D, Table D-21, units kg/MWh

REPF = applicable renewable energy procurement factor from Table 7.4.1.2

7.6.2.2.1 Long-Run Marginal Emission Rates Building Performance Factors. Building performance factors for carbon from Table 7.6.2.2.1 shall be used.

Delete Section 7.6.3 in its entirety.

~~**7.6.3 Zero Energy Performance Index.** The zero energy performance index ($zEPI_{2004}$) of the proposed design, including on-site renewable energy systems, shall be less than the target ($zEPI_{2004\ Target}$). $zEPI_{2004}$ and $zEPI_{2004\ Target}$ shall be calculated as follows:~~

$$\cancel{\mathrm{zEPI}_{2004} = \frac{\sum_i \mathrm{PDSE}_i \times r_i - \sum_k \mathrm{RE}_k \times \mathrm{REPF}_k \times r_e}{\sum_i \mathrm{BBSE}_i \times r_i}}$$

~~where~~

~~$zEPI_{2004}$ = zero energy performance index relative to the Standard 90.1 *baseline building design* as defined in the performance rating method of Standard 90.1, Normative Appendix G~~

~~$PDSE_i$ = *proposed design* site energy use for energy type i~~

~~$BBSE_i$ = baseline building site energy use for energy type i; created following the rules in Standard 90.1, Normative Appendix G~~

~~r_i = source energy conversion factor for energy type i; taken from Table 7.6.2.1~~

~~RE_k = annual renewable energy electricity production for renewable energy procurement method k (see Table 7.4.1.2)~~

~~$REPF_k$ = renewable energy factor from Table 7.4.1.2 for renewable energy procurement method k~~

~~r_e = source energy conversion factor taken from Table 7.6.2.1 for electricity. U.S. Locations shall use values for eGRID subregions from Table 7.6.2.1 for electricity. Locations outside the U.S. shall use the value for "All other electricity" or locally derived values.~~

$$\cancel{zEPI_{2004Target} = \frac{[BBUSE + (BBRSE \times BPF)] \times (1 - RF)}{BBUSE + BBRSE}}$$

~~where~~

~~$zEPI_{2004\ target}$ = zero energy performance index target required for achieving compliance with the standard, unitless~~

~~BBUSE = baseline building *unregulated energy use* expressed in source units~~

~~BBRSE = baseline building *regulated energy use* expressed in source units.~~

~~BPF_c = building performance factor for cost taken from Table 7.6.1, unitless~~

~~RF_c = renewable fraction for cost from Table 7.6.1, unitless~~

~~***Informative Notes:***~~

1. ~~On-site thermal energy and renewable energy contributions to *district energy plants* are accounted for in the $PDSE_i$ term through reductions in electricity and/or gas use. The RE_k term will always be electricity.~~
2. ~~Informative Appendix H details a methodology for converting $zEPI_{2004}$ to zEPI. $zEPI_{2004}$ uses Standard 90.1, Normative Appendix G, to define the baseline building. The traditional definition of zEPI uses the median energy of the existing building stock in the year 2000 as the baseline. The traditional zEPI definition is used by the Architecture 2030 program and other programs.~~
3. ~~The values in Table 7.6.2.1 are derived from United States data. The procedures in Informative Appendix I may be used to develop source energy conversion factors when conditions are different.~~

Renumber Section 7.6.4 as 7.6.3:

~~7.6.4~~ 7.6.3 [JO] Energy Simulation Aided Design. For building projects that exceed 25,000 ft² (2300 m²) of gross floor area, the building project shall comply with the requirements of ANSI/ASHRAE Standard 209, Section 4.2.1.

Delete Informative Appendix H, zEPI Conversion Methodology *in its entirety and reletter all subsequent appendices.*

~~INFORMATIVE APPENDIX H~~

~~*zEPI CONVERSION METHODOLOGY*~~

~~The procedures in Section 7.6.3 result in a zEPI target ($zEPI_{2004\ Target}$) and a zEPI rating ($zEPI_{2004}$) that use Standard 90.1, Normative Appendix G, to define the baseline building. The traditional baseline for zEPI uses CBECS 2003 to approximate the building stock at the turn of the millennium. Both $zEPI_{2004\ Target}$ and $zEPI_{2004}$ can be converted to the traditional baseline by applying the multipliers in Table H-1.~~

$$\cancel{zEPI = zEPI_{2004} \times M}$$

$$\cancel{zEPI_{Target} = zEPI_{2004\ Target} \times M}$$

~~where~~

~~zEPI~~	=	~~zero energy performance index using CBECS 2003 as the baseline~~
~~$zEPI_{2004}$~~	=	~~zero energy performance index using Standard 90.1, Appendix G, as the baseline~~
~~$zEPI_{Target}$~~	=	~~zero energy performance index target using CBECS 2003 as the baseline~~
~~$zEPI_{2004\ Target}$~~	=	~~zero energy performance index target using Standard 90.1, Appendix G, as the baseline~~

~~**Table H-1 zEPI Conversion Factors, *M***~~

	~~1A~~	~~2A~~	~~3A~~	~~4A~~	~~5A~~	~~6A~~	~~7~~	~~2B~~	~~3B~~	~~4B~~	~~5B~~	~~6B~~	~~3C~~	~~4C~~	~~8~~
~~Multifamily~~	~~0.93~~	~~0.86~~	~~0.81~~	~~0.78~~	~~0.79~~	~~0.79~~	~~0.76~~	~~0.86~~	~~0.91~~	~~0.80~~	~~0.80~~	~~0.79~~	~~0.82~~	~~0.77~~	~~0.74~~
~~Health care/hospital~~	~~0.82~~	~~0.83~~	~~0.82~~	~~0.83~~	~~0.86~~	~~0.86~~	~~0.87~~	~~0.81~~	~~0.82~~	~~0.82~~	~~0.85~~	~~0.86~~	~~0.87~~	~~0.83~~	~~0.85~~
~~Hotel/motel~~	~~0.80~~	~~0.85~~	~~0.88~~	~~0.92~~	~~0.95~~	~~0.98~~	~~1.01~~	~~0.83~~	~~0.87~~	~~0.91~~	~~0.95~~	~~0.97~~	~~0.91~~	~~0.93~~	~~1.03~~
~~Office~~	~~0.75~~	~~0.76~~	~~0.71~~	~~0.71~~	~~0.72~~	~~0.72~~	~~0.70~~	~~0.75~~	~~0.73~~	~~0.71~~	~~0.72~~	~~0.72~~	~~0.78~~	~~0.72~~	~~0.68~~
~~Restaurant~~	~~0.92~~	~~0.93~~	~~0.92~~	~~0.92~~	~~0.92~~	~~0.91~~	~~0.90~~	~~0.93~~	~~0.94~~	~~0.92~~	~~0.92~~	~~0.92~~	~~0.94~~	~~0.93~~	~~0.88~~
~~Retail~~	~~0.61~~	~~0.62~~	~~0.59~~	~~0.61~~	~~0.61~~	~~0.61~~	~~0.61~~	~~0.61~~	~~0.59~~	~~0.61~~	~~0.60~~	~~0.62~~	~~0.61~~	~~0.64~~	~~0.61~~
~~School~~	~~0.83~~	~~0.83~~	~~0.79~~	~~0.81~~	~~0.82~~	~~0.84~~	~~0.83~~	~~0.82~~	~~0.81~~	~~0.80~~	~~0.83~~	~~0.84~~	~~0.84~~	~~0.80~~	~~0.75~~
~~Semiheated warehouse~~	~~2.07~~	~~0.94~~	~~0.80~~	~~0.68~~	~~0.61~~	~~0.56~~	~~0.54~~	~~1.02~~	~~1.06~~	~~0.74~~	~~0.66~~	~~0.60~~	~~0.88~~	~~0.75~~	~~0.49~~
~~All others~~	~~0.93~~	~~0.81~~	~~0.78~~	~~0.78~~	~~0.78~~	~~0.78~~	~~0.79~~	~~0.81~~	~~0.83~~	~~0.78~~	~~0.78~~	~~0.80~~	~~0.81~~	~~0.79~~	~~0.77~~

~~***Note:*** For climate zones 0A/0B, use the values for 1A/1B, respectively~~

In Informative Appendix I, Delete Section I.1, Source Energy Conversion Factors and Table I.1- Table I.3., and renumber all subsequent sections and table numbers.

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not been processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on infor- mative material are not offered the right to appeal at ASHRAE or ANSI.)

INFORMATIVE APPENDIX I
DERIVATION OF SOURCE ENERGY CONVERSION FACTORS AND CO_2e EMISSION FACTORS

This informative appendix documents the procedures used to develop the source energy conversion factors and CO_2e emission factors in Table 7.5.3 of Standard 189.1 and provides guidance on how the data can be modified for non-United States locations. Example data used to illustrate the procedure is for the entire United States electric grid in 2019. A similar procedure was used to develop source energy conversion factors and CO_2e emission factors for the eGRID subregions based on EPA eGRID data for 2019, the only difference being the mix of electric generators.

The GHG emission rates in this appendix are applicable to the operation of the building and are keyed to building energy use. This appendix does not address the embodied carbon emissions related to building construction or demolition and recycling at the end-of-life.

~~I1. SOURCE ENERGY CONVERSION FACTORS~~

~~I1.1 Source Energy Conversion Factors for Fossil Fuels~~

~~For the United States, the source energy conversion factors for fossil fuel delivered to buildings or power plants are listed in Table I1. These factors represent the additional energy required to extract, process, and deliver the fuel to a building or power plant. The values for bituminous coal are assumed for all U.S. coal-fired power plants.~~

~~Table I.1 – Source Energy Conversion Factors for Fuel Delivered to Buildings~~

~~Fuel~~	~~Source Energy Conversion Factor ($SECF_{Fuel}$)~~
~~Anthracite Coal~~	~~1.029~~
~~Bituminous Coal~~	~~1.048~~
~~Sub-bitumious Coal~~	~~1.066~~
~~Lignite Coal~~	~~1.102~~
~~Natural Gas~~	~~1.092~~
~~Residual Fuel Oil~~	~~1.191~~
~~Distillate Fuel Oil~~	~~1.158~~
~~Gasoline~~	~~1.187~~
~~LPG~~	~~1.151~~
~~Kerosene~~	~~1.205~~

~~Data Source: Michael Deru and Paul Torcellini , Source Energy and Emission Factors for Energy Use in Buildings, National Renewable Energy Laboratory, Technical Report NREL/TP-550-38617, Revised June 2007, Table 5. This data was derived from the U.S. LCI (life cycle inventory) database, maintained by NREL.~~

~~I1.2 Source Conversion Factors for Electricity~~

~~For electricity, the source energy conversion factors represent the energy required to extract, process, and deliver fuel to power plants plus the energy used at the power plant to generate electricity. Transmission and distribution losses are also accounted for.~~

~~I1.2.1 Distribution Efficiency~~

~~For 2019 the U.S. Energy Information Agency (EIA) reports that, 3,965 billion kWh were generated at domestic power plants in the United States and that 211 billion kWh (5.3%) were lost through the transmission and distribution (T&D) system. This results in a distribution~~

~~efficiency of 94.7%. These data are taken from Table 7.1 of the EIA Monthly Energy Report (MER). The nation-wide distribution efficiency is assumed for each of the eGRID subregions in the U.S. T&D losses in the U.S. have been fairly stable for the last 30 years or so, averaging about 7.2%. When the procedure in this appendix is applied to the electric grid in other countries, the assumption on T&D losses should be updated based on local conditions.~~

~~I1.2.2 Heat Rates~~

~~The efficiency of power plants is commonly stated in terms of a heat rate, which represents the amount of fuel needed to generate a unit of electricity. The common units in the U.S. are Btu/kWh. The heat rate for coal, petroleum and nuclear power plants has not changed much in the last 20 years, but the heat rate of natural gas power plants has significantly declined, mainly because new plants use more efficient combined-cycle technology. Heat rates are reported by EIA in Table A6 of their MER and are listed here in Table I2. The heat rate for biomass plants is not directly reported by EIA, but is calculated by dividing the heat input to wood and waste power plants from Table 10.2c of EIA's MER by the electricity generated by these plants which is reported in Table 7.2b of EIA's MER. The heat rate of non-combustible renewable power plants (wind, solar, hydro, and geothermal) is assumed to be zero.~~

~~The power plant efficiency is determined by dividing the heat content of a kWh of electricity (3,412 Btu/kWh) by the heat rate.~~

~~I1.2.3 Source Energy Conversion Factor for Power Plant Types~~

~~The source energy conversion factor for each type of power plant is calculated as shown in Equation I1. Calculated values for each type of power plant are shown in Table I2~~

~~Equation I1~~

$$\cancel{SECF_{PowerPlant} = \frac{SECF_{Fuel}}{DeliveryEfficiency \times PowerPlantEfficiency}}$$

~~where~~

~~$SECF_{PowerPlant}$ Source energy conversion factor for each power plant type (unitless)~~

~~$SECF_{Fuel}$ Source energy conversion factor of the fuel used at the power plant (unitless) taken from Table I1.~~

~~$HeatRate_{PowerPlant}$ Heat rate (efficiency) of the power plant (Btu/kWh)~~

~~DeliveryEfficiency Delivery efficiency (see I1.2.1)~~

~~PowerPlantEfficiency Power plant efficiency, determined by dividing 3,412 Btu/kWh by the heat rate.~~

~~Table I1 – Calculation of SECF for Power Plant Types~~

~~Power Plant Type~~	~~Heat $Rate_{PowerPlant}$~~	~~Power Plant Efficiency~~	~~$SECF_{Fuel}$~~	~~Delivery Efficiency~~	~~$SECF_{PowerPlant}$~~
~~Coal~~	~~10,551~~	~~32.3%~~	~~1.048~~	~~94.7%~~	~~3.42~~
~~Petroleum~~	~~11,135~~	~~30.6%~~	~~1.191~~	~~94.7%~~	~~4.11~~
~~Natural Gas~~	~~7,732~~	~~44.1%~~	~~1.092~~	~~94.7%~~	~~2.61~~
~~Other Gases~~	~~7,732~~	~~44.1%~~	~~1.092~~	~~94.7%~~	~~2.61~~
~~Nuclear~~	~~10,442~~	~~32.7%~~	~~1.000~~	~~94.7%~~	~~3.23~~
~~Pumped Storage~~	~~8,904~~	~~38.3%~~	~~1.000~~	~~94.7%~~	~~2.76~~
~~Hydroelectric~~	~~0~~	~~n.a.~~	~~n.a.~~	~~94.7%~~	~~0~~
~~Wood~~	~~16,682~~	~~20.5%~~	~~1.025~~	~~94.7%~~	~~5.29~~
~~Waste~~	~~15,388~~	~~22.2%~~	~~1.025~~	~~94.7%~~	~~4.88~~
~~Geothermal~~	~~0~~	~~n.a.~~	~~n.a.~~	~~94.7%~~	~~0~~
~~Solar~~	~~0~~	~~n.a.~~	~~n.a.~~	~~94.7%~~	~~0~~
~~Wind~~	~~0~~	~~n.a.~~	~~n.a.~~	~~94.7%~~	~~0~~

~~Notes:~~

~~1 Heat rates are taken from Table A6 of EIA's MER for 2019.~~

~~2 The heat rate for wood and waste is the 2019 fuel consumption from Table 10.2c of the EIA Monthly Energy Report~~

~~divided by the 2019 biomass net generation from Table 7.2b of the MER.~~

~~I1.2.4 Source Energy Conversion Factors for Electric Generation Mix~~

~~The source energy conversion factor for the United States and for each eGRID subregion is calculated as the weighted average of the source energy conversion factors for each power plant type from Table I2, based on the generation mix for each electric grid or sub-grid (see Equation I2).~~

~~Equation I2~~

$$\cancel{SECF_{GenMix} = \sum_{i=1}^{n} SECF_i \times GenMix_i}$$

~~where~~

~~$SECF_{GenMix}$ Overall SECF for the mix of generator types in the electric grid~~
~~$SECF_i$ Source energy conversion factor of the i^{th} generator type~~
~~$GenMix_i$ The fraction of total electric generation provided by the i^{th} generator type~~
~~i Index for the i^{th} generator type~~
~~n The number of generator types in the electric grid~~

~~Table I3 shows the mix of electricity generated in the United States in 2019 (from EIA MER Table 7.2b) and illustrates how the source energy conversion factor is calculated as a weighted average. A similar process was used to calculate the SECF for each eGRID subregion, the only difference being the mix of generator types.~~

~~Table I2 – United States Electricity Generation Mix for 2019~~

~~Source: Energy Information Agency, Monthly Energy Report, Table 7.2b~~

~~Generator Type~~	~~Percent of Generation~~		~~Source Energy Conversion Factor for Generator Type~~		~~Product~~
~~Coal~~	~~24.2%~~	×	~~3.42~~	=	~~0.83~~
~~Petroleum~~	~~0.4%~~	×	~~4.11~~	=	~~0.02~~
~~Natural Gas~~	~~37.3%~~	×	~~2.61~~	=	~~0.97~~
~~Other Gases~~	~~0.1%~~	×	~~2.61~~	=	~~0.00~~
~~Nuclear~~	~~20.4%~~	×	~~3.23~~	=	~~0.66~~
~~Pumped Storage~~	~~-0.1%~~	×	~~2.76~~	=	~~(0.00)~~
~~Hydroelectric~~	~~7.2%~~	×	~~0~~	=	~~-~~
~~Wood~~	~~0.3%~~	×	~~5.29~~	=	~~0.02~~
~~Waste~~	~~0.4%~~	×	~~4.88~~	=	~~0.02~~
~~Geothermal~~	~~0.4%~~	×	~~0~~	=	~~-~~
~~Solar~~	~~1.8%~~	×	~~0~~	=	~~-~~
~~Wind~~	~~7.4%~~	×	~~0~~	=	~~-~~
			~~Sum Product~~		~~2.51~~

In Informative Appendix I, renumber all subsequent sections and table numbers. The rest of informative appendix I remains unchanged.

I1 ~~I2~~ . CARBON DIOXIDE EQUIVALENT (CO_2E) EMISSIONS

I~~2~~1.1 Fossil Fuel Emissions.

Fossil fuel combustion results in the release of three significant greenhouse gases: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). While the amount of of CH_4 and N_2O are small compared to CO_2, these gases have a much larger impact on global warming than CO_2 for a given mass of emissions. The global warming potential (GWP) for 20-year and 100-year cumulative forcing as determined by the International Panel of Climate Change (IPCC) is used in the analysis (see Table I1 ~~I4~~). These data are used to determine the CO_2e values and are used to calculate the CO_2e for both fuels delivered to power plants and directly to buildings.

Table I1 I3 – Global Warming Potential (unitless multipliers)

	Carbon Dioxide (CO_2)	Methane (CH_4)	Nitrous Oxide (N_2O)
20 Year Cumulative Forcing	1	82.5	273
100 Year Cumulative Forcing	1	29.8	273

Source: These values are taken from Table 7.15 of the IPCC AR6 Draft, released August 7, 2021 report (page 7-125)

Greenhouse gas emissions are released at the point of combustion (stack emissions) but emissions also result from the mining of coal, production of oil and gas, refinement, pumping, trucking, rail transport and/or piping of fuels. Table I2 ~~I5~~ lists both the combustion and pre-combustion emission rates of CO_2, CH_4 and N_2O per unit of fuel consumed by power plants. Table I3 ~~I6~~ lists the emission rates for fuels delivered to buildings. CO_2e is calculated for both 20 and 100-year global warming potentials.

Table I2 ~~I4~~ – Combustion and Pre-Combustion Emissions for Fossil Fuels Use at Power Plants

Fuel	Carbon Dioxide (CO_2)	Methane (CH_4)	Nitrous Oxide (N_2O)	$Emissions_{Fuel}$ CO_2e (20-year)	$Emissions_{Fuel}$ CO_2e (100-year)
Combustion Emissions (kg/MWh of fuel consumption)					
Coal	326.90	0.0385	0.0056	331.61	329.58
Petroleum	261.44	0.0108	0.0022	262.93	262.36
Natural Gas	183.64	0.0034	0.0004	184.02	183.84
Other Gases	183.64	0.0034	0.0004	184.02	183.84
Nuclear	0.00	0.0000	0.0000	0.00	0.00
Pumped Storage	0.00	0.0000	0.0000	0.00	0.00
Hydroelectric	0.00	0.0000	0.0000	0.00	0.00
Wood	161.09	0.0110	0.0188	167.13	166.55
Waste	161.09	0.0110	0.0188	167.13	166.55
Geothermal	0.00	0.0000	0.0000	0.00	0.00
Solar	0.00	0.0000	0.0000	0.00	0.00
Wind	0.00	0.0000	0.0000	0.00	0.00
Pre-Combustion Emissions (kg/MWh of fuel consumption)					
Coal	7.40	0.5233	0.0001	50.60	23.02
Petroleum	35.94	0.5573	0.0006	82.08	52.72
Natural Gas	16.47	0.7350	0.0000	77.13	38.40
Other Gases	16.47	0.7350	0.0000	77.13	38.40
Nuclear	0.00	0.0000	0.0000	0.00	0.00
Pumped Storage	0.00	0.0000	0.0000	0.00	0.00
Hydroelectric	0.00	0.0000	0.0000	0.00	0.00
Wood	7.53	0.0090	0.0000	8.28	7.81
Waste	7.53	0.0090	0.0000	8.28	7.81
Geothermal	9.07	0.0000	0.0000	9.07	9.07
Solar	0.00	0.0000	0.0000	0.00	0.00
Wind	0.00	0.0000	0.0000	0.00	0.00
Total Emissions (kg/MWh of fuel consumption)					
Coal	334.30	0.5618	0.0057	382.21	352.60
Petroleum	297.39	0.5681	0.0028	345.01	315.08
Natural Gas	200.11	0.7385	0.0004	261.15	222.23
Other Gases	200.11	0.7385	0.0004	261.15	222.23
Nuclear	0.00	0.0000	0.0000	0.00	0.00
Pumped Storage	0.00	0.0000	0.0000	0.00	0.00
Hydroelectric	0.00	0.0000	0.0000	0.00	0.00
Wood	168.62	0.0201	0.0188	175.41	174.36
Waste	168.62	0.0201	0.0188	175.41	174.36
Geothermal	9.07	0.0000	0.0000	9.07	9.07
Solar	0.00	0.0000	0.0000	0.00	0.00
Wind	0.00	0.0000	0.0000	0.00	0.00

Source of Data:
Combustion and pre-combustion emissions for coal (bituminous assumed), petroleum, and natural gas are taken from the National Renewable Energy Laboratory LCI database. Values were first published in Michael Deru and Paul Torcellini , Source Energy and Emission Factors for Energy Use in Buildings, National Renewable Energy Laboratory, Technical Report NREL/TP-550-38617, Revised June 2007. These data were updated by NREL in 2021.
Pre-combustion methane emissions for natural gas are based on total losses of 1.09% for gas delivered to power plants. These data were derived from Table ES-1 of Life Cycle Analysis of Natural Gas Extraction and Power Generation, April 19, 2019, DOE/NETL-2019/2039.
Values for biomass were not reported in the NREL document. Data in this table were derived separately from EIA data and information from the California Air Resources Board (CARB). The cumulative net emissions for the 20-year and 100-year periods are adjusted by subtracting the estimated counterfactual emissions.
Emissions at geothermal plants are small, but not zero. A value of 20 lb of CO_2 per MWh of production is assumed based on geothermal plants in the western United States.

Table I3 ~~I5~~ – Combustion and Pre-Combustion Emissions for Fossil Fuels Use at Buildings

Fuel	Carbon Dioxide (CO_2)	Methane (CH_4)	Nitrous Oxide (N_2O)	$Emissions_{Fuel}$ CO_2e (20-year)	$Emissions_{Fuel}$ CO_2e (100-year)

Combustion Emissions (kg/MWh of fuel consumption)					
Natural Gas	183.64	0.0034	0.0004	184.02	183.84
LPG or propane	224.56	0.0037	0.0166	229.40	229.21
Fuel oil (residual)	264.06	0.0024	0.0012	264.59	264.46
Fuel oil (distillate)	254.48	0.0026	0.0013	255.06	254.92
Coal	326.90	0.0385	0.0056	331.61	329.58
Gasoline	254.48	0.0026	0.0013	255.06	254.92
Pre-Combustion Emissions (kg/MWh of fuel consumption)					
Natural Gas	16.47	0.9324	0.0001	93.42	44.28
LPG or propane	34.87	0.3709	0.0006	65.64	46.10
Fuel oil (residual)	36.97	0.3945	0.0007	69.70	48.91
Fuel oil (distillate)	36.61	0.3895	0.0007	68.93	48.40
Coal	7.40	0.5233	0.0001	50.60	23.02
Gasoline	43.35	0.4613	0.0008	81.62	57.31
Total Emissions (kg/MWh of fuel consumption)					
Natural Gas	200.11	0.9358	0.0004	277.44	228.12
LPG or propane	259.43	0.3745	0.0172	295.05	275.31
Fuel oil (residual)	301.03	0.3969	0.0019	334.29	313.37
Fuel oil (distillate)	291.09	0.3921	0.0020	323.99	303.32
Coal	334.30	0.5618	0.0057	382.21	352.60
Gasoline	297.83	0.4639	0.0021	336.68	312.23

Source of Data:
Combustion and pre-combustion emissions for coal (bituminous assumed), petroleum, and natural gas are taken from the National Renewable Energy Laboratory LCI database. Values were first published in Michael Deru and Paul Torcellini , Source Energy and Emission Factors for Energy Use in Buildings, National Renewable Energy Laboratory, Technical Report NREL/TP-550-38617, Revised June 2007. These data were updated by NREL in 2021.
Data for LPG, fuel oil and gasoline are taken from Michael Deru and Paul Torcellini , Source Energy and Emission Factors for Energy Use in Buildings, National Renewable Energy Laboratory, Technical Report NREL/TP-550-38617, Revised June 2007.
Pre-combustion methane emissions for natural gas are based on total losses of 1.37% for gas delivered to buildings. These data were derived from Table ES-1 of Life Cycle Analysis of Natural Gas Extraction and Power Generation, April 19, 2019, DOE/NETL-2019/2039.

I1~~2~~.2. CO_2e Emissions for Power Plant Types

The CO_2e emissions are calculated for each power plant type using Equation I1~~3~~. Table I4~~7~~ shows the emissions for each power plant type for both 20 and 100-year GWPs.

$$PowerPlantEmissions = \frac{Emissions_{Fuel}}{DeliveryEfficiency \times PowerPlantEfficiency} \quad \text{(I-1~~3~~)}$$

where

PowerPlantEmissions Emission rate for each power plant type (CO_2e/MWh)
$Emissions_{Fuel}$ Emissions per unit of fuel consumed at the power plant (lb/MWh), taken from Table I2~~5~~.
DeliveryEfficiency Delivery efficiency (see I1.1~~2~~.1)
PowerPlantEfficiency Power plant efficiency, determined by dividing 3,412 Btu/kWh by the heat rate.

Table I4~~6~~ – U.S. CO_2e Emissions for each Power Plant Type

Power Plant Type	Power Plant Efficiency	Emissions per Unit of Fuel Consumption (kg CO_2e/MWh) (20-year)	Emissions per Unit of Fuel Consumption (kg CO_2e/MWh) (100-year)	Delivery Efficiency	Power Plant Emissions (kg CO_2e/MWh) (20-year)	Power Plant Emissions (kg CO_2e/MWh) (100-year)
Coal	32.3%	382.21	352.60	94.7%	1,248.45	1,151.74
Petroleum	30.6%	345.01	315.08	94.7%	1,189.34	1,086.13
Natural Gas	44.1%	261.15	222.23	94.7%	625.12	531.96

Other Gases	44.1%	261.15	222.23	94.7%	625.12	531.96
Nuclear	32.7%	0.00	0.00	94.7%	-	-
Pumped Storage	38.3%	0.00	0.00	94.7%	-	-
Hydroelectric	n.a.	0.00	0.00	94.7%	-	-
Wood	20.5%	175.41	174.36	94.7%	905.92	900.46
Waste	22.2%	175.41	174.36	94.7%	835.65	830.61
Geothermal	n.a.	9.07	9.07	94.7%	9.59	9.59
Solar	n.a.	0.00	0.00	94.7%	-	-
Wind	n.a.	0.00	0.00	94.7%	-	-

I1~~2~~.3. CO_2e Emissions for Electric Generation Mix

The CO_2e emissions rate for the United States grid or for an eGRID subregion is calculated as the weighted average of the power plant emissions calculated in Table I4~~7~~, using Equation I2~~4~~. Calculated values are shown in Table I8 for the entire United States. A similar procedure is used for each of the eGRID subregions.

$$Emissions_{GenMix} = \sum_{i=1}^{n} PowerPlantEmissions_i \times GenMix_i$$ Equation I2~~3~~

where

$Emissions_{GenMix}$ (lb/MWh)	Total emissions for the mix of generator types in the electric grid
$PowerPlantEmissions_i$	Source energy conversion factor of the i^{th} generator
$GenMix_i$	The fraction of total electric generation provided by the i^{th} generator type
i	Index for the i^{th} power plant type
n	The number of power plant types

Table I5~~8~~ shows the mix of electricity generated in the United States for 2019 and illustrates how the CO_2e emissions rate is calculated for the entire United States electric grid. A similar process was used to calculate the CO_2e emissions for each eGRID subregion, the only difference being the mix of generator types.

Table I5~~7~~ – CO_2e Emissions for United States Electricity Generation Mix for 2019
Source: Energy Information Agency, Monthly Energy Report, Table 7.2b

Generator Type	Percent of Generation	CO_2e Emissions for Power Plant Type (kg/MWh)		Power Plant Emissions multiplied times the Percent of Generation (kg/MWh)	
		20-year GWP	100-year GWP	20-year GWP	100-year GWP
Coal	24.2%	1,248.45	1,151.74	301.90	278.51
Petroleum	0.4%	1,189.34	1,086.13	5.20	4.75
Natural Gas	37.3%	625.12	531.96	232.89	198.19
Other Gases	0.1%	625.12	531.96	0.64	0.54
Nuclear	20.4%	-	-	-	-
Pumped Storage	-0.1%	-	-	-	-
Hydroelectric	7.2%	-	-	-	-
Wood	0.3%	905.92	900.46	2.75	2.73
Waste	0.4%	835.65	830.61	3.39	3.37
Geothermal	0.4%	9.59	9.59	0.04	0.04

Solar	1.8%	-	-	0.00	0.00
Wind	7.4%	-	-	-	-
			Sum Product	546.73	488.20

I2~~3~~. DISTRICT ENERGY SYSTEMS

District energy systems are assumed to use electricity for cooling and natural gas for heating. Values in Table 7.5.3 were calculated based on the district energy efficiency assumptions shown in Table I6~~9~~. These or other assumptions appropriate for local conditions should be used when values in Table 7.5.3 are modified. Please note that the published values for district energy systems can be overridden through district energy modeling procedures in Appendix B.

Table I6~~8~~ – Efficiency Assumptions for District Energy Systems

Heating Efficiency	70%	Overall Efficiency
Cooling Efficiency	4.4	Overall COP
Losses CHW	5%	
Losses HW	10%	
Losses Steam	15%	
Source: Defaults from 2.4.1.2.3 of LEED District Energy Guide		

I3~~4~~. CALCULATION RESULTS FOR THE UNITED STATES

The CO_2e emission rates published in Standard 189.1 are based on a 20-year GWP for CH_4 and N_2O. For comparison, emission rates are shown here for both 20 and 100-year GWP. Care must be taken to ensure that a consistent time-horizon is used when comparing or combining CO2e values. Table I8~~11~~ has data for a 100-year time-horizon for this purpose.

Table I7~~9~~ – Results for 20-Year GWP

	Source Energy Conversion Factor	CO_2e Emission Rates (kg/MWh)		
		Combustion	Pre-Combustion	Total
Fossil Fuels Delivered to Buildings				
Natural gas	1.092	184	93	277
LPG or propane	1.151	229	66	295
Fuel oil (residual)	1.191	265	70	334
Fuel oil (distillate)	1.158	255	69	324
Coal	1.048	332	51	382
Gasoline	1.187	255	82	337
Other fuels not specified in this table	1.048	332	51	382
Electricity				
AKGD - ASCC Alaska Grid	2.47	514	159	673
AKMS - ASCC Miscellaneous	1.35	289	93	383
AZNM - WECC Southwest	2.57	444	121	565
CAMX - WECC California	1.66	255	88	343
ERCT - ERCOT All	2.32	431	126	558
FRCC - FRCC All	2.78	442	155	596
HIMS - HICC Miscellaneous	3.15	681	211	892
HIOA - HICC Oahu	3.87	895	233	1128
MROE - MRO East	2.92	770	150	920
MROW - MRO West	2.21	534	94	628
NEWE - NPCC New England	2.66	287	96	383
NWPP - WECC Northwest	1.48	349	76	426
NYCW - NPCC NYC/Westchester	2.89	269	110	379
NYLI - NPCC Long Island	2.84	481	169	650
NYUP - NPCC Upstate NY	1.81	132	48	180
PRMS - Puerto Rico Miscellaneous	3.27	731	214	944
RFCE - RFC East	2.90	350	106	456
RFCM - RFC Michigan	2.93	594	133	727
RFCW - RFC West	2.97	532	113	645
RMPA - WECC Rockies	2.16	580	120	699
SPNO - SPP North	2.21	515	93	608
SPSO - SPP South	2.05	460	123	583
SRMV - SERC Mississippi Valley	2.84	418	137	555
SRMW - SERC Midwest	3.09	779	134	913
SRSO - SERC South	2.89	496	133	629
SRTV - SERC Tennessee Valley	2.82	473	104	577
SRVC - SERC Virginia/Carolina	2.91	360	97	456
All other electricity	2.51	436	111	547
Thermal Energy				
Chilled water	0.60	104	26	131
Steam	1.84	309	157	466
Hot Water	1.73	292	148	440

Table I8~~10~~ – Results for 100-Year GWP

	Source Energy Conversion Factor	CO_2e Emission Rates (kg/MWh)		
		Combustion	Pre-Combustion	Total
Fossil Fuels Delivered to Buildings				
Natural gas	1.092	184	44	228
LPG or propane	1.151	229	46	275
Fuel oil (residual)	1.191	264	49	313
Fuel oil (distillate)	1.158	255	48	303
Coal	1.048	330	23	353
Gasoline	1.187	255	57	312
Other fuels not specified in this table	1.048	330	23	353
Electricity				
AKGD - ASCC Alaska Grid	2.47	512	83	595
AKMS - ASCC Miscellaneous	1.35	289	58	347
AZNM - WECC Southwest	2.57	443	59	501
CAMX - WECC California	1.66	255	44	299
ERCT - ERCOT All	2.32	430	62	491
FRCC - FRCC All	2.78	441	77	518
HIMS - HICC Miscellaneous	3.15	679	134	814
HIOA - HICC Oahu	3.87	892	145	1,037
MROE - MRO East	2.92	766	72	838
MROW - MRO West	2.21	531	44	575
NEWE - NPCC New England	2.66	287	49	336
NWPP - WECC Northwest	1.48	348	37	384
NYCW - NPCC NYC/Westchester	2.89	269	55	324
NYLI - NPCC Long Island	2.84	481	87	568
NYUP - NPCC Upstate NY	1.81	132	24	156
PRMS - Puerto Rico Miscellaneous	3.27	729	120	849
RFCE - RFC East	2.90	349	52	402
RFCM - RFC Michigan	2.93	591	64	655
RFCW - RFC West	2.97	530	54	584
RMPA - WECC Rockies	2.16	577	57	634
SPNO - SPP North	2.21	512	44	556
SPSO - SPP South	2.05	459	60	519
SRMV - SERC Mississippi Valley	2.84	417	68	485
SRMW - SERC Midwest	3.09	774	62	836
SRSO - SERC South	2.89	494	66	560
SRTV - SERC Tennessee Valley	2.82	471	49	520
SRVC - SERC Virginia/Carolina	2.91	358	47	406
All other electricity	2.51	434	54	488
Thermal Energy				
Chilled water	0.60	104	13	117
Steam	1.84	309	74	383
Hot Water	1.73	292	70	362

I5. APPLYING THE CO_2e EMISSIONS PROCEDURE TO SPECIAL CASES

This section of the informative appendix shows how the assumptions used for the United States can be modified and how the procedure can be applied to other countries or special cases within the US. The inputs to the procedure that are most likely to change are:

- The mix of electric generators
- Power plant efficiency
- Delivery efficiency
- Pre-combustion emissions, especially for imported liquified natural gas (LNG) or coal

I5.1 Case Study #1—Community Choice Aggregator

A community choice aggregator in the US buys electricity on behalf of the customers it serves. The mix of electricity purchased is 40% wind, 20% solar and 40% natural gas. The emissions for each power plant type are assumed to be equal to the US fleet average values shown in Table I8. The GHG emissions for this special condition are 250 kg/MWh for GWP_{20} and 213 kg/MWh for GWP_{100} as calculated in Table I9~~12~~.

Table I9~~12~~ – CO_2e Emissions for Special US Jurisdiction

		Power Plant Emissions per Unit of Delivered electricity (kg CO_2e / MWh)		Weighted Average Emissions for Power Grid (kg CO_2e/MWh)	
Power Plant Type	Generation Mix	(20-year)	(100-year)	(20-year)	(100-year)
Natural Gas	40%	625.12	531.96	250	213
Solar	20%	0	0	0	0
Wind	40%	0	0	0	0
			Sum Product	250	213

I5.2 Case Study #2—Hypothetical Electric Grid

Consider the following hypothetical electric grid:

- Generation mix: 30% domestic coal, 50% domestic natural gas, and 20% wind
- Power plant efficiency: coal fleet average 25% and natural gas fleet average 40%
- Delivery efficiency is 92% (8% transmission and distribution losses)

The first step is to calculate the emissions for the fleet average coal and natural gas power plants. These calculations use Equation I3 and are shown in Table I10~~13~~. Emission rates for coal and natural gas consumption are assumed to be the same as the United States, as documented in Table I2~~5~~.

Table I10~~13~~ – CO_2e Emissions for each Power Plant Type

			Emissions per Unit of Fuel Consumption (kg CO_2e / MWh)		Power Plant Emissions per Unit of Delivered electricity (kg CO_2e / MWh)	
	Power Plant Efficiency	Delivery Efficiency	(20-year)	(100-year)	(20-year)	(100-year)
Coal	25%	92%	382.21	352.60	1,662	1,533
Natural Gas	40%	92%	261.15	222.23	710	604

The second step is to calculate the weighted average for the mix of electric generators. These calculations use Equation I2~~4~~ and are shown in Table I11~~14~~

Table I11~~14~~ – CO_2e Emissions for Hypothetical Electric Grid

Power Plant Type	Generation Mix	Power Plant Emissions per Unit of Delivered electricity (kg CO_2e / MWh)	Weighted Average Emissions for

				Power Grid (kg CO_2e/MWh)	
		(20-year)	(100-year)	(20-year)	(100-year)
Coal	30%	1,662	1,533	499	460
Natural Gas	50%	710	604	355	302
Wind	20%	0	0	0	0
			Sum Product	853	762

I3 Case Study #3 – Liquified Natural Gas to Europe or Asia

The pre-combustion emissions for liquified natural gas (LNG) are significantly greater than for domestic production of natural gas or even foreign natural gas that arrives through a pipeline. The pre-combustion emissions in Tables I2~~5~~ and I3~~6~~ include emissions from extraction at the well, processing, and pipeline transport, including methane leaks. But these data do not include additional emissions that occur for LNG due to:

Liquefaction. The gas is further treated to remove CO_2, H_2S, water, and heavy hydrocarbons. It is then cooled to minus 162 C to reduce its volume and convert it to liquid form. After liquefaction, 0.02% to 0.1% of the gas boils off while in storage.

Tanker Transport, The LNG is loaded onto special tankers with pressurized containers and shipped to importing countries. Travel distances from the U.S to foreign markets range from 9,000 to 32,000 km. Boil-off gas during transport is used to help power the ship.

Regasification. When the LNG reaches its destination, it is regasified to make it suitable for power plants, industrial applications and buildings.

Additional source energy and additional GHG emissions result at each of these steps. The top part of Table I15 is an estimate of the additional CO_2e emissions related to LNG. These figures are normalized by the electricity delivered to power plants or customers.

Table I12~~15~~ – Additional CO_2e Emissions for Liquified Natural Gas (kg CO_2e/MWh)

		From U.S. to Europe		From U.S. to Asia	
		20-year GWP	100-year GWP	20-year GWP	100-year GWP
Additional CO_2e Emissions for LNG (kg CO_2e / MWh of delivered electricity)	Liquefaction	53	38	54	41
	Tanker Transport	32	28	91	76
	Regasification	5	4	5	4
	Total LNG Emissions	90	70	150	121
Emissions for Natural Gas Power Plant	Power Plant Emissions (Table I7)	625	532	625	532
	Power Plant Emissions with LNG	715	602	775	653
	Percent Increase	14%	13%	24%	23%

Source of Data: Data taken from Table 1, page 11, Sailing to Nowhere: Liquefied Natural Gas is not an Effective Climate Strategy, Natural Resources Defense Council, December 2020, R: 20-08-A. However, the data cited by NRDC is attributed to Life Cycle Greenhouse Gas Perspective on Exporting Liquefied Natural Gas from the United States: 2019 Update, DOE/NETL-2019/2041

The combustion emissions for LNG are the same as for domestic natural gas, but the pre-combustion emissions are greater by the values shown in Table I12~~15~~. Assuming the same natural gas power plant efficiency and delivery efficiency as the United States, the second part of Table I11~~14~~ shows that total natural gas power plant emissions are increased about 13% for U.S. shipments to Europe and about 23% for shipments to Asia.

I4 Case Study #4—Imported Coal

The pre-combustion emissions for coal in Tables I2~~5~~ and I3~~6~~ do not include the emissions from transporting coal from one country to another, typically by ship. Based on the following assumptions, the additional pre-combustion emissions for coal transport are about 1.85 kg/MWh for each 1,000 km of transport distance:

- A Panamax size bulk carrier uses 240,000 liters of fuel oil per day at a speed of about 40 km/h (21 knots). This works out to be 250,000 liters per 1,000 km traveled.

- At 334 kg/MWh of carbon emissions per unit of fuel oil consumption (from Table I6), ship emissions are 960,000 kg of CO_2e per 1,000 km traveled.

- This ship can carry 73,000 metric tons of coal with a heat content of about 520,000 MWh.

- This works out to be 1.85 kg/MWh for a distance of 1,000 km.

The distance from Sydney to Tokyo or Shanghai is about 8,000 km and the additional CO_2e emissions are 14.8 kg/MWh of coal delivered, a 29% increase in pre-combustion emissions. Note that this is a rough estimate that does not include the possibility that the ship will return to the coal destination empty, nor do the emissions include loading and unloading the coal at the ports.

I4~~5~~. LONG-RUN MARGINAL EMISSION RATES

The long-run marginal emission rates published in normative Appendix E were taken from the Cambium database as published in the Cambium21_LRMER_GEARegions.XLSX workbook, and using the settings shown in Table I13~~16~~.

Table I13~~16~~ – Cambium Assumptions Used for Long-Run Marginal Emission Rates

Setting	Value	Choices/Description
Emission	CO_2e	CO_2, CH_4, N_2O, CO_2e
Emission stage	Combined	Combustion, Pre-Combustion, Combined
Start year	2023	First year of emissions
Evaluation period (years)	20	Period over which emissions are tabulated
Discount rate (real)	0.03	Future emissions are discounted this much each year
Scenario	Low RE Costs	Mid-case, Low RE Costs, High RE Costs, 95% Decarb by 2050, 95% Decarb by 2035
Global Warming Potentials	20-year (AR5)	20-year (AR5), 100-year (AR5), custom
Location	End-use	End-use, Busbar

Avoided emissions in Table E21 are based on the hourly signatures of electricity production for solar, wind and hydro, taken from the Cambium database. The avoided emissions for “other renewables” assume that the generators produce a constant amount of electricity for all hours of the year.