Public Review Draft

Proposed Addendum s to Standard 189.1-2023

Standard for the Design of High-Performance Green Buildings

Except Low-Rise Residential Buildings

First Public Review (September 2025)
(Draft Shows Proposed Changes to Current Standard)

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(This foreword 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 informative material are not offered the right to appeal at ASHRAE or ANSI.)

Foreword

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 informative material are not offered the right to appeal at ASHRAE or ANSI.

This addendum is part of the changes in Addendum r and does not show underline and strikethrough for brevity. The entirety of the Informative Appendix J is updated here and will be a full replacement.

For reviewers note that Section J5 remains unchanged.

[Note to Reviewers: This addendum changes the entirety of the Informative Appendix and therefore there are not changes indicated in the text by <u>underlining</u> (for additions) and ~~strikethrough~~ (for deletions). Highlights used to assist reviewer with particular changes from the previous standard. 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 s to 189.1-2023; Advisory Public Review

Replace Appendix J with all of the following and will be relettered according to final appendix letter

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INFORMATIVE APPENDIX J
DERIVATION OF CO_2e EMISSION FACTORS

This informative appendix documents the procedures used to develop CO_2e emission factors in Standard 189.1, Table 7.6.2.1 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 2024. A similar procedure was used to develop emission factors for the eGRID subregions based on EPA eGRID data for 2023, 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 construction of buildings or power plants, and their demolition or recycling at end-of-life.

J1. CARBON DIOXIDE EQUIVALENT (CO_2e) EMISSIONS

J1.1 Fossil Fuel Emissions.

The use of fossil fuel (both combustion as well as extraction, processing and transportation) 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 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 J1). 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 J1 – 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 (combustion emissions) but emissions also result from the mining of coal, extraction of oil and gas, processing, refinement, pumping, trucking, rail transport and/or piping of fuels (pre-combustion emissions). Table J2 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 J3 lists the emission rates for fuels delivered to buildings. The data in these tables represents the emissions per MWh of fuel consumed at the building or power plant.

Table J2 – Combustion and Pre-Combustion Emissions for Fossil Fuels Use at Power Plants (kg/MWh)

kg of CO2e emissions per MWh of fuel consumed at a power plant. Power plant efficiency and T&D losses are not considered

	Combustion Emissions (kg/MWh)			Pre-Combustion Emissions (kg/MWh)				Total Emissions (kg/MWh)		
Fuel	CO2	CH4	N20		CO2	CH4	N20	CO2	CH4	N20
Coal	326.81	0.0385	0.0056		7.39	0.5232	0.0001	334.20	0.5617	0.0057
Petroleum	261.37	0.0109	0.0022		35.93	0.5571	0.0006	297.30	0.5680	0.0028
Natural Gas and Other Gases	183.59	0.0035	0.0003	Midwest	17.97	0.4308	0.0001	201.56	0.4343	0.0005
				Northeast	13.00	0.3177	0.0001	196.58	0.3212	0.0005
				Pacific	28.74	0.4256	0.0003	212.33	0.4291	0.0006
				Rocky Mtn.	24.59	0.3788	0.0002	208.18	0.3822	0.0006
				Southeast	18.18	0.5511	0.0001	201.76	0.5546	0.0005
				Southwest	18.53	0.4972	0.0001	202.12	0.5007	0.0004
				US Average	16.96	0.3696	0.0001	200.54	0.3731	0.0005
Nuclear	0	0	0		0	0	0	0	0	0
Pumped Storage	0	0	0		0	0	0	0	0	0
Hydroelectric	0	0	0		0	0	0	0	0	0
Wood	163.72	0.0136	0.0000		12.59	0.1953	0.0002	176.32	0.2089	0.0002
Waste	163.72	0.0136	0.0000		12.59	0.1953	0.0002	176.32	0.2089	0.0002
Geothermal	0	0	0		9.07	0	0	9.07	0	0
Solar	0	0	0		0	0	0	0	0	0
Wind	0	0	0		0	0	0	0	0	0

Data Sources:

1. 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.
2. Pre-combustion emissions for natural gas are taken from DOE/NETL-2024/4862, Life Cycle Analysis of Natural Gas Extraction and Power Generation: U.S. 2020 Emissions Profile, December 2024. Data is taken from Appendix F.
3. Biomass emissions were determined from the U.S. Energy Information Agency (EIA), Monthly Energy Reports (MER). Biomass emissions are taken from Table 12.7. Electric generation from biomass is taken from Table 10.2c. A net emissions factor of 0.5 is applied to the CO_2 combustion emissions to account for the counterfactual emissions.
4. Emissions at geothermal plants are small, but not zero. A value of 20 lb of CO_2 per MWh (9.07 kg/MWh) of electricity production is assumed based on geothermal plants in the western United States.

Table J3 – Combustion and Pre-Combustion Emissions for Fossil Fuels Use at Buildings (kg/MWh)

kg of emissions per MWh of consumption of fuel

	Combustion Emissions (kg/MWh)			Pre-Combustion Emissions (kg/MWh)				Total Emissions (kg/MWh)		
Fuel	CO2	CH4	N20		CO2	CH4	N20	CO2	CH4	N20
Natural Gas	183.59	0.0035	0.0003	Midwest	17.99	0.4954	0.0001	201.58	0.4989	0.0005
				Northeast	13.01	0.3795	0.0001	196.59	0.3829	0.0005
				Pacific	28.75	0.4830	0.0003	212.34	0.4864	0.0006
				Rocky Mtn.	24.59	0.5311	0.0002	208.18	0.5345	0.0006
				Southeast	18.23	0.6288	0.0001	201.82	0.6323	0.0005
				Southwest	18.53	0.5614	0.0001			
				US Average	16.97	0.4285	0.0001	200.56	0.4319	0.0005
LPG or propane	224.50	0.0037	0.0166		34.86	0.3708	0.0006	259.36	0.3744	0.0173
Fuel oil (residual)	263.98	0.0024	0.0012		36.96	0.3944	0.0007	300.94	0.3968	0.0019
Fuel oil (distillate)	254.41	0.0026	0.0013		36.60	0.3894	0.0007	291.01	0.3920	0.0020
Coal	326.81	0.0385	0.0056		7.39	0.5232	0.0001	334.20	0.5617	0.0057
Gasoline	254.41	0.0026	0.0013		43.33	0.4612	0.0008	297.74	0.4638	0.0021
Other fuels not specified	326.81	0.0385	0.0056		7.39	0.5232	0.0001	334.20	0.5617	0.0057

Data Sources:

1. Combustion and pre-combustion emissions for fossil fuels 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.
2. Pre-combustion emissions for natural gas are taken from DOE/NETL-2024/4862, Life Cycle Analysis of Natural Gas Extraction and Power Generation: U.S. 2020 Emissions Profile, December 2024. Data is taken from Appendix F.
3. Values for coal are used for "other fuels not specified".

Table J4 and Table J5 give the combustion and pre-combustion emissions for the fuels shown in Table J2 and Table J3.

Table J4 – CO_2e Emissions for Fossil Fuels Used at Power Plants (kg/MWh)

kg of emissions per MWh of electricity generated at the power plant but not T&D losses

		CO2e Emissions (20-y GWP)			CO2e Emissions (100-y GWP)		
		Combustion	Pre-Combustion	Total	Combustion	Pre-Combustion	Total
Coal		332	51	382	329	23	352
Petroleum		263	82	345	262	53	315
Natural Gas and Other Gases	Midwest	184	54	238	184	31	215
	Northeast	184	39	223	184	22	206
	Pacific	184	64	248	184	42	225
	Rocky Mtn.	184	56	240	184	36	220
	Southeast	184	64	248	184	35	218
	Southwest	184	60	244	184	33	217
	US Average	184	47	231	184	28	212
Nuclear		0	0	0	0	0	0
Pumped Storage		0	0	0	0	0	0
Hydroelectric		0	0	0	0	0	0
Wood		165	29	194	164	18	183
Waste		165	29	194	164	18	183
Geothermal		0	9	9	0	9	9
Solar		0	0	0	0	0	0
Wind		0	0	0	0	0	0

Table J5 – CO_2e Emissions for Fossil Fuels Use at Buildings (kg/MWh)

kg of emissions per MWh of consumption of fuel at building

		CO2e Emissions (20-y GWP)			CO2e Emissions (100-y GWP)		
		Combustion	Pre-Combustion	Total	Combustion	Pre-Combustion	Total
Natural Gas	Midwest	184	59	243	184	33	217
	Northeast	184	44	228	184	24	208
	Pacific	184	69	253	184	43	227
	Rocky Mtn.	184	68	252	184	40	224
	Southeast	184	70	254	184	37	221
	Southwest	184	65	249	184	35	219
	US Average	184	52	236	184	30	214
LPG or propane		229	66	295	229	46	275
Fuel oil (residual)		265	70	334	264	49	313
Fuel oil (distillate)		255	69	324	255	48	303
Coal		332	51	382	329	23	352
Gasoline		255	82	337	255	57	312
Other fuels not specified		332	51	382	329	23	352

J1.2. CO_2e Emissions for Power Plant Types

The emissions for each power plant type depend on the efficiency of the plant (or the heat rate) and the electricity that is lost through transmission and distribution.

J1.2.1 Power Plant Efficiency

In the United States, the efficiency of power plants is commonly stated in terms of a heat rate, which represents the amount of fuel in Btu needed to generate a kWh of electricity. 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. The efficiency of power plants is shown in Table J6 where applicable. The US fleet average power plant efficiency is assumed for all eGRID subregions.

J1.2.2 Distribution Efficiency

For 2024 the U.S. Energy Information Agency (EIA) reports that, 4.15 trillion kWh were generated at domestic power plants in the United States and that 220 billion kWh (5.3%) were lost through the transmission and distribution (T&D) system or otherwise unaccounted for. This results in a distribution efficiency of 94.7%. See Table J6. 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. The US nation-wide distribution efficiency is assumed for each of the eGRID subregions in the U.S.

Table J6 –Power Plant Heat Rate, Power Plant Efficiency and Delivery Efficiency

Power Plant Type	Power Plant Efficiency	Delivery Efficiency
Coal	31.8%	94.7%
Petroleum	29.8%	94.7%
Natural Gas	44.2%	94.7%
Other Gases	44.2%	94.7%
Nuclear	n. a.	94.7%
Pumped Storage	n. a.	94.7%
Hydroelectric	n. a.	94.7%
Biomass	22.0%	94.7%
Geothermal	n. a.	94.7%
Solar	n. a.	94.7%
Wind	n. a.	94.7%

Data Sources:

1. Heat rates for fossil fuel power plants are reported by EIA in Table A6 of their Monthly Energy Report (MER). These values are converted to efficiency (unitless) by dividing 3,412 Btu/kWh by the heat rate (in Btu/kWh).
2. 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.
3. The heat rate of nuclear and non-combustible renewable power plants (wind, solar, hydro, and geothermal) is not applicable since these plants generate no greenhouse gases.

J1.2.3 Power Plant Emissions

The CO_2e emissions are calculated for each power plant type using Equation J1. Table J7 shows the emissions for each power plant type for both 20 and 100-year GWPs.

Equation J1

$$PowerPlantEmissions = \frac{E_{CO2} + E_{CH4} \times GWP_{CH4} + E_{N2O} \times GWP_{N2O}}{DeliveryEfficiency \times PowerPlantEfficiency}$$

where

PowerPlantEmissions	Emission rate for each power plant type (CO_2e/MWh)
E_{CO2}, E_{CH4}, E_{N2O}	Carbon dioxide, methane and nitrous oxide emissions per unit of fuel consumed at the power plant (kg/MWh), taken from Table J2
GWP_{CO2}, GWP_{CH4}, GWP_{N2O}	Global warming potential for carbon dioxide, methane and nitrous oxide, taken from Table J1.
DeliveryEfficiency	Delivery efficiency (see J1.2.2)
PowerPlantEfficiency	Power plant efficiency (see J1.2.1)

Table J7 – U.S. Fleet Average CO_2e Emissions for each Power Plant Type (kg/MWh)
kg of emissions per MWh of electricity generated at the power plant

		20-year GWP			100-year GWP		
Power Plant Type	Gas Region	Combustion	Pre-Combustion	Total	Combustion	Pre-Combustion	Total
Coal	n. a.	1103	168	1271	1096	77	1172
Oil	n. a.	933	291	1224	931	187	1118
Natural Gas	Midwest	440	128	568	439	74	513
	Northeast		94	533		54	493
	Pacific		153	592		99	538
	Rocky Mtn.		134	573		86	525
	Southeast		152	592		83	522
	Southwest		142	582		80	519
	US Average		113	553		67	506
Nuclear	n. a.	0	0	0	0	0	0
Hydro	n. a.	0	0	0	0	0	0
Biomass	n. a.	793	138	931	789	89	878
Wind	n. a.	0	0	0	0	0	0
Solar	n. a.	0	0	0	0	0	0
Geothermal	n. a.	0	9	9	0	9	9
Other Fuels	n. a.	440	113	553	439	67	506

J1.3. Electric Generation Mix

The generation mix for each generator type is the net production from that generator type divided by the total net generation for the same period of time. The EPA eGRID database is an excellent source of information on net electricity generation by generator type, however the time period is for an entire year

The mix of electricity generation is a key factor in estimating the carbon intensity of electricity consumption, since carbon emissions vary considerably among generator types, as shown in Table J7, with coal and petroleum being the dirtiest and wind and solar being virtually carbon free. The generation mix is constantly changing as grid operators match supply with demand. Generators with the lowest marginal cost are dispatched first and generators with the highest marginal cost are dispatched last. In general, carbon emissions are lower when electricity demand is lower and higher when demand is higher,

since the generators with a high marginal cost of operation also tend to produce more greenhouse gas; the marginal cost to operate wind and solar generators is essentially zero. The emission rates in Table 7.6.2.1 are based on the generation mix for annual net production and do not account for these time-dependent differences. Use the jurisdictional option procedures in Section 7.6.2.2 (LRMER) to better account for the time dependency of electricity use.

The 2023 eGRID data (and previous versions) represent ***grid-average (i.e. location-based) electric generation***, since it includes all generation for a geographic area (eGRID subregion, state, etc.), including wind, solar and other renewable energy generators that have been constructed through power purchase agreements or other voluntary green electricity purchases whereby the investor/purchaser is claiming the benefits from the generated renewable energy through the possession of the associated renewable energy certificates (RECs). By contrast, ***residual (i.e. market-based) electric generation*** excludes the renewable energy for which private or public entities have claimed the environmental benefits (RECs). Carbon emissions based on residual electric generation are higher than emissions based on the grid-average mix, since some of the zero-carbon generators (wind, solar, etc.) are excluded, increasing the share of fossil-fuel generators.

To estimate the carbon emissions for residual electric generation, the wind, solar and geothermal generation that is procured through voluntary programs where the purchaser is claiming credit for the environmental benefits is subtracted from the total production from these generator types. The amount of renewable electricity that is procured through voluntary mechanisms such as power purchase agreements, green tariffs, etc. is documented by the National Renewable Energy Laboratory (NREL).

Table J8 shows the residual electricity mix used in this analysis.

Table J8 – NREL Adjusted Residual Electric Generation Mix for eGRID Subregions (percent)

SUBRGN	Coal	Oil	Gas	Nuclear	Hydro	Biomass	Wind	Solar	Geothermal	OtherFossil	Unknown
	SRGENACL	SRGENAOL	SRGENAGS	SRGENANC	SRGENAHY	SRGENABM	SRGENAWI	SRGENASO	SRGENAGT	SRGENAOF	SRGENAOP
ACTAKGD	15%	9%	61%	0%	14%	1%	0%	0%	0%	0%	0%
AKMS	0%	25%	7%	0%	68%	0%	0%	0%	0%	0%	0%
AZNM	13%	0%	49%	20%	3%	0%	6%	6%	3%	0%	0%
CAMX	2%	0%	43%	9%	15%	2%	6%	18%	3%	1%	0%
ERCT	17%	0%	66%	11%	0%	0%	4%	1%	0%	0%	0%
FRCC	5%	1%	77%	13%	0%	1%	0%	3%	0%	1%	0%
HIMS	0%	67%	0%	0%	4%	5%	11%	6%	7%	0%	0%
HIOA	0%	84%	0%	0%	0%	3%	4%	7%	0%	3%	0%
MROE	40%	0%	43%	0%	4%	3%	5%	4%	0%	0%	0%
MROW	39%	0%	15%	9%	5%	1%	31%	1%	0%	0%	0%
NEWE	0%	0%	59%	24%	9%	5%	1%	1%	0%	2%	0%
NWPP	17%	0%	26%	3%	41%	1%	8%	2%	0%	0%	0%
NYCW	0%	0%	98%	0%	0%	1%	0%	0%	0%	1%	0%
NYLI	0%	2%	88%	0%	0%	4%	0%	2%	0%	5%	0%
NYUP	0%	0%	26%	33%	34%	1%	4%	2%	0%	0%	0%
PRMS	15%	39%	44%	0%	0%	0%	1%	1%	0%	0%	0%
RFCE	5%	0%	55%	37%	1%	1%	0%	0%	0%	1%	0%
RFCM	26%	2%	51%	10%	0%	2%	6%	1%	0%	2%	0%
RFCW	26%	0%	40%	30%	1%	0%	2%	0%	0%	1%	0%
RMPA	35%	0%	29%	0%	12%	0%	20%	4%	0%	0%	0%
SPNO	44%	0%	20%	20%	0%	0%	16%	0%	0%	0%	0%
SPSO	20%	1%	55%	0%	3%	2%	19%	0%	0%	0%	0%
SRMV	8%	0%	67%	23%	1%	1%	0%	-2%	0%	1%	0%
SRMW	52%	0%	17%	17%	1%	0%	11%	1%	0%	0%	0%
SRSO	15%	0%	57%	21%	3%	4%	0%	0%	0%	0%	0%
SRTV	29%	0%	30%	33%	8%	1%	0%	-1%	0%	0%	0%
SRVC	11%	0%	41%	42%	2%	2%	0%	2%	0%	0%	0%

J1.4. CO_2e Emissions Weighted by Electric Generation Mix

The CO_2e emissions rate for the entire United States grid or for an eGRID subregion is calculated as the weighted average of the fleet-average power plant emissions from Table J7. The emissions are weighted by the residual generation mix in from Table J8.

Equation J2

$$Emissions_{GenMix} = \sum_{i=1}^{n} PowerPlantEmissions_i \times GenMix_i$$

where

$Emissions_{GenMix}$	Total emissions for the mix of generator types in the electric grid (kg/MWh)
$PowerPlantEmissions_i$	The CO_2e emissions for 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	Number of power plant types

J2. DISTRICT ENERGY SYSTEMS

District energy systems are assumed to use electricity for cooling and natural gas for heating. Values in Table 7.6.2.1 were calculated based on the district energy efficiency assumptions shown in Table J9. These or other assumptions appropriate for local conditions should be used when values in Table 7.6.2.1 are modified. Please note that the published values for district energy systems can be overridden through district energy modeling procedures in Appendix C.

Table J9 – 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

J3. 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 in Table J10 for both 20 and 100-year GWP. Care must be taken to ensure that a consistent time-horizon is used when comparing or combining CO_2e values.

Table J10 – CO_2e Results (kg/MWh)

kg of emissions per MWh of consumption at the building site.

		20-year GWP			*100-year GWP*		
		Combustion	*Pre-Comb*	*Total*	*Combustion*	*Pre-Comb*	*Total*
Fuels used Directly in Buildings							
Natural gas	Midwest	184	59	243	184	33	217
	Northeast	184	44	228	184	24	208
	Pacific	184	69	253	184	43	227
	Rocky Mtn.	184	68	252	184	40	224
	Southeast	184	70	254	184	37	221
	Southwest	184	65	249	184	35	219
	US Average	184	52	236	184	30	214
LPG or propane		229	66	295	229	46	275
Fuel oil (residual)		265	70	334	264	49	313
Fuel oil (distillate)		255	69	324	255	48	303
Coal		332	51	382	329	23	352
Gasoline		255	82	337	255	57	312
Other fuels not specified in this table		332	51	382	329	23	352
Electricity[1]							
AKGD	ASCC Alaska Grid	521	122	643	519	70	589
AKMS	ASCC Miscellaneous	263	80	343	262	51	314
AZNM	WECC Southwest	358	92	450	357	49	406
CAMX	WECC California	235	74	309	235	47	282
ERCT	ERCOT All	481	123	605	480	66	546
FRCC	FRCC All	407	129	536	406	70	476
HIMS	HICC Miscellaneous	668	204	872	666	131	798
HIOA	HICC Oahu	815	251	1067	814	161	975
MROE	MRO East	659	128	787	656	66	722
MROW	MRO West	506	87	592	503	42	545
NEWE	NPCC New England	309	65	373	308	38	346
NWPP	WECC Northwest	320	72	392	319	41	360
NYCW	NPCC NYC/Westchester	444	95	539	443	55	498
NYLI	NPCC Long Island	453	97	549	452	56	508
NYUP	NPCC Upstate NY	126	27	153	126	15	142
PRMS	Puerto Rico Miscellaneous	722	188	911	720	114	834
RFCE	RFC East	305	62	367	305	35	339
RFCM	RFC Michigan	549	118	667	546	63	610
RFCW	RFC West	472	97	569	470	51	521
RMPA	WECC Rockies	517	98	615	514	52	566
SPNO	SPP North	577	100	678	574	49	623
SPSO	SPP South	485	117	602	483	62	546
SRMV	SERC Mississippi Valley	403	120	523	402	64	466
SRMW	SERC Midwest	649	110	759	646	53	698
SRSO	SERC South	449	118	567	447	63	510
SRTV	SERC Tennessee Valley	455	95	550	453	48	501
SRVC	SERC Virginia/Carolina	319	84	403	318	44	363
EIA Data	All other Electricity	371	78	448	369	42	412
Thermal Energy							
Chilled Water		89	19	107	88	10	99
Steam		309	88	397	309	50	359
Hot Water		292	83	375	292	47	339

1. The electricity emissions rates are based on the residual generation mix

J4. 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

J4.1 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 J8. 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 J12.

Table J12 – 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%	448	412	179	165
Solar	20%	0	0	0	0
Wind	40%	0	0	0	0
			Sum Product	179	165

J4.2 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 J3 and are shown in Table J13. Emission rates for coal and natural gas consumption are assumed to be the same as the United States, as documented in Table J5.

Table J13 – CO_2e Emissions for each Power Plant Type (kg/MWh)

	Power Plant Efficiency	Delivery Efficiency	Emissions per Unit of Fuel Consumption (kg CO_2e / MWh)		Power Plant Emissions per Unit of Delivered electricity (kg CO_2e / MWh)	
			(20-year)	(100-year)	(20-year)	(100-year)
Coal	25%	92%	345	325	1500	1413
Natural Gas	40%	92%	231	212	628	576

The second step is to calculate the weighted average for the mix of electric generators. These calculations use Equation J4 and are shown in Table J14

Table J14 – CO_2e Emissions for Hypothetical Electric Grid (kg/MWh)

		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)
Coal	30%	1500	1413	450	424
Natural Gas	50%	628	576	314	288
Wind	20%	0	0	0	0
			Sum Product	764	712

J4.3 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 J5 and J6 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. The CO_2e estimated for liquification is estimated to be 38 kg/MWh of natural gas for a 100-year GWP and 53 kg/MWh for a 20-year GWP.
- 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. Transport emissions depend on the distance traveled and are estimated to be 0.0031 kg/MWh-km for a 100-year GWP and 0.0036 kg/MWh-km for a 20-year GWP.
- Regasification. When the LNG reaches its destination, it is regasified to make it suitable for power plants, industrial applications and buildings. The CO_2e emissions for regasification are estimated to be 4 kg/MWh for both 100-year and 20-year GWP.

The above data are taken from *Life Cycle Greenhouse Gas Perspective on Exporting Liquified Natural Gas from the United States: 2019 Update*, DOE/NETL-2019/2041, Exhibit 5-10 and A-1. The following equation provides a way to estimate the additional emissions (kg/MWh) related to liquified natural gas.

Equation J3

$$\text{LNG Addition (kg/MWh)} = \text{Liquification} + \text{Regasification} + \text{Transport}$$

$$\text{LNG Addition (100-y GWP)} = 38 + 4 + 0.0031 * \text{Distance (km)}$$

$$\text{LNG Addition (20-y GWP)} = 53 + 4 + 0.0036 * \text{Distance (km)}$$

J4.4 Case Study #4—Imported Coal

The pre-combustion emissions for coal in Tables J5 and J6 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 J6), 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, an approximate 30% 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.

J5. 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 J11.

Table J11 – 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 annual emissions in Table 7.6.2.2.1 and avoided monthly average hourly emissions in Normative Appendix D 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.